TUGAS AKHIR – ME 184834

ANALISA RISIKO WELL PIPES DAN SEPARATOR PADA FASILITAS PEMBANGKIT GEOTHERMAL WAYANG WINDU MENGGUNAKAN METODE RISK-BASED INSPECTION (RBI).

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Surabaya 2019

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LEMBAR PENGESAHAN

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Abstrak

Pada pembangkit listrik tenaga geothermal, sumber energi yang digunakan berupa panas bumi dimana dalam proses pengambilan sumber panas yang dibutuhkan oleh turbin, terdapat risiko terjadi kerusakan equipment yang menyebabkan kegagalan proses produksi. Kerusakan yang sering terjadi pada pembangkit listrik geothermal adalah fouling dan korosi yang disebabkan sumber reservoir mengandung zat kimia tertentu. Untuk mengurangi terjadinya kerusakan equipment dan mengelola risiko dengan memfokuskan upaya inspeksi pada equipment proses yang memiliki tingkat risiko tinggi di PLTP Wayang Windu, kabupaten Bandung, analisa risiko dengan menggunakan proses Risk Based Inspection (RBI) diterapkan pada separator Vessel VS-80-001 to VS-80-003 dan well pipes pada fasilitas SEGWWL unit 2.

Hasil analisis Probability of Failure (PoF) pada separator Vessel VS-80-001 to VS-80-003 bernilai 0.0837 (RBI plan date) yang menunjukkan bahwa laju kegagalan meningkat sebesar 0.0837/tahun. Sedangkan analisis Consequence of Failure (CoF) menunjukkan bila terjadi kerusakan pada equipment (separator) maka area yang terpengaruh 652m2. Analisis resiko menunjukkan bahwa hasil probability range dikategorikan sebagai 5A medium risk. Hasil analisis Probability of Failure (PoF) pada VS pipeline bernilai 0.019 (RBI plan date) yang menunjukkan bahwa laju kegagalan meningkat sebesar 0.0019/tahun. Sedangkan analisis Consequence of Failure (CoF) menunjukkan bila terjadi kerusakan pada equipment (pipeline) maka area yang terpengaruh 184.8m2. Analisis resiko menunjukkan bahwa untuk probability range dikategorikan sebagai 4D medium high risk.

Keywords **:** ***power plant, geothermal, separator, Risk-based Inspection***

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RISK ANALYSIS FOR WELL PIPES AND SEPARATOR FOR WAYANG WINDU GEOTHERMAL POWER PLANT USING RISK-BASED INSPECTION METHODOLOGY (RBI)

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Abstract

Geothermal power plants use hot steam from inside the earth to produce electrical energy. In the process of retrieving the heat source needed by the turbine, there is a risk of equipment damage that causes a failure of the production process. Damage that is common in geothermal power plants, is fouling and corrosion caused by reservoir sources containing certain chemicals. To reduce the occurrence of equipment damage and manage risk by focusing inspection efforts on process equipment that has a high risk level (separator) at the Wayang Windu PLTP, Bandung district, Risk Based Inspection (RBI) risk analysis is applied. Probability of Failure (PoF) analysis results are 0.0837 (plan date RBI) which indicates that the failure rate increased by 0.0837 / year. While the analysis of Consequence of Failure (CoF) shows that if there is damage to the equipment (separator) then the affected area is 652m2. The result of risk analysis shows that the probability range results are categorized as 5A medium risk. While the results of Probability of Failure (PoF) analysis on VS pipeline are 0.019 (plan date RBI) shows that the failure rate increases by 0.0019 / year. Tthe analysis of Consequence of Failure (CoF) shows that if there is damage to the equipment (pipeline), the affected area is 184.8m2. Risk analysis shows that the probability range for pipeline is categorized as 4D medium high risk.

Keywords **: *power plant, geothermal, separator, Risk-based Inspection***

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KATA PENGANTAR

Puji syukur penulis haturkan atas rahmat dan kuasa Allah SWT, karena dengan nikmat rahmat, berkat dan karunia-Nya penulis dapat menyelesaikan tugas akhir ini dengan baik, lancar dan tepat waktu. Tugas akhir yang berjudul “Analisa risiko well pipes dan separator pada fasilitas pemervibangkit geothermal wayang windu menggunakan metode risk-based inspection (RBI).” ini diajukan sebagai salah satu persyaratan kelulusan program strata satu teknik di Departemen Teknik Sistem Perkapalan, Fakultas Teknologi Kelautan, Institut Teknologi Sepuluh Nopember Surabaya.

Dalam menulis tugas akhir ini, penulis banyak mendapat dukungan dari beberapa pihak seperti sebagai berikut:

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Penulis menyadari bahwa tugas akhir ini terdapat banyak kendala dan keterbatasan ilmu pengetahuan serta wawasan penulis menjadikan tugas akhir ini masih jauh dari kata sempurna. Oleh karena itu, saran dan kritik yang membangun sangat diharapkan demi penulisan yang lebih baik di kemudian hari. Penulis juga memohon maaf apabila dalam proses pengerjaan tugas akhir ini terdapat banyak kesalahan yang disengaja maupun tidak disengaja. Besar harapan penulis, bahwasannya tugas akhir ini dapat bermanfaat bagi penulis secara khusus, pembaca, serta nusa dan bangsa. Semoga Allah SWT melimpahkan Rahmat, Karunia dan kasih sayang-Nya kepada kita semua. Terima kasih.

Surabaya, Juli 2019

Penulis

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BAB I
PENDAHULUAN

1.1 Latar Belakang

Untuk memenuhi kebutuhan pasokan listrik di Pulau Jawa-Madura-Bali, khususnya Provinsi Jawa Barat, dibutuhkan sebuah pembangkit listrik yang dapat memenuhi kebutuhan listrik provinsi tersebut, pembangkit listrik geothermal milik Star Energy Geothermal Wayang Windu dapat menghasilkan Energi listrik yang berasal dari PLTP unit 1 sebesar 110 MW dan unit 2 sebsar 117 MW. Pembangkit listrik tenaga panas bumi Wayang Windu adalah salah satu fasilitas panas bumi yang beroperasi di Indonesia, Terletak 40 km di selatan Bandung di Jawa Barat. Wayang Windu Power Generation dioperasikan oleh Star Energy Geothermal (Wayang Windu) Limited atau SEGWWL adalah anak perusahaan yang sepenuhnya dimiliki oleh Star Energy. (PLTP SEGWWL, 2012)

Pembangkit listrik tenaga geothermal berfungsi dengan menggunakan uap panas yang berada di dalam bumi untuk menghasilkan energi listrik (Marliska, 2012). Energi panas dari bumi diekstraksi dalam bentuk cairan panas bumi. Cairan dari beberapa sumur produksi digabungkan dan dikirimkan melalui dua jalur fase ke cyclonic separator dimana uap dan air sisa (brine) dipisahkan (Ompusunggu, 2016). Setelah itu uap dan brine akan dialirkan, dimana uap akan dialirkan ke turbin untuk menggerakan turbin tersebut, dan brine di kembalikan ke reservoir. Energi listrik dihasilkan dari turbine yang diputar menggunakan panas bumi.

Dalam proses pengambilan sumber panas yang dibutuhkan oleh turbin, terdapat risiko terjadi kerusakan equipment yang menyebabkan kegagalan proses produksi. Kerusakan yang dapat terjadi pada pembangkit listrik geothermal, umumnya, adalah fouling dan korosi. Fouling atau scaling terjadi bila panas yg diambil dari sumber reservoir mengandung zat kimia seperti $CaCO_3$, $CaSO_4$, $Ca_3(PO_4)_2$ (Baticci dkk, 2010). Sedangkan bila terdapat Cl-H_2S/HS^-, SO_4^{2-}, HCO_3, O_2, H+ dan F dalam jumlah besar dapat menyebabkan korosi (Andritsos, 2002; Tomarov dkk, 2015). Bila permasalahan ini tidak di atasi dengan benar, kegagalan dalam proses produksi dapat terjadi. Kegagalan proses dapat berupa kebocoran yang disebabkan oleh korosi serta turunnya performa dari equipment akibat adanya scaling atau fouling (. Hal ini akan mengakibatkan proses produksi berhenti sehingga akan menyebabkan terjadinya kerugian yang sangat besar bagi perusahaan.

Untuk mengurangi terjadinya kerusakan equipment tersebut, perlu dilakukan proses analisa risiko. Dalam hal ini Star Energy Geothermal (Wayang Windu) menggunakan pendekatan yang terukur melalui Program Manajemen Pemeliharaan. Ruang lingkup program ini mencakup Sistim Manajemen Pemeliharaan. Risiko didefinisikan sebagai hasil dari kemungkinan kegagalan dan konsekuensi kegagalan (referensi). Kemungkinan didefinisikan sebagai kemungkinan mekanisme kerusakan tertentu yang mengakibatkan kegagalan komponen

Salah satu cara penilaian risiko adalah dengan menggunakan proses Risk Based Inspection (RBI). RBI sendiri adalah bagian dari Sistim Manajemen Pemeliharaan, dimana RBI adalah sebuah proses analisa kuantitatif dan kualitatif untuk menilai probabilitas kegagalan dan konsekuensi dari kegagalan tersebut. Risiko kegagalan dalam RBI didapatkan dari perhitungan Probability of Failure (PoF) dan Consequence of Failure (CoF) dari sebuah equipment. Dalam RBI, tingkatan risiko dari setiap equipment di prioritaskan secara sistematis, karena itu, equipment yang memiliki tingkat risiko yang tinggi dapat di prioritaskan (Rød, 2015).

RBI juga digunakan untuk mengelola risiko dengan memfokuskan upaya inspeksi pada equipment proses yang memiliki tingkat risiko tinggi. Pada umumnya inspeksi dilakukan secara berkala dengan interval waktu yang tetap, baik pada peralatan kritikal maupun non- kritikal. Selain itu, metode inspeksi yang digunakan umumnya pada pengukuran ketebalan. Inspeksi tersebut memiliki kelemahan yaitu:

1. interval inspeksi tidak ditentukan berdasarkan kajian risiko sehingga bisa terjadi kegagalan sebelum inspeksi berikutnya atau inspeksi dilakukan terlalu sering padahal bisa diperpanjang intervalnya.

2. metode inspeksi pengukuran ketebalan belum tentu sesuai, karena mungkin modus kegagalan bukan penipisan, melainkan retakan (Rød, 2015).

Untuk mengatasi kelemahan tersebut, inspeksi ditentukan atau direncanakan berdasarkan kajian risiko/RBI.

1.2 Rumusan Permasalahan

Rumusan masalah yang dianalisa pada tugas akhir ini adalah:

1. Bagaimana cara menghitung Probability of Failure (PoF) dan Consequence of Failure (CoF) dari pipeline dan separator *Vessel VS-80-001 to VS-80-003* pada fasilitas SEGWWL unit 2 menggunakan metode Risk-based Inspection?
2. Bagaimana cara menentukan perencanaan inspeksi yang tepat pada equipment pipeline dan separator *Vessel VS-80-001 to VS-80-003* dengan menggunakan metode RBI?

1.3 Batasan Masalah

Batasan masalah dalam tugas akhir ini adalah:

1. Perhitungan RBI dilakukan pada fasilitas SEGWWL unit-2
2. Tugas akhir di lakukan pada equipment *MBD-5 Well pipes* dan *Separator Vessel VS-80-001 to VS-80-003*.

1.4 Tujuan Penelitian

Tujuan dari penelitian adalah:

1. Mengetahui tingkat risiko yang dapat terjadi pada well pipes dan separator pada fasilitas SEGWWL unit 2 dengan analisis RBI menggunakan API 581.
2. Melakukan pemetaan risiko serta perencanaan inspeksi pada well pipes dan separator

1.5 Manfaat Penelitian

1. Memberikan informasi mengenai risiko yang berpnegaruh pada well pipes dan separator *Vessel VS-80-001 to VS-80-003* di SEGWWL unit-2 sehingga kemungkinan adanya kegagalan dapat dikurangi.
2. Memberikan informasi mengenai metode inspeksi dan penjadwalan inspeksi yang sesuai pada well pipes dan separator *Vessel VS-80-001 to VS-80-003* di SEGWWL unit-2

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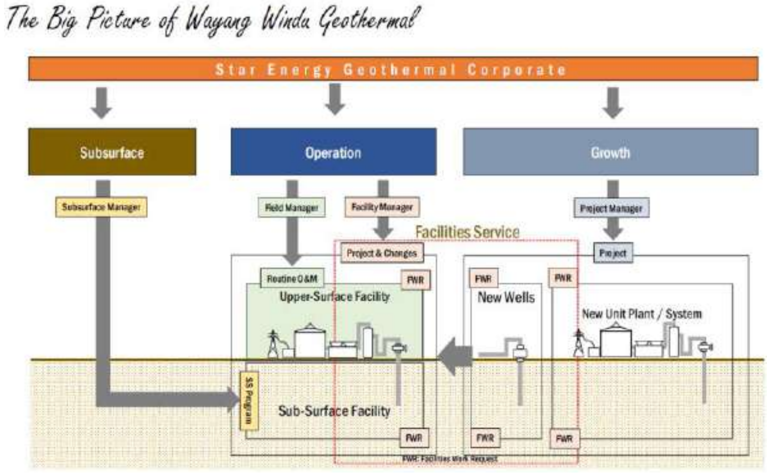
BAB II
TINJAUAN PUSTAKA

2.1. PLTP Wayang Windu

Fasilitas Geothermal Wayang Windu adalah salah satu fasilitas panas bumi yang beroperasi di Indonesia. Terletak 40 km di selatan Bandung di Jawa Barat, Wayang Windu Power Generation dioperasikan oleh Star Energy Geothermal (Wayang Windu) Limited atau SEGWWL adalah anak perusahaan yang sepenuhnya dimiliki oleh Star Energy. SEGWWL dikelola di bawah Kontrak Operasi Bersama dengan Pertamina untuk mengembangkan sumber daya panas bumi dalam wilayah kontrak seluas 12.960 hektar. Perjanjian Penjualan Energi antara Star Energy, Pertamina dan PLN, perusahaan utilitas milik negara, memberikan Star Energy hak untuk mengembangkan hingga 400 MW listrik - menghasilkan kapasitas selama 42 tahun, dengan setiap unit pembangkit yang dijadwalkan beroperasi untuk setidaknya 30 tahun. JOC memiliki potensi untuk memberikan lebih dari 400 MW beban dasar yang sudah dikontrakkan ke pembangkit listrik Jawa Barat (PLTP SEGWWL, 2012).

Unit pertama (kapasitas 110 MW) di Wayang Windu selesai dibangun pada tahun 1999, dan telah berproduksi pada kapasitas penuh (dengan tingkat ketersediaan lebih dari 98%) sejak tahun 2000. Pada tahun 1999, unit satu adalah turbin geothermal terbesar di dunia. Pada Maret 2009, Wayang Windu Unit 2 dioperasikan dengan kapasitas pembangkitan dari satu turbin/generator, sebesar 117 MW. Dengan demikian, Wayang Windu kini mengirimkan total 227 MW listrik kepada PLN, yang mengirimkan listrik ke jaringan transmisi Jawa Barat. Potensi untuk ekspansi lebih lanjut secara signifikan di Wayang Windu menjadi jelas selama pengeboran pengembangan untuk Unit 2. Beberapa sumur yang dibor untuk Unit 2 menguji lebih dari 50 MWe steam, dan menghasilkan keberlanjutan di lebih dari 40 MWe, sebagai produksi uap keberlanjutan kemungkinan terbesar di dunia untuk satu sumur tunggal (PT. SEGWWL, 2012).



Gambar 2. 1. Pembangkit Listrik Tenaga Geothermal-Wayang Windu (PT. SEGWWL, 2012)

2.2. **Geothermal Powerplant**

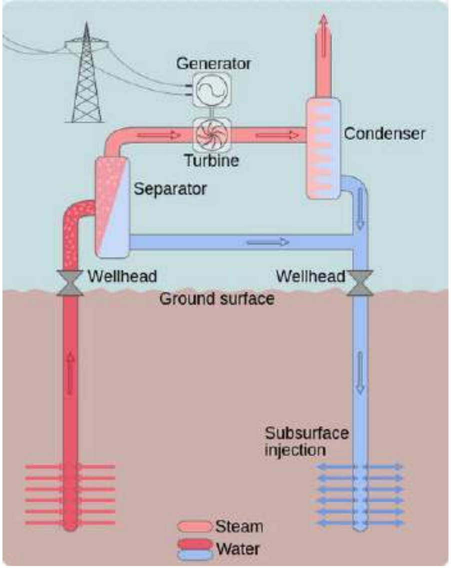
Geothermal power plant adalah pembangkit listrik yang menggunakan energi geothermal atau panas bumi untuk menghasilkan energi listrik. Energi yang digunakan oleh pembangkit ini adalah air panas atau uap panas yang diambil dari dalam bumi menggunakan sumur untuk menggerakan turbin uap.

Terdapat tiga tipe geothermal power plant, berdasarkan cara power plant mengambil dan menggunakan uap air yang ada dari dalam bumi (Ozkaraca, 2018).

Tipe tersebut meliputi:

1. *Flash Cycle Steam Plants*.

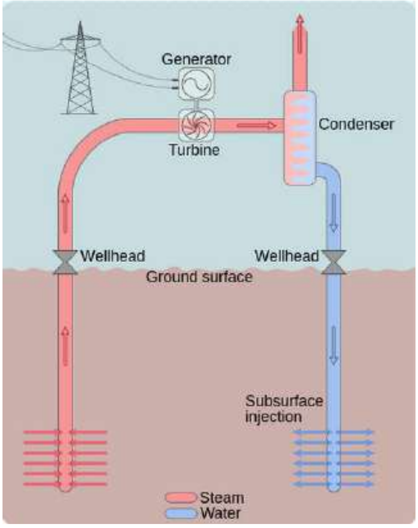
Panas bumi yang berupa fluida misalnya air panas alam (*hot spring*) di atas suhu 175°C dapat digunakan sebagai sumber pembangkit *Flash Steam Power Plants*. Fluida panas tersebut dialirkan kedalam tangki flash yang tekanannya lebih rendah sehingga terjadi uap panas secara cepat. Uap panas yang disebut dengan flash inilah yang menggerakkan turbin untuk meng-aktifkan generator yang kemudian menghasil-kan listrik. Sisa panas yang tidak terpakai masuk kembali ke reservoir melalui *injection well* (gambar 2.2).



Gambar 2. 2. Flash Cycle Steam Plant

2. *Dry Cycle Steam Plants*.

Pembangkit tipe ini adalah yang pertama kali ada. Pada tipe ini uap panas (*steam*) langsung diarahkan ke turbin dan mengaktifkan generator untuk bekerja menghasilkan listrik. Sisa panas yang datang dari *production well* dialirkan kembali ke dalam reservoir melalui injection well (gambar 2.3).

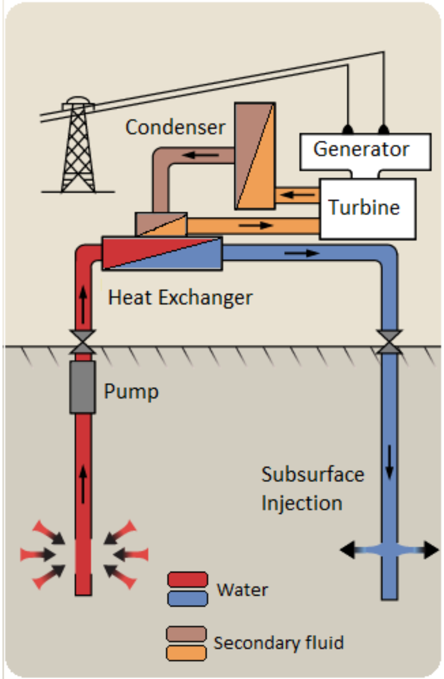


Gambar 2. 3. Dry Steam Plant

3. *Binary Cycle Power Plants (BCPP)*

BCPP menggunakan teknologi yang berbeda dengan kedua teknologi sebelumnya yaitu *dry steam dan flash steam*. Pada BCPP air panas atau uap panas yang berasal dari sumur produksi (*production well*) tidak pernah menyentuh turbin. Air panas bumi digunakan untuk memanaskan apa yang disebut dengan *working fluid* pada *heat exchanger*. *Working fluid* kemudian menjadi panas dan menghasilkan uap berupa *flash*. Uap yang dihasilkan di *heat exchanger* tadi lalu dialirkan untuk memutar turbin dan selanjutnya menggerakkan generator untuk menghasilkan sumber daya listrik. Uap panas yang dihasilkan di heat exchanger inilah yang disebut sebagai *secondary* (*binary*) *fluid*. *Binary Cycle Power Plants* ini sebetulnya merupakan sistem tertutup. Dengan demikian tidak ada panas yang dilepas ke atmosfer. Keunggulan dari BCPP ialah dapat dioperasikan pada suhu rendah yaitu 90-175°C (gambar 2.4).

Proses produksi PLTP SEGWWL menggunakan sistem BCPP dalam proses produksinya.



Gambar 2. 4. Binary Cycle Steam Plant.

Pada prinsipnya, penggerak sumber tenaga pembangkit listrik berupa uap panas didapat dari geothermal fluid yang berada di reservoir air di bawah tanah yang dekat dengan kerak bumi. Geothermal fluid yang disebut sebagai brine di ekstraksi dari kerak bumi dengan menggunakan well system, air panas ini terekstrak akibat adanya tekanan yang di hasilkan dibawah permukaan tanah. Setelah melalui proses ekstraksi, air tersebut akan dialirkan ke turbin. Dalam proses pengaliran air akan melewati proses separasi, scrubbing, dan kondensasi. Pada proses separasi, air dan uap akan dipisahkan, karena hanya uap saja yang di butuhkan untuk menggerakan turbin. Air yang telah di proses akan di kembalikan kembali ke reservoir well, dimana air akan terpanaskan lagi dan proses akan termulai kembali. Air panas atau brine ini memiliki kandungan unsur kimia, yang bila dalam jumlah banyak, dapat menyebabkan kerusakan pada equipment geothermal.

2.3. **Pipeline.**

Pada pembangkit listrik geothermal, dibutuhkan sistem perpipaan yang digunakan untuk mengalirkan air dan uap panas untuk menggerakan turbin. pada fasilitas pembangkit listrik Wayang Windu, sistem perpipaan dibagi menjadi empat kategori, yaitu:

- *Two-Phase pipeline.*
- *Steam pipeline.*
- *Brine pipeline.*
- *Condensate pipeline.*

Pipa *Two-phase* pipelines yang tersambung dari *wellpads* menuju *separator* memiliki ukuran 36” menggunakan material *carbon steel*, dengan perkiraan jarak sejauh 4 km. Pipa *Steam pipeline* yang tersambung dari *separator* menuju *power station* memiliki ukuran 40” *carbon steel pipe,* dan panjang 1 km. Steam yang sudah dipisahkan dari brine keluar dari Separator menuju Scrubber di SBS-I di Power Station. 30” steam line mengalirkan steam keluar dari Separator menuju ke 30” Balancing Header. Sebuah drain pot disediakan di low point Separator steam outlet dan berfungsi untuk menampung kondensat dan mengalirkannya ke 3” Close Condensate Collecting System yang kemudian meneruskannya ke 30” Main Brine Line Injection.

Sekitar 500 m steam piping bagian pertama yang berfungsi sebagai scrubbing pipe dibungkus insulasi setebal 1” dengan maksud agar terjadi kondensasi di sepanjang pipa tersebut. Kondensat dari pipa tersebut dikumpulkan di drain-pot (8 buah untuk masing-masing steam line) yang ditempatkan pada setiap ± 50 m sepanjang jalur pipa tersebut. Dari drain pot tersebut kemudian kondensat, melalui normally-open 2” drain line, dialirkan ke Close Condensate Collecting System (3” pipe) yang kemudian meneruskannya ke 30” main brine injection line.

Selain itu, drainpot tersebut dilengkapi dengan steam trap yang digunakan pada saat *condensate collecting header* tidak difungsikan, seperti pada saat start-up. Kapasitas semua steam trap adalah 200% dari estimasi maksimum condensate dan wash water flow rate. Setiap drain pot juga dilengkapi dengan 2” blowdown line. Discharge dari steam trap dan blowdown drain valve dialirkan ke 42” flash tank yang terletak disamping setiap drain pot, dan kemudian dialirkan ke thermal pond melalui main drain. Selebihnya steam piping dibungkus dengan insulasi setebal 2” dan hanya berfungsi sebagai penghantar saja.

36” Header dilengkapi dengan 36’ isolation valve dipasang up-stream Scrubber. Di sekitar isolation valve dipasang 4” by-pass valve yang berfungsi untuk start-up pre-heating. Dari Header, dua jalur 36” steam line mengalirkan steam ke masing-masing scrubber (dua buah scrubber tersedia di Power Station area, yaitu VS-81-007 dan VS-81-008). Dalam keadaan normal Scrubber berfungsi untuk melindungi turbin dari Separator flooding (steam yang masuk ke turbin diharapkan kering, karena kalau ada sedikit saja kondensat masuk ke turbin akan mengakibatkan vibrasi dan korosif pada turbin blade. Oleh karena itulah Separator diharapkan dapat menghasilkan steam dengan kadar kekeringan 99,98 %) (PLTP SEGWWL, 2012).

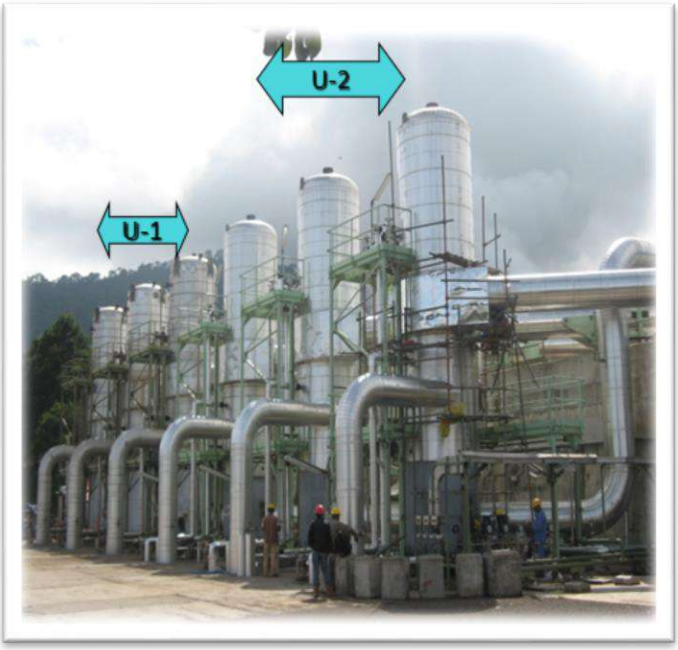
Pada perpipaan geothermal, permasalahan yang sering dihadapi adalah scaling atau fouling dan korosi. Permasalahan ini timbul akibat karakteristik fluida geothermal yang mengandung komponen zat kimia yang bersifat korosif dalam jumlah banyak.

Gambar 2. 5. Contoh Permasalahan Scaling pada Pipa Akibat CaCO3 (Andritsos, dkk, 2014)

Gambar 2. 6. Contoh Permasalahan Underdeposit Corrosion pada Pipa (Andritsos, dkk, 2014)

2.4. **Separator (Vessel)**

Konsep dari penggunaan separator adalah untuk mengakomodasi variasi steam dari hasil sumur-sumur produksi guna menghasilkan steam yang murni tanpa kandungan brine. Artinya separator berfungsi untuk memisahkan kandungan steam dengnan brine. Separator digunakan untuk daerah pembangkit dengan karakteristiksteam dua fase, dimana tingkat prosentase pemisahan steam dengan brine di separator sangat menentukan kualitas steam yang akan digunakan untuk memutar turbin. Diharapkan separator mampu memisahkan prosentase steam dnegan brine sebesar-besarnya sehingga steam yang dihasilkan betul-betul bebas dari kandungan brine (steam murni). Gambar 2.7 menunjukan Separator station yang ada pada PLTP SEGWWL.



Gambar 2. 7. Separator Station di PLTP SEGWWL

2.5. Peraturan Pemerintah

Undang-undang yang mengatur tentang panas bumi adalah Undang-Undang Republik Indonesia Nomor 21 Tahun 2014. Pada bagian keempat tentang Kewajiban Pemegang Izin Panas Bumi Pasal 52 ayat 1 poin a dan b menyebutkan bahwa perusahaan harus[1]:

- Memahami dan menaati peraturan bidang keselamatan dan kesehatan kerja serta perlindungan lingkungan.
- Melakukan pengendalian pencemaran / kerusakan lingkungan.

Meskipun begitu, tidak ada pasal yang mengatur tentang jangka waktu inspeksi dan ketentuan pemeliharaan komponen dari pembangkit listrik tenaga geothermal. Diluar undang-undang tersebut pun tidak ada peraturan yang mengatur tentang jangka waktu inspeksi maupun pemeliharaan komponen dari pembangkit listrik tenaga geothermal.

Sebelum menerapkan metode Risk-Based Inspection di tahun 2014, SEGWWL melakukan inspeksi berkala setiap 4 tahun sekali. Ini berdasarkan rekomendasi pihak produsen komponen. Pertimbangan ini pun sesuai dengan Undang-

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[1] Undang-Undang Republik Indonesia Nomor 21 Tahun 2014 Tentang Panas Bumi

Undang Nomor 1 Tahun 1970 Tentang Keselamatan kerja, Bab III Syarat-syarat keselamatan kerja, Pasal 3 yaitu[2]:

- Mencegah dan mengurangi kemungkinan kecelakaan.
- Mencegah dan mengendalikan timbulnya / menyebarluasnya suhu, kelembaban, debu, kotoran, asap, uap, gas, hembusan angin, cuaca, radiasi, suara dan getaran.
- Mencegah dan mengendalikan timbulnya penyakit akibat kerja baik fisik, psikis, peracunan, infeksi, dan penularan.

2.6. Manajemen Risiko dan Mitigasi Risiko

Risiko adalah kombinasi dari kemungkinan suatu peristiwa yang terjadi selama periode waktu tertentu dan konsekuensi (umumnya negatif) yang berkaitan dengan kejadiannya. (API 580, 2009). Manajemen risiko, adalah proses untuk menilai risiko, untuk menentukan apakah pengurangan risiko diperlukan dan untuk mengembangkan rencana untuk mempertahankan risiko pada tingkat yang dapat diterima. Dalam manajemen risiko, terdapat unsur pengurangan/minimalisasi risiko. Pengurangan risiko adalah tindakan mitigasi suatu risiko yang dianggap terlalu tinggi ke yang lebih rendah, tingkat dengan level risiko yang dapat diterima dengan beberapa bentuk kegiatan pengurangan risiko. Dengan menggunakan manajemen risiko, beberapa risiko dapat diidentifikasi sebagai diterima sehingga tidak ada pengurangan risiko (mitigasi) yang diperlukan.

2.7. Risk-Based Inspection.

Manajemen risiko secara umum telah menjadi kebutuhan dalam dunia industri dan masyarakat dalam beberapa dekade ini. Dalam perindustrian, proses deteriorasi merupakan seperti fatig, perkembangan crack, dan korosi merupakan masalah umum yang selalu ada dalam setiap peralatan yang ada di industri, permasalah ini perlu dihadapi karena dapat menyebabkan berkurangnya perfoma dari sistem hingga dapat menyebabkan terjadinya kegagalan sebuah sistem. Untuk memastikan bahwa sebuah sistem dapat bekerja secara maksimal maka perlu dilakukan pengendalian terhadap laju deformasi yang ada, dan bila diperlukan, dilakukan langkah corrective maintenance. Umumnya, inspeksi merupakan cara yang paling relevan serta efektif dalam mengontrol deformasi.

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[2] Undang-Undang Republik Indonesia Nomor 1 Tahun 1970 Tentang Keselamatan Kerja

Gambar 2. 8. Inspection and Maintenance planning complex (Faber M.H, 2002).

Hal yang diperlukan dalam merencanakan inspeksi adalah bagaimana cara melakukan inspeksi, apa saja yang perlu di inspeksi, dimana dan seberapa sering dilakukan inspeksi. Salah satu metode atau pendekatan inspeksi adalah dengan menggunakan metode Risk-based Inspection (RBI). Pendekatan RBI dilakukan berdasarkan kuantifikasi dari risiko yang tidak hanya ada pada sebuah komponen dasar, tapi juga pada seluruh komponen dalam sebuah system (Faber, 2002; API 581, 2008).

Risk-Based Inspection merupakan salah satu metode inspeksi yang dilakukan dengan mengkuantifikasi risiko kegalalan pada sebuah system atau komponen

RBI digunakan karena lebih fleksibel dan lebih dapat beradaptasi dengan kondisi equipment pada lingkungan kerjanya. Dengan demikian hasil inspeksi menjadi lebih detail, ini dikarenakan metode RBI mempertimbangkan seluruh risiko kegagalan dari tiap tiap equipment dan dari risiko kegagalan tersebut dapat menjadi pertimbangan perencanaan inspeksi serta tindakan mitigasi.

Secara umum tujuan dari Risk-Based Inspection adalah sebagai berikut:

1. Mengklasifikasikan peralatan yang sedang beroperasi untuk mengidentifikasi area yang memiliki tingkat risiko tinggi
2. Menentukan nilai risiko pada tiap peralatan berdasarkan metodologi yang konsisten,
3. Adanya prioritas berdasarkan nilai risiko yang terukur,
4. Merancang rencana inspeksi yang cocok untuk dilakukan,
5. Secara sistematis mengatur risiko pada kegagalan alat dan penanggulangannya jika terjadi kegagalan.

Keuntungan menggunakan pendekatan berbasis risiko pada perencanaan inspeksi antara lain adalah:

1. Sebuah gambaran yang sistematis dari instalasi dicapai bersama-sama dengan rincian eksplisit, sistematis dan dokumentasi risiko instalasi ini dapat menunjukkan penentu risiko dan merekomendasikan tindakan yang tepat.
2. Upaya inspeksi difokuskan pada item dengan risiko keselamatan, ekonomi atau lingkungan yang tinggi; sementara upaya yang diterapkan pada sistem berisiko rendah dikurangi.
3. Metode probabilistik dapat digunakan dalam menghitung tingkat degradasi dan karenanya memungkinkan variasi dan ketidakpastian parameter proses, korosivitas, dan dengan demikian tingkat degradasi dan kerusakan sejauh mana dapat diukur.
4. Konsekuensi dari kegagalan diperhitungkan, sehingga perhatian dapat difokuskan di mana ia akan memiliki dampak yang signifikan. Jika ada ketidakpastian yang signifikan dalam hasil, ini dapat dimodelkan dengan menyelidiki probabilitas dari berbagai hasil dengan menggunakan pendekatan pohon kejadian/event tree.
5. RBI berkontribusi secara produktif dan terfokus untuk memastikan bahwa risiko instalasi keseluruhan tidak melebihi batas penerimaan risiko yang ditetapkan oleh otoritas dan / atau operator.
6. Identifikasi inspeksi yang optimal atau pemantauan metode sesuai dengan mekanisme degradasi teridentifikasi dan strategi yang disepakati

Risiko kegagalan dalam RBI didapatkan dari perhitungan Probability of Failure (PoF) dan Consequence of Failure (CoF) dari sebuah equipment. Dalam RBI, tingkatan risiko dari setiap equipment di prioritaskan secara sistimatis, karena itu, equipment yang memiliki tingkat risiko yang tinggi dapat di prioritaskan.

2.8. Probability of Failure.

Probability of Failure (PoF) adalah nilai perhitungan peluang kemungkinan terjadinya kegagalan pada suatu peralatan. Dalam API 581, RBI probabilitas sebuah kegagalan dapat di rumuskan sebagai berikut

$$P_f\ (t) = gff.D_f\ (t).P_f$$

dimana $P_f\ (t)$ adalah probabilitas kegagalan yang ditentukan oleh *gff* (generic failure frequency), $D_f\ (t)$ sebagai factor kerusakan, dan faktor management sistem F_{MS}.[3] Generic failure frequency merupakan sebuah nilai representative dari data refining dan kegagalan dari tipe tipe komponen yang berbeda. Frekuensi kegagalan umum sebuah komponen diperkirakan menggunakan catatan dari peralatan-peralatan dalam sebuah perusahaan atau dari berbagai pabrik dalam sebuah industri, dari sumber literatur, dan data umum keandalan komersial. GFF di gunakan sebagai frekuensi kegagalan sebelum terjadinya kerusakan yang di akibatkan oleh eksposure terhadap lingkungkan operasi sebuah komponen.

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[3] API RP 581. 2016. Risk-based Inspection Methodology, 3rd Edition. Washington. D.C:API Publishing Services.

2.8.1 Damage Mechanism

Damage mechanism, adalah sebuah proses yang menginduksi perubahan mikro atau makro pada material yang berubah dari waktu ke waktu sehingga menjadi berbahaya bagi kondisi material tersebut atau properties mekanik material tersebut. Memahami equipment dan lingkungan proses dari equipment tersebut (baik internal maupun eksternal) dan lingkungan mekanik adalah kunci untuk mengidentifikasi damage mechanism. [4] Korosi, keretakan, kerusakan mekanikal serta metalurgi termasuk pada damage mechanism, damage mechanism diperlukan untuk:

a. Analisa probability of failure (PoF)
b. Pemilihan interval inspeksi yang sesuai, lokasi, serta teknik yang digunakan
c. Sebagai acuan membuat keputusan untuk mengurangi atau menghilangkan

Failure modes dapat digunakan untuk mengidentifikasi bagaimana sebuah komponen yang rusak dapat gagal (contoh, kebocoran atau rupture), memahami failures mode penting karena tiga alasan berikut:[5]

a. Analisa Consequence of Failure (CoF)
b. Acuan penentuan keputusan *run-or-repair*.
c. Pemilihan cara perbaikan dari sebuah equipment.

2.8.2 Damage Factor.

Damage factor (D_f) atau faktor kerusakan dapat disebabkan oleh berbagai macam faktor. Faktor kerusakan ditentukan dari mekanisme kerusakan (korosi, keretakan, dan lain-lain) yang relevan terhadap material konstruksi dan proses servis. Faktor kerusakan ini berpengaruh terhadap gff dan F_{ms}.

Damage Factor yang dapat terjadi pada pressurized vessels, berdasarkan API RP 581 meliputi:

1. Thinning
2. Component Lining
3. SCC Damage Factor – Caustic Cracking
4. SCC Damage Factor – Amine Cracking
5. SCC Damage Factor – Sulfide Stress Cracking
6. SCC Damage Factor – HIC / SOHIC – H2S
7. SCC Damage Factor – Carbonate Cracking
8. SCC Damage Factor – PTA Cracking
9. SCC Damage Factor – CLSCC
10. SCC Damage Factor – HSC-HF
11. SCC Damage Factor – HIC / SOHIC – HF

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[4] API RP 580. 2009. Risk-Based Inspection, 2nd Edition, Washington. D.C:API Publishing Services.

[5] API RP 580. 2009. Risk-Based Inspection, 2nd Edition, Washington. D.C:API Publishing Services.

12. External Corrosion Damage Factor – Ferritic Component
13. External CLSCC Damage Factor Austenitic Component
14. CUI Damage Factor – Ferritic Component
15. External CUI CLSCC Damage Factor – Austenitic Component
16. HTHA Damage Factor
17. Brittle Damage Factor
18. Temper Embrittlement Damage Factor
19. 885 Embrittlement Damage Factor
20. Sigma Phase Embrittlement Damage Factor
21. Piping Mechanical Fatigue Damage Factor.

Damage factor yang digunakan untuk penelitian ini dapat dilihat pada table 2.1.

Tabel 2. 1. Kriteria Penyaringan untuk Faktor Kerusakan (API RP 581)

No.	Damage Factor	Screening Criteria	Yes/No
1	Thinning	*All component should be checked for thining*	Y
2	SCC Damage Factor – Sulfide Stress Cracking	*If the component's material of construction contains is carbon or low alloy steel and the process environment contains water and H2S in any concentration, then the component should be evaluated to Sulfide Stress Cracking*.	Y
3	SCC Damage Factor – HIC/SOHIC-H_2S	*If the component's material of construction contains is carbon or low alloy steel and the process environment contains water and H2S in any concentration, then the component should be evaluated to HIC/SOHIC-H2S cracking.*	Y

2.8.3 Management System Factor.

Management System Factor (F_{MS}), merupakan faktor dari pengaruh management system terhadap integritas mekanik dari plant equipment. Faktor ini terdiri dari probabilitas kerusakan yang terakumulasi dalam waktu lama dan proporsional terhadap kualitas dari integritas program mekanikal dari sebuah fasilitas. Evaluasi sistem manajemen dijabarkan dalam API 581 pada Annex 2.A. Evaluasi tersebut terdiri dari pertanyaan-pertanyaan yang sebagian besar terdiri dari banyak bagian. Maksimum skor yang dapat diperoleh adalah 1000. Skor yang didapatkan kemudian dimasukkan ke dalam persamaan berikut:

$$pscore = \frac{Score}{1000} 100[unit\ is\ \%]$$

Selanjutnya nilai *pscore* tersebut dimasukkan kedalam persamaan berikut untuk mendapatkan nilai F_{MS}.

$$F_{MS} = 10^{(-0.02\,pscore+1)}$$

2.9 Consequence of Failure (CoF).

Analisa konsekuensi pada Inspeksi Berbasis Risiko atau RBI adalah salah stu program yang dilakukan untuk mendiskriminasikan antara satu equipment dengan equipment lainnya berdasarkan signifikannya potensi keruskanan alat equipment tersebut. Analisa konsekuensi perlu dilakukan untuk mengestimasikan konsekuensi yang akan terjadi akibat failure modes dari damage mechanism yang telah teridentifikasi.

2.10 Penentuan Risiko.

Sebuah risiko dapat dikalkulasikan sebagai fungsi waktu. Ekuasi ini menggabungkan probabilitas kegagalan dan konsekuensi kegagalan.

$$R(t) = P_f(t).C(t)$$

Dalam API RBI, konsekuensi kegagalan *C(t)* yang diasumsikan tidak relevan dalam waktu, dan dapat diubah tergantung pada risiko yang di asumsikan, bisa pada berbasis area atau financial.

$R(t) = P_f(t).CA$ untuk risiko berbasis area.
$R(t) = P_f(t).FC$ untuk risiko berbasis financial.

Merencanakan nilai POF dan COF pada matriks risiko adalah metode yang efektif untuk menggambarkan risiko secara grafis. POF diplot di sepanjang satu sumbu, meningkatkan besarnya dari asalnya, sedangkan COF diplot di sepanjang sumbu lainnya. Hasil tingkat risiko dapat diresentasikan dalam matriks untuk menunjukan distribusi risiko untuk komponen. [6]

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[6] API RP 581. 2016. Risk-based Inspection Methodology, 3rd Edition. Washington. D.C:API Publishing Services

2.11 Inspection Plan

Dalam API 581 untuk pressure vessel tidak diberikan suatu persamaan ataupun formula pasti untuk menghitung jadwal inspeksi. Hal ini dikarenakan setiap perusahaan/ memiliki standar sendiri mengenai risiko yang bisa diterima dan hal ini mempengaruhi penjadwalan inspeksi tersebut. Dengan demikian penjadwalan inspeksi diserahkan kepada perusahaan alat dengan mempertimbangkan hasil yang didapat dari analisa RBI.

Jika melihat API 510 Pressure Vessel Inspection Code, disebutkan interval inspeksi dilakukan sesuai dengan jenis inspeksi. Jenis inspeksi menurut API 510 ada 3, yaitu inspeksi internal, on-stream dan eksternal. Bedanya antara inspeksi internal dengan on-stream adalah inspeksi internal harus dilakukan pada saat alat tidak beroperasi,sedangkan inspeksi onstream dilakukan pada saat peralatan sedang beroperasi. Inspeksi eksternal dilakukan hanya menggunakan visual untuk mengecek apakah kondisi struktural atau eksternal dari alat dalam kondisi yang baik. Untuk jadwal inspeksi, API 510 menyebutkan bahwa untuk inspeksi internal dan on-dtream pada pressure vessel dilakukan maksimal 10 tahun atau setengah dari sisa umur pakai (Remaining Life) dari peralatan. Apabila nilai Remaining Life pada peralatan kurang dari 4 tahun, maka interval inspeksinya adalah full Remaining Life atau maksimal 2 tahun. Nilai sisa umur pakai didapatkan menggunakan persamaan berikut:

$$\text{Remaining life} = \frac{t\ actual - t\ required}{corrosion\ rate}$$

Rencana inspeksi dikembangkan dari analisis beberapa sumber data. Peralatan harus dievaluasi berdasarkan mekanisme kerusakan yang ada atau yang mungkin terjadi. Metode dan tingkat NDE harus dievaluasi untuk memastikan mereka dapat mengidentifikasi mekanisme kerusakan dan tingkat keparahan kerusakan secara memadai[7]. Pemeriksaan harus dijadwalkan pada interval yang mempertimbangkan

a. Type of damage;
b. Rate of damage progression;
c. Tolerance of the equipment to the type of damage;
d. Probability of the NDE method to identifY the damage; and
e. Maximum intervals as defined in codes and standards..

Rencana inspeksi harus memuat tugas dan jadwal inspeksi yang diperlukan untuk memonitor mekanisme kerusakan dan memastikan integritas mekanis dari peralatan (pressure vessel atau pressure relieve device). Rencana tersebut harus[8]:

a. Tentukan jenis inspeksi yang diperlukan.
b. Identifikasi tanggal inspeksi berikutnya untuk setiap jenis inspeksi;
c. Jelaskan teknik inspeksi dan NDE;
d. Jelaskan tingkat dan lokasi inspeksi dan NDE;

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[7] API 510, Pressure Vessel Inspection Code: In-Service Inspection, Rating, Repair and Alteration, 9th edition, june 2006.

[8] API 510, Pressure Vessel Inspection Code: In-Service Inspection, Rating, Repair and Alteration, 9th edition, june 2006.

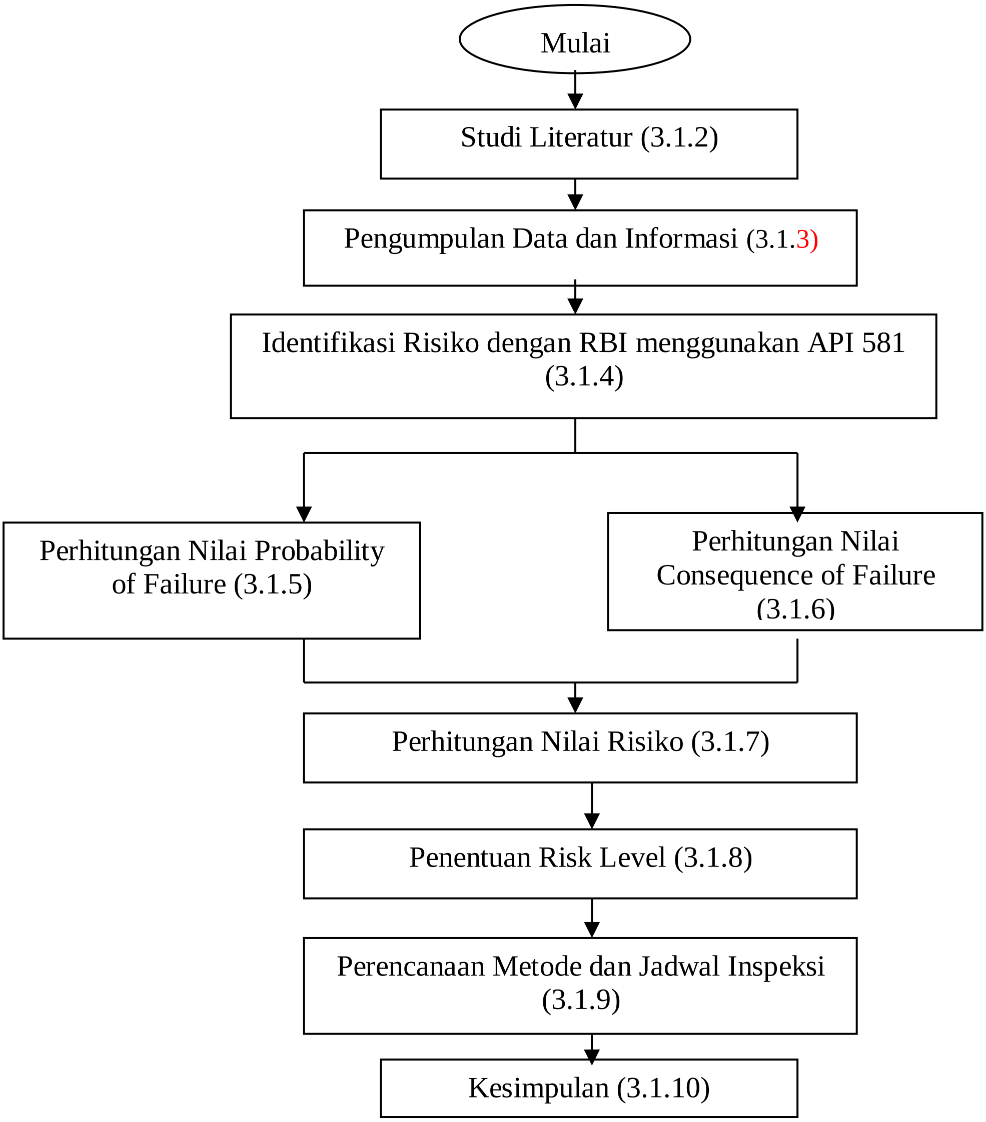
e. Jelaskan persyaratan pembersihan permukaan yang diperlukan untuk inspeksi dan pemeriksaan;
f. Jelaskan persyaratan dari setiap uji tekanan yang diperlukan, mis. Jenis pengujian, tekanan uji, dan durasi; dan
g. Jelaskan perbaikan yang diperlukan.

“Halaman ini sengaja dikosongkan”

BAB III
METODOLOGI PENELITIAN

3.1 Diagram Alur Penelitian

Metode penelitian dijelaskan melalui diagram alur yang terdiri dari langkah-langkah proses dalam melakukan penelitian tugas akhir ini. Langkah langkah pengerjaan dapat dilihat pada gambar 2.9



Gambar 3. 1. Flow Chart Metodologi

Diagram alur dijelaskan sebagai berikut :

3.1.1 Identifikasi masalah

Langkah pertama yang dilakukan untuk mengerjakan analisa ini adalah mengidentifikasi masalah yang akan dikaji.

3.1.2 Studi Literatur.

Setelah memahami isi permasalah yang akan dikaji, langkah berikutnya adalah untuk melakukan studi dari berbagai topik literatur. Studi Literatur bertujuan untuk memahami dan mendalami metode Risk Based Inspection (RBI) menggunakan API 581 serta bagaimana perhitungan Probability of failure (PoF) dan Consequence of failure (CoF), sehingga didapatkan sebuah risk level dan nilai risiko. Selain itu juga mempelajari tentang objek inspeksi yaitu well pipes dan separator pada SEGWWL unit-2

Studi literatur yang dilakukan dapat diringkas pada table 3.1:

Tabel 3. 1 Review dari Studi Literatur

Referensi	Author	Ringkasan
Geothermal Power Technology	Kenneth H. Williamson, Richard P. Gunderson, Gerald M. Hamblin, Darrell L. Gallup, dan Kevin Kitz	Paper ini menjelaskan tentang teknologi pembangkit listrik pemanfaatan panas bumi. Bagian-bagian utama pada prosesnya adalah production wells, separator, scrubber, turbin, condenser, dan cooling tower.
Design of Wayang Windu Unit 2 Geothermal Power Station	Naoko Yamaguchi	Pembangunan wayang windu unit 2 sempat ditunda karena krisis ekonomi 1997. Desain dirancang identik dengan unit 1. Setelah ekonomi indonesia membaik, pembangunan dilanjutkan dengan peningkatan pada pembangkit dan sistem integrasinya. Pada pembangkit, peningkatan difokuskan pada menurunkan tekanan kondenser daripada meningkatkan tekanan atau laju uap.
Geothermal Energy: Power Plant Technology and Direct Heat Applications	Diego Moya, Clay Aldas, Prasad Kaparaju	Menerangkan tentang tipe-tipe pembangkit listrik geothermal (single flash, double flash, dry-steam, dan binary / kalina cycle), dan pemanfaatan fluida geothermal selain untuk pembagkit listrik
Corrosion and Material	Tefvik Kaya, Pelin Hosan	Menjelaskan tipe-tipe korosi yang terjadi di geothermal plant, dan

Selection for Geothermal Systems		faktor-faktor yang mempengaruhinya.
Guideline: -API RP 581	American Petroleum Institute	Sebagi guidelines untuk pengerjaan Risk-Based Inspection.

3.1.3 Pengumpulan Data dan Informasi.

Untuk melakukan *Risk-Based Inspection* maka diperlukan beberapa data serta sumber data yang mengacu pada API 581 dan API 580. Sumber data yang diperlukan untuk melakukan RBI yaitu data desain dan konstruksi, data inspeksi dan maintenance sebelumnya, analisa hazard dan MOC, pemilihan material serta analisa korosi pada equipment. Sedangkan data yang dibutuhkan untuk melakukan analisa RBI adalah tipe dari pipeline dan separator yang akan di analisa, material dari konstruksi equipment tersebut, data inspeksi, perbaikan serta penggantian bagian dari equipment, komposisi fluida, invetori fluida, kondisi operasi, sistem keselamatan, sistem pendeteksi, *damage mechanism*, lajur, dan *severity* dari *damage mechanism* tersebut, densitas personel, *coating, cladding,* dan insulasi.

Data yang dikumpulkan dalam penelitian ini meliputi:

- P&ID dari fasilitas powerplant, (lampiran 1)
- *Chemical analysis* dari powerplant. (lampiran 2)
- *Corrosion report.*
- Laporan inspeksi sebelumnya.

Data yang didapat dari akan diolah untuk menemukan *Probability of Failure* dan *Consequence of Failure* untuk menentukan *Inspection Plan* selanjutnya.

3.1.4 Identifikasi risiko dengan RBI

Setelah mendapatkan data, tahap selanjutnya adalah melakukan penentuan *damage mechanism* dari equipment yang di teliti. Potensi dari damage mechanism di indetifikasi dari tipe material, process parameter, dan lingkungan korosi.

3.1.5 Probability of Failure (PoF)

Setelah menentukan damage mechanism yang ada pada equipment tersebut, kalkulasi Probability of Failure (PoF) dapat dilakukan. Perhitungan PoF dicakup dari API RBI 581 Part 2. PoF dihitung berdasarkan tipe komponen dan damage mechanism yang ada.

Perhitungan Probability of Failure bertujuan untuk mendapatkan nilai dari kemungkinan kegagalan yang terjadi berdasarkan satu atau beberapa faktor kerusakan di bawah ini:

1. Thinning
2. Component Lining
3. External Damage

4. Stress Corrosion Cracking (SCC)
5. High Temperature Hydrogen Attack
6. Mechanical Fatigue
7. Brittle Fracture

Pemilihan faktor kerusakan yang terjadi pada alat didasari dari kondisi alat tersebut dan disesuaikan dengan faktor kerusakan yang ada.

3.1.6 Consequence of Failure (CoF)

API RP 581 mencantumkan langkah-langkah perhitungan dari consequence of failures yang mana dikutip pada tabel berikut.

Tabel 3. 2. Consequence of failures analysis steps

Step	**Description**	**Section in this Part**	
		Level 1 Consequence analysis	**Level 2 consequence analysis**
1	Determine the released fluid and its properties, including the release phase.	4.1	5.1
2	Select a set of release hole sizes to determine the possible range of consequence in the risk calculation	4.2	
3	Calculate the theoritical release rate	4.3	5.3
4	Estimate the total amount of fluid available for release	4.4	
5	Determine the type of release, continuous or instantaneous, to determine the method used for modelling the dispersion and consequence	4.5	
6	Estimate the impact of detection and isolation systems on release magnitude.	4.6	
7	Determine the release rate and mass for the consequence analysis	4.7	5.7
8	Calculate flammable/explosive consequence	4.8	5.8
9	Calculate toxic consequence	4.9	5.9
10	Calculate non-flammable, non-toxic consequence	4.1	5.1
11	Determine the final probability weighted component damage and personnel injury consequence areas	4.11	5.11
12	Calculate financial consequence	4.12	

Dalam perhitungan consequence area dari well pipes dan separator ini menggunakan Level 1 COF karena cairan utama yang terkandung di dalam pressure vessel telah ditentukan dalam daftar cairan representatif yang disediakan oleh API RP 581 sendiri.

Langkah-langkah untuk perhitungan consequence level 1 tanpa memperhatikan segi ekonomis dijelaskan sebagai berikut[13]:

1. **Tentukan fluida yang dikeluarkan serta karakteristiknya.**

1.1. Tentukan fluida representatif dari table 4.1 dari API RP 581 Part 3. Fluida representatif ditentukan berdasarkan komposisi kimia dari fluida, fluida paling dominan lah yang dipilih menjadi representatif. Namun, apabila berupa campuran ada pertimbangan yang perlu diperhatikan. Tercantum pada API RP 581 Annex 3.A, yaitu

> "*If a mixture contains inert materials such as* CO_2 *or water, the choice of representative fluid should be based on the flammable/toxic materials of concern, excluding these materials. This is a conservative assumption that will result in higher COF results, but it is sufficient for risk prioritization*".

1.2. Tentukan fase fluida yang tersimpan
Penentuan jenis fluida yang tersimpan di steam scrubber dan steam ejector (gas removal system) apakah gas atau cairan. Fase fluida yang melewati steam scrubber dan gas removal system adalah gas/vapour.

1.3. Tenetukan karakter dari fluida yang tersimpan
Parameter yang ditentukan adalah sebagai berikut:

- MW : Molecular Weight (kg/kg-mol)
- k : Ideal gas specific heat ratio
- AIT : Auto-ignition Temperature (K(°R))

Nilai dari parameter tersebut tercantum di table 4.2 API RP 581 Part 3.

1.4. Tentukan fase tetap fluida setelah terlepas ke atmosfer dan fase saat masih tersimpan seperti pada langkah 1.2.

Table 3.3 Langkah 1 - fase fluida

Phase of Fluid at Normal Operating (Storage) Conditions	**Phase of Fluid at Ambient (after release) Conditions**	**Determination of Final Phase of Consequence Calculation**
Gas	Gas	Model as gas
Gas	Liquid	Model as gas
Liquid	Gas	Model as gas unless the fluid boiling point at ambient conditions is greater than 80°F, then model as a liquid

Liquid	Liquid	Model as liquid

2. **Pilih ukuran lubang (release hole size) untuk menentukan rentang nilai konsekuensi di perhitungan.**
   2.1. Calculate of release hole sizes by determining each diameter (d_n)
   Berdasarkan API RP 581 Part 3 Annex 3.A menunjukkan bahwa untuk peralatan bejana tekan, ukuran empat lubang pelepasan standar diasumsikan untuk semua ukuran dan semua jenis bejana tekan. Jadi, mulai dari ukuran lubang rilis kecil, ukuran lubang rilis menengah, ukuran lubang rilis besar, dan sampai ukuran lubang rilis pecah harus dihitung masing-masing.

Table 3.4 Ukuran lubang keluaran

Release hole no.	Sizes	Range of diameter	Release hole diameter
1	Small	0 – ¼	d_1= 0.25
2	Medium	> 1/4 – 2	d_2= 1
3	Large	>2 – 6	d_3= 4
4	Rupture	>6	d_4= 16

   2.2. Tentukan nilai gff_n, untuk tiap n^{th} ukuran release hole.
   Langkah ini dijelaskan pada tabel 3.2 dari API RP 581 Part 2.

3. **Hitung theoretical release rate**
   3.1. Memilih persamaan release rate berdasarkan fase fluida di langkah 1.2.
   Karena fase fluida yang ditentukan di langkah 1.2. adalah gas atau vapour dan storage pressure dari equipment P_s lebih besar dari transition pressure P_{trans}. Maka, menggunakan

$$W_n = \frac{Cd}{C2} \; x \; An \; \mathrm{x} \; Ps \sqrt{\left(\frac{k \; x \; MW \; x \; gc}{R \; x \; Ts}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}} \qquad (3.1)$$

   3.2. Hitung luasan release hole size, A_n, di tiap release hole dengan,

$$An = \frac{\pi dn^2}{4} \qquad (3.2)$$

3.3. Untuk liquid releases, hiitung viscosity correction factor untuk setiap lubang keluaran ($K_{v,n}$).

Karena fase release adalah vapour / gas. Maka langkah ini dapat dilewat.

3.4. Hitung release rate untuk setiap lubang keluaran, Wn , untuk setiap luasan An.

Hitung theoretical release rate (W_n) untuk setiap lubang keluaran berdasarkan luasan (A_n) yang sudah ditentukan di langkah 3.2.

4. Estimasi total fluida yang dapat dikeluarkan

4.1. Menentukan grup komponen and equipment menjadi inven.

API RP 581 memberikan deskripsi apa pun untuk Konsekuensi Kegagalan (COF) untuk item peralatan yang dinilai adalah untuk digabungkan dengan komponen lain yang dapat berkontribusi untuk menambah jumlah rilis inventaris.

4.2. Menghitung massa fluida,massa$_{comp}$, dalam komponen yang dievaluasi menggunakan persamaan di bawah ini.

$$Mass_{comp} = \rho \text{ x } 90\% \ V_{gas} \tag{3.3}$$

Dalam hal ini menggunakan 90% volume gas karena rekomendasi API 581 di Annex 3.A untuk equipment tipe KODRUM mengambil volume gas 90% dan liquid 10%.

4.3. Menghitung massa fluida di masing-masing komponen lain yang termasuk dalam kelompok inventaris,massa$_{comp,\, i}$.

4.4. Menghitung massa fluida dalam grup inventaris,massa$_{inv}$, menggunakan persamaan ini di bawah ini.

$$\sum mass_{inv} = \sum_{i=1}^{n} mass_{comp,i} \tag{3.4}$$

4.5. Hitung laju aliran dari lubang diameter 203 mm (8 inci), W_{max}

Hitung laju aliran dari lubang 203 mm (8 inci) diameter, Wmax8, menggunakan persamaan 5 seperti yang berlaku dengan An = A8 = 32,450 mm^2 (50,3 inch^2). Ini adalah laju aliran maksimum yang dapat ditambahkan ke massa cairan peralatan dari peralatan di sekitarnya dalam grup inventory.

$$W_{max8} = \frac{Cd}{C2}\ x\ An \text{ x } Ps \sqrt{\left(\frac{k\ x\ MW\ x\ gc}{R\ x\ Ts}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}} \tag{3.5}$$

4.6. Menghitung laju massa fluida mass$_{add,n}$ di tiap lubang keluaran

Menentukan massa fluida tambahan untuk setiap ukuran lubang pelepasan yang dihasilkan dari tiga menit aliran dari kelompok persediaan menggunakan persamaan di bawah ini di bawah ini.

$$Mass_{add,n} = 180\ .\ min[Wn\ , Wmax8] \tag{3.6}$$

4.7. Calculate the available mass for release for each hole size

Untuk setiap ukurang lubang keluaran, calculate the available mass for release using this below equation below.

$$Mass_{avail,n} = min\ [\{\text{Mass}_{\text{comp}} + \text{Mass}_{\text{add,n}}\}, \text{Mass}_{\text{inv}}] \quad (3.7)$$

5. **Tentukan tipe keluaran (continuous, atau instantaneous)**.

INSTATANEOUS RELEASE

Pelepasan sesaat atau embusan adalah sesuatu yang terjadi begitu cepat sehingga fluida menyebar sebagai satu awan atau kumpulan besar.

CONTINOUS RELEASE

Pelepasan yang terus menerus adalah yang terjadi dalam periode waktu yang lebih lama, memungkinkan cairan untuk membubarkan dalam bentuk elips memanjang (tergantung pada kondisi cuaca).

5.1. Hitung waktu yang dibutuhkan untuk melepaskan 4536 kg (10.000 lbs) cairan untuk setiap ukuran lubang

Untuk menentukan waktu yang dibutuhkan untuk melepaskan 4536 kg (10.000 lbs) cairan untuk setiap ukuran lubang dapat diadopsi dari persamaan di bawah ini

$$t_n = \frac{C3}{W_n} \quad (3.8)$$

5.2. Menentukan apakah tipe rilisnya instan atau berkelanjutan menggunakan kriteria berikut ini.

- Jika ukuran lubang pelepasan adalah 6,35 mm (0,25 inci) atau kurang, maka jenis pelepasan secara kontinu.
- If $t_n \leq 180$ sec dan massa pelepasan lebih dari 4536 kgs (10000 lbs.), maka itu adalah isntan; jika tidak maka itu kontinu.

6. **Estimasi dampak dari system deteksi dan isolasi pada setiap keluaran**

Setiap perusahaan energi umumnya memiliki seperti sistem deteksi, sistem isolasi, dan juga sistem mitigasi dirancang untuk mengurangi kemungkinan besarnya dari komposisi atau cairan berbahaya. Berdasarkan Tabel 4.5 API RP 581 Bagian 3 tercantum tentang skenario sistem deteksi dan isolasi yang mungkin milik perusahaan minyak dan gas tertentu sebagai sistem keselamatannya setiap kali magnitude terjadi.

6.1. Menentukan sistem deteksi dan isolasi yang ada di unit

Jenis dukungan keselamatan yang tersedia di unit adalah SDV yang berfungsi untuk mendeteksi segala perubahan tekanan, baik tekanan berlebih maupun kebocoran. Di sisi lain, sistem isolasi diaktifkan langsung dari instrumentasi proses dengan detektor, tanpa intervensi operator.

6.2. Memilih klasifikasi yang sesuai (A, B, atau C) untuk sistem deteksi menggunakan Tabel 4.5.

6.3. Memilih klasifikasi yang sesuai (A, B, atau C) untuk sistem isolasi menggunakan Tabel 4.5.

6.4. Menentukan faktor reduksi pelepasan, $fact_{di}$, menggunakan Tabel 4.6 dan klasifikasi dari tabel 4.5 sebagaimana dipilih dalam Langkah 6.2 dan 6.3

6.5. Menentukan total durasi kebocoran untuk setiap ukuran lubang rilis yang dipilih, $ld_{max,\ n}$, menggunakan Tabel 4.7 dan klasifikasi dari langkah 6.2 dan 6.3.

7. Tentukan release rate dan mass untuk analisa consequence

CONTINOUS RELEASE RATE

Untuk rilis yang berkelanjutan, rilis dimodelkan sebagai kondisi keadaan stabil: oleh karena itu, release rate digunakan sebagai input untuk analisis konsekuensi. Laju pelepasan yang digunakan dalam analisis adalah pelepasan teoritis yang disesuaikan dengan keberadaan unit deteksi dan isolasi sebagaimana dirumuskan dalam persamaan di bawah ini:

$$Rate_n = \mathrm{W}_n \, (1 - fact_{di}) \qquad (3.9)$$

INSTATANEOUS RELEASE RATE

Untuk pelepasan instan, laju pelapasan massa diperlukan untuk analisa lebih lanjut. Laju pelepasan massa, $mass_{avail,n}$, digunakan sebagai batas atas laju pelepasan massa, $mass_n$, as shown in the equation below:

$$\mathrm{Mass}_n = min\,.\,[\{\mathrm{Rate}_n\,.\,\mathrm{ld}_n\},\mathrm{Mass}_{avail,n}] \qquad (3.10)$$

7.1. Hitung adjusted release rate, $rate_n$, menggunakan persamaan (2.10).

7.2. Hitung waktu kebocoran, ld_n, untuk setiap release hole dengan,

$$\mathrm{ld}n = min\,.\,[\{\frac{\mathrm{Mass}_{avail,n}}{Rate_n}\},\{60\,.\,\mathrm{ld}_{max,n}] \qquad (3.11)$$

7.3. Hitung release mass, $mass_n$, untuk setiap ukuran release hole.
Untuk setiap ukuran release hole, hitung release mass, $mass_n$, menggunakan rumus 3.12 diatas menggunakan release rate, $rate_n$, durasi kebocoran, Id_n, dan, $mass_{avail,n}$.

8. Hitung flammable/explosive consequence

Consequence of Area (CA) diestimasi dengan release rate ($Rate_n$) untuk continuous release type dan Mass rate ($Mass_n$) untuk tipe instantaneous release.

8.1. Memilih faktor reduksi mitigasi area konsekuensi, $fact_{mit}$, dari Table 4.10

8.2. Hitung efisiensi energi, $eneff_n$, untuk setiap ukuran lubang menggunakan persamaan yang disebutkan di bawah ini.

$$eneff_4 = 4. log_{10}[C_4 . mass_n] - 15 \quad (3.12)$$

Persamaan di atas hanya diterapkan untuk tipe instantaneous release, jadi, untuk tipe continue release tidak perlu dipertimbangkan.

8.3. Menentukan tipe fluida, baik tipe 0 atau tipe 1 dari tabel 4.1 API 581

8.4. Untuk setiap ukurang lubang keluaran, hitung consequence area dari kerusakan komponen untuk Auto-Ignition Not Likely, Continuous Release (AINT-CONT), $CA^{AINL\text{-}CONT}$.

Consequence area untuk Component Damage Auto-Ignition Not Likely untuk continuous release dapat dihitung dengan:

$$CA_{cmd,n}^{AINL-CONT} = \alpha(rate_n)^b \;.\; (1 - fact_{mit}) \quad (3.13)$$

8.5. Untuk setiap ukurang lubang keluaran, hitung consequence area dari kerusakan komponen untuk Auto-Ignition Likely, Continuous Release (AIT-CONT), $CA^{AIL\text{-}CONT}$.

Consequence area untuk Component Damage Auto-Ignition Likely untuk continuous release dapat dihitung dengan:

$$CA_{cmd,n}^{AIL-CONT} = \alpha(rate_n)^b \;.\; (1 - fact_{mit}) \quad (3.14)$$

8.6. Untuk setiap ukurang lubang keluaran, hitung consequence area dari kerusakan komponen untuk Auto-Ignition Not Likely, Instantaneous Release (AINT-INST), $CA^{AINL\text{-}INST}$.

Consequence area untukr Component Damage Auto-Ignition Not Likely untuk instantaneous release dapat dihitung dengan:

$$CA_{cmd,n}^{AINL-INST} = \alpha(mass_n)^b \;.\; \left(\frac{1-fact_{mit}}{eneff_n}\right) \quad (3.15)$$

8.7. Untuk setiap ukurang lubang keluaran, hitung consequence area dari kerusakan komponen untuk Auto-Ignition Likely, Instantaneous Release (AIT-INST), $CA^{AIL\text{-}INST}$.

Consequence area untuk Component Damage Auto-Ignition Not Likely untuk instantaneous release dapat dihitung dengan:

$$CA_{cmd,n}^{AIL-INST} = \alpha(mass_n)^b \;.\; \left(\frac{1-fact_{mit}}{eneff_n}\right) \quad (3.16)$$

8.8. Untuk setiap ukurang lubang keluaran, calculate the personnel injury consequence areas untuk Auto-Ignition Not Likely, Continuous Release (AINL-CONT), $CA^{AINL\text{-}CONT}$.

Consequence area untuk Personnel Injury Auto-Ignition Not Likely untuk continuous release dapat dihitung dengan:

$$CA_{inj,n}^{AINL-CONT} = [\alpha.(rate_n^{AINL-CONT})^b].(1 - fact_{mit}) \quad (3.17)$$

8.9. Untuk setiap ukurang lubang keluaran, calculate the personnel injury consequence areas untuk Auto-Ignition Likely, Continuous Release (AIT-CONT), $CA^{AIL\text{-}CONT}$.

Consequence area untuk Personnel Injury Auto-Ignition Not Likely untuk continuous release dapat dihitung dengan:

$$CA_{inj,n}^{AIL-CONT} = [\alpha.(rate_n^{AIL-CONT})^b].(1 - fact_{mit}) \quad (3.18)$$

8.10. Untuk setiap ukurang lubang keluaran, calculate the personnel injury consequence areas untuk r Auto-Ignition Not Likely, Instantaneous Release (AINL-INST), $CA^{AINL\text{-}INST}$.

Consequence area for Personnel Injury Auto-Ignition Not Likely untuk instantaneous release dapat dihitung dengan:

$$CA_{inj,n}^{AINL-INST} = [\alpha.(mass_n^{AINL-INST})^b].\left(\frac{1 - fact_{mit}}{eneff_n}\right) \quad (3.19)$$

8.11. Untuk setiap ukurang lubang keluaran, calculate the personnel injury consequence areas for Auto-Ignition Likely, Instantaneous Release (AIL-INST), $CA^{AIL\text{-}INST}$.

Consequence area for Personnel Injury Auto-Ignition Likely untuk instantaneous release dapat dihitung dengan::

$$CA_{inj,n}^{AIL-INST} = [\alpha.(mass_n^{AIL-INST})^b].\left(\frac{1 - fact_{mit}}{eneff_n}\right) \quad (3.20)$$

8.12. Hitung instantaneous/continuous blending factor, $fact_n$, untuk setiap lubang keluaran yang sesuai dengan tipe keluaran pada tiap lubang.

a. For continuous release type

$$fact_n^{IC} = \min\left[\left\{\frac{rate_n}{C_5}\right\}, 1.0\right] \quad (3.21)$$

b. For instantaneous release type

For instantaneous releases, the blending factor is not required. Since the definition of instantaneous release is one with an adjusted release rate, $rate_n$,, greater than 25.2 kg/s (55.6 lbs.)

(4356 kg/s (10000 lbs.) in 3 minutes), the blending factor is equal to 1.0.

$$fact_n^{IC} = 1.0 \tag{3.22}$$

8.13. Hitung AIT blending factor, $fact^{AIT}$, menggunakan persamaan (2.23), (3.24), or (3.25) as applicable.

$$fact^{AIT} = 0 \qquad \text{if } T_s + C_6 \leq AIT \tag{3.23}$$

$$fact^{AIT} = \frac{(T_s - AIT + C_6)}{2\ x\ C_6} \qquad \text{if } T_s + C_6 > AIT > T_s - C_6 \tag{3.24}$$

$$fact^{AIT} = 1 \qquad \text{if } T_s - C_6 \geq AIT \tag{3.25}$$

8.14. Hitung continuous/instantaneous blended consequence area untuk komponen dan personil using equation (2.26) through (2.29) based on the consequence area that have been calculated in the previous steps.

$$CA_{cmd,n}^{AIL} = CA_{cmd,n}^{AIL-INST}\, x\, fact_n^{IC} + CA_{cmd,n}^{AIL-CONT}\, x\, (1 - fact_n^{IC})$$
(2.26)

$$CA_{cmd,n}^{AINL} = CA_{cmd,n}^{AINL-INST}\, x\, fact_n^{IC} + CA_{cmd,n}^{AINL-CONT}\, x\, (1 - fact_n^{IC})$$
(2.27)

$$CA_{inj,n}^{AIL} = CA_{inj,n}^{AIL-INST}\, x\, fact_n^{IC} + CA_{inj,n}^{AIL-CONT}\, x\, (1 - fact_n^{IC})$$
(2.28)

$$CA_{inj,n}^{AINL} = CA_{inj,n}^{AINL-INST}\, x\, fact_n^{IC} + CA_{inj,n}^{AINL-CONT}\, x\, (1 - fact_n^{IC})$$
(2.29)

8.15. Hitung AIT blended consequence areas untuk komponen menggunakan persamaan (2.30) dan (2.31).

$$CA_{cmd,n}^{flam} = CA_{cmd,n}^{AIL}\, x\, fact^{AIT} + CA_{cmd,n}^{AINL} x\, (1 - fact^{AIT})$$
(2.30)

$$CA_{inj,n}^{flam} = CA_{inj,n}^{flam-AIL}\, x\, fact^{AIT} + CA_{inj,n}^{AINL} x\, (1 - fact^{AIT})$$
(2.31)

8.16. Hitung consequence areas final untuk kerusakan komponen dan personil menggunakan persamaan (2.32) and (2.33).

$$CA_{cmd}^{flam} = \left(\frac{\sum gff_n \cdot CA_{cmd,n}^{flam}}{gff_{total}} \right) \tag{3.32}$$

$$CA_{inj}^{flam} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{flam}}{gff_{total}} \right) \tag{3.33}$$

9. Hitung toxic consequence

9.1. Untuk setiap lubang keluaran, hitung durasi efektif penyebaran toxic menggunakan persamaan:

$$ld_n^{tox} = \min\left(3000\ ,\ \left\{\frac{mass_n}{W_n}\right\},\ \left\{60.\,ld_{max,n}\right\}\right) \quad (3.34)$$

9.2. Menentukan persentase toksik dari komponen toksik, dalam bahan rilis. Fluida lepas adalah fluida murni, = 1.0. perhatikan bahwa jika ada lebih dari satu komponen toksik dalam campuran cairan pelepasan, prosedur ini dapat diulang untuk setiap komponen toksik.

9.3. Untuk setiap ukuran lubang pelepasan, hitung laju pelepasan, dan lepaskan massa yang akan digunakan dalam analisis toksik menggunakan persamaan (2.35) and (2.36).

a. For continuous release type

$$rate_n^{tox} = mfrac^{tox}.W_n \quad (3.35)$$

b. For instantaneous release type

$$mass_n^{tox} = mfrac^{tox}.mass_n \quad (3.36)$$

9.4. Untuk setiap ukuran lubang pelepasan, hitung area konsekuensi toksik untuk setiap ukuran lubang pelepasan.

Langkah ini diperlukan apabila komposisi kimia dalam aliran fluida mengandung H_2S dan/atau HF. Menggunakan (2.37) untuk continuous release dan (2.38) untuk instantaneous release type.

a. For continuous release type

$$CA_{inj,n}^{toxCONT} = e(Rate_n^{tox})\hat{}f \quad (3.37)$$

b. For instantaneous release type

$$CA_{inj,n}^{tox-INST} = e(Mass_n^{tox})\hat{}f \quad (3.38)$$

9.5. If there are additional toxic component in the release fluid mixture, langkah 9.2 through 9.4 should be repeated.

Because of there is no other toxic chemical content, so, the langkah 9.5 can be ignored.

9.6. Determining the final toxic consequence areas for personnel injury in accordance with equation (3.76)

$$CA_{inj}^{tox} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{tox}}{gff_{total}}\right) \quad (3.39)$$

10. Hitung non-flammable, non-toxic consequence

Karena steam scrubber ini mengandung gas dan uap, maka uap dari fluida tersebut termasuk ke non-flammable dan non-toxic consequence yang harus dihitung dengan cara.

10.1. Untuk setiap ukurang lubang keluaran, hitung non-flammable dan non-toxic consequence are menggunakan persamaan (3.40) and (3.41)

Karena tidak ada acid dan caustic content, maka menghitung the stream non-flammable dan non-toxic menggunakan:

a. For continuous release type

$$CA^{CONT}_{inj,n} = C_9 \ . \ \text{Rate}_n \ ) \tag{3.40}$$

b. For instantaneous release type

$$CA^{INST}_{inj,n} = C_{10} . \ \text{Mass}_n \ )^{0.6384} \tag{3.41}$$

10.2. Untuk setiap ukuran lubang pelepasan, hitung faktor pencampuran kontinyu / instan, $fact_{id}$, untuk steam.

10.3. Untuk setiap ukuran lubang pelepasan, hitung area konsekuensi cedera personel yang tidak mudah terbakar, tidak beracun untuk uap atau kebocoran asam menggunakan persamaan berdasarkan konsekuensinya dari langkah 10.1 dan faktor pencampuran dari langkah 10.2 perhatikan bahwa tidak perlu menghitung area kerusakan komponen untuk pelepasan tidak mudah terbakar level 1 (uap atau asam / kaustik)= 0

$$CA^{leak}_{cmd,n} \tag{3.42}$$

$$CA^{leak}_{inj,n} = CA^{INST}_{inj,n} . \ fact^{IC}_{n} + CA^{CONT}_{inj,n} \ . \ (1 - fact^{IC}_{n}) \tag{3.43}$$

10.4. Tentukan non-flammable, non-toxic consequence areas final untuk personnel injury menggunakan (3.43)

$$CA^{nfnt}_{inj} = \left(\frac{\sum gff_n \ . \ CA^{leak}_{inj,n}}{gff_{total}} \right) \tag{3.44}$$

11. Hitung consequence untuk kerusakan komponen dan personil, untuk menghitung total consequence

11.1. Hitung component damage consequence area final, CA_{cmd}, menggunakan persamaan (3.45)

$$CA_{cmd} = CA^{flam}_{cmd} \tag{3.45}$$

11.2. Hitung personnel injury consequence area final, CA_{inj}, menggunakan persamaan (3.46)

$$CA_{inj} = \max \left[CA^{flam}_{inj} , \ CA^{tox}_{inj} \ , \ CA^{nfnt}_{inj} \right] \tag{3.46}$$

11.3. Calculate the final consequence rea, CA, menggunakan persamaan (2.47)

$$\text{CA}=\max \left[CA_{cmd}, CA_{inj} \right] \tag{3.47}$$

3.1.7 Perhitungan Nilai Risiko

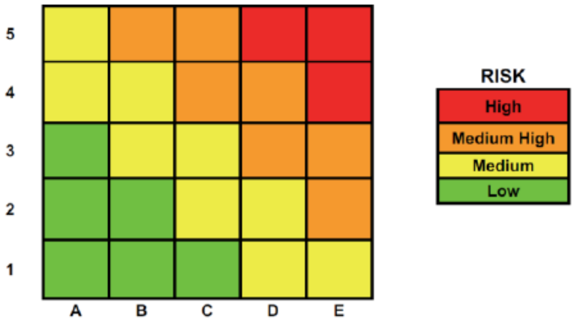
Tujuannya adalah menentukan risk level dari alat yang dianalisis apakah termasuk low risk, medium risk, atau high risk equipment. Penentuan ini berdasarkan nilai risiko yang telah dihitung sebelumnya. Penentuan risiko dan perencanaan inspeksi didasarkan atas nilai PoF dan CoF.

Berdasarkan API RP 581, penentuan rumus dapat ditulis sebagai:

$$R(t) = Pf(t)\ .\ Cf \qquad (3,48)$$

3.1.8 Penentuan Risk level

Tingkat risiko dari sebuah equipment dapat ditentukan dengan menggunakan metoda matriks risiko (risk matrix), matriks risiko adalah sebuah diagram kotak 5x5 dengan kategori pemetaan risiko, contoh matriks risiko dapat dilihat pada gamnar __



Gambar 3. 2. Contoh Matriks Risiko

Penentuan tingkatan risiko pada matriks risiko dapat menagcu pada tabel 4.1M API RP 581.

Tabel 3.5 Tingkatan nilai untuk penentuan matriks risiko

Category	Probability Category		Consequence Category	
	Probability range	Damage factor range	Category	Range (m^2)
1	$P_f(t,I_E) \leq$ 3.06E-05	$D_{f-total} \leq 1$	A	CA≤9.29
2	3.06E-05 < $P_f(t,I_E)$ ≤3.06E-04	$1 < D_{f-total} \leq 10$	B	9.29<CA≤92.9
3	3.06E-04 < $P_f(t,I_E)$ ≤3.06E-03	$10 < D_{f-total} \leq 100$	C	92.9<CA≤929
4	3.06E-03 < $P_f(t,I_E)$ ≤3.06E-02	$100 < D_{f-total} \leq 1000$	D	929<CA≤9290
5	$P_f(t,I_E) >$ 3.06E-02	$D_{f-total} > 1000$	E	CA>9290

3.1.9 Perencanaan Metode dan Jadwal Inspeksi

Tujuannya adalah untuk merancang jadwal inspeksi dengan memperhatikan risk level Inspeksi dirancang berdasarkan level risiko dari sebuah equipment sesuai dari analisa risiko menggunakan RBI. Equipment dengan level risiko yang lebih tinggi akan diprioritaskan untuk diinspeksi. Inspeksi dilaksanakan ketika risiko atau kondisi equipment sudah melebihi target yang dipasang oleh perusahaan. Target-target yang dapat ditentukan dengan RBI untuk tindakan mitigasi adalah15:

- Target Risiko – tingkat risiko minimum untuk mengadakan perencanaan inspeksi. Dapat berupa unit area (m2/tahun) atau finansial ($/tahun).
- Target PoF – Batas maksimum dari frekuensi kegagalan/kebocoran yang dapat diterima (#/tahun) atau dapat memicu perencanaan inspeksi.
- Target DF – Batas maksimum nilai kerusakan (merupakan faktor dari PoF) yang dapat diterima atau dapat memicu perencanaan inspeksi.
- Target CoF – Tingkatan consequence area (CA) atau financial consequence (FA) yang tidak dapat diterima.
- Target Thickness – Ketebalan minimum yang dapat diterima atau dapat memicu perencanaan inspeksi.
- Target Interval – Interval maksimum untuk waktu pelaksanaan inspeksi.

Dalam menentukan target, API RP 581 tidak menyediakan panduan spesifik dalam penentuannya dan harus ditentukan berdasarkan keputusan owner.

Inspeksi dilaksanakan dengan tujuan mengurangi risiko dari equipment tersebut dan mendapatkan informasi terkini mengenai kondisi equipment tersebut (pelaksanaan inspeksi hanya akan mengurangi probability of failure sedangkan untuk mengurangi consequence, desain harus ditinjau ulang). Akurasi dari metode inspeksi itulah yang disebut dengan inspection effectiveness. Setiap jenis damage factor memiliki inspection effectiveness sendiri yang dijelaskan pada API RP 581 3rd Edition – Annex 2.C. Untuk local thining dan stress corrosion cracking dijelaskan sebagai berikut.dari alat dan hasil evaluasi.

3.1.10 Kesimpulan

Tujuannya adalah untuk merancang jadwal inspeksi dengan memperhatikan risk level dari alat dan hasil evaluasi.

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BAB IV
HASIL DAN PEMBAHASAN

4.1 Data Separator.

Data separator yang digunakan adalah data produksi dari separator VS-80-001, VS-80-002, dan VS-80-003 milik SEGWWL. General data selengkapnya ditulis pada lampiran 1.

GENERAL SPECIFICATION	
Tag Number	VS-80-001
Quantity	1
Service	Separator
Serial No.	0825-BBI-PV
Manufactured by	PT. Rekayasa Industri
Type of Pressure Vessel	Horizontal
	Drum
Geometry Data	Elliptical Head
Code	ASME Section VIII Division I Ed. 2015
Design Pressure	1450 Kpa
Design Temperature	50-200 C
Operating Pressure	1060 Kpa
Operating Temperature	187°C
Operating Steam Flow rate	115.96 Kg/s
Dimension	1930 ID x 9070 T-T
Empty Weight	18247 kg
Operating Weight	21290 kg
Full of Water	47754 kg
Vessel Volume	28160 liter
Support	Skirt
Joint Efficiency (Head/Shell)	1
Insulation (Hot/Cold)	50 mm
Corrosion Allowance	3.00 mm
	0.1181 inch
Year built	2000
Material	SA 516 Gr. 70
Last inspection	3 Juli 2014

4.2 P&ID Data

P&ID data adalah salah satu data yang dibutuhkan untuk menganalisa risiko, P&ID data digunakan untuk menentukan objek yang dianalisa. Untuk P&ID dari Pressure Vessel VS-80-001, VS-80-002, VS-80-003 dan well pipes MD-5 disimpan pada lampiran 2.

Deskripsi proses dari ekuipment tersebut adalah sebagai berikut:

A. Pressure Vessel VS-80-001.
   Pressure vessel VS-80-001 adalah sebuah separator. Separator adalah sebuah vessel yang berfungsi untuk memisahkan liquid yang masuk dari inlet separator tersebut dan mengalihkan liquid yang telah dipisah kepada equipment yang berbeda. pada VS-80-001,002, dan 003, input liquid yang masuk pada separator adalah geothermal fluid dan steam, dimana pada separator kedua imput tersebut akan dipisah, steam liquid akan dialirkan menuju scrubber lalu turbine, sedangkan hasil olahan geothermal fluid yang terpisah akan dialirkan menuju injection well untuk di injeksikan kembali menuju reservoir geothermal.

B. MD-5 Well Pipeline.
   MD-5 Well pipeline adalah system perpipaan yang mengalirkan geothermal fluid dari well exctractor. Aliran fluida yang dialirkan oleh MD-5 well pipe akan menuju separator.

4.3 Risk Based Analysis.

4.3.1 Hasil RBI untuk VS-80-001

4.3.1.1 Probability of Failure

1. **Penentuan Thinning Damage Factor**

Setiap komponen perlu di periksa terhadap indicator kerusakan yang diakibatkan *ge factor* yang dapat diakibatkan oleh *general* dan *local thinning.* Untuk perhitungan selengkapnya dicantumkan pada lampiran 4.

Langkah-langkah berikut digunakan untuk menentukan damage factor untuk thinning adalah.

a. Menentukan furnished thickness dan umur dari equipment, ditentukan hasil dari furnished thickness adalah 28.85 dan umur dari equipment adalah 14 tahun.
b. Menentukan lajur korosi berdasarkan material dasar (C_{rbm}) berdasarkan material konstruksi serta lingkungan dan cladding/overlay. Berdasarkan penjelasan dari section 4.5.2 API RP 581, laju korosi dihitung dengan menggunakan pendekatan Annex 2B dari API RP 581, untuk menghitung laju korosi perlu ditentukan

tipe korosi yang ada dengan menggunakan screening questions yang disediakan oleh tabel 2B.1.1. Dari screening question ditentukan bawha tipe korosi yang ada pada equipment adalah Sour water corrosion dan laju korosi yang telah disesuaikan adalah 0.287.

c. Menentukan waktu in-service,
d. Menentukan age$_{rc}$ untuk komponen cladding/overlay, dikarenakan tidak adanya cladding, maka step ini dilewat.
e. Menentukan thickness minimum dari equipment, ada 4 metoda yang dapat digunakan untuk menentukan minimum thickness dari sebuah equipment, untuk perhitungan ini, metoda perhitungan pertama digunakan karena metoda ini digunakan komponen cylindrical, spherical, atau head. Hasil dari perhitungan didapatkan bahwa minimum thickness dari equipment adalah 25.91 mm atau 1.02” inch.
f. Menentukan parameter A$_{rt}$, dari perhitungan A$_{rt}$ hasil yang didapatkan adalah 0.39820014 (calculated corrosion rate) dan 0.0013867 (berdasarkan data yang didapat).
g. Menentukan Flow stress dari equipment, dengan mengkalkulasikan Yield Strenght dan Tensile Strength, didapatkan hasil flow stress sebesar 35887
h. Menghitung parameter strength ratio dengan menggunakan equasi yang tepat, dimana didapatkan hasil 0.686
i. Menentukan jumlah inspeksi sebelumnya untuk inspection effectiveness dengan menggunakan section 4.5.6 dari API RP 581 Part 2, berdasarkan data sebelumnya, inspection effectiveness dari data yang didapat memiliki kategori E, dimana berdasarkan kategori tersebut inspeksi yang dilakukan sangat tidak effective atau tidak dilakukan inspeksi sama sekali.
j. Menentukan inspection effective factor, tiap factor harus dihitung berdasarkan scenario damage state, dengan menggunakan Table 4.5 dan tabel 4.6 dari API RP 581, didapatkan hasil $I_1^{thin}, I_2^{thin}, I_3^{thin}$ senilai 0.50, 0.30, dan 0.20
k. Menentukan parameter $\beta_1, \beta_2, dan\ \beta_3$, dan didapatkan hasil 1.5390, 1.5390, 1.53056 dan 1.51375
l. Maka didapatkan hasil damage factor sebesar 0.200745959.

2. Perhitungan Damage Factor Stress Corrosion Cracking – Sulfide Stress Cracking.

Caustic cracking didefinisikan sebagai keretakan sebuah material dibawah campuran *tensile stress* dan korosi yang di akibatkan oleh sodium hydroxide (NaOH) pada temperatur yang tinggi. Untuk menentukan *Damage Factor* SCC-SSC, dapat digunakan kalkulasi yang mengacu pada API RBI 581. Perhitungan lengkap dari SCC-SSC Df dilampirkan pada lampiran 4

Langkah-langkah berikut di gunakan untuk menentukan damage factor untuk SCC-SSC.

a. Menentukan *Enviromental Severity* untuk keretakan berdasarkan konten air dan pH dari H_2S menggunakan Tabel 8.2 (API RBI 581). Dimana pH air adalah 5.52 dan konten air sebesar 1000 ppm, dapat di tentukan bahwa *environmental severity* dari SSC adalah **Moderate.**

b. Menentukan kerentanan dari keretakan menggunakan *figure 8.1* dan tabel 8.3 (API RBI 581) berdasarkan dari *environmental severity* dari langkah 1. Berdasarkan tabel tersebut, dengan kriteria dimana *Max Brinnel Hardness* bernilai <200 dan *Enviromental Severity* berada pada *Moderate*, dan tidak adanya PWHT pada equipment, maka didapatkan hasil **Low** untuk *susceptibility to SSC-SCC.*

c. Berdasarkan dari kerentanan yang di dapatkan pada langkah ke dua, ditentukan *severity index* (S_{vi}) menggunakan tabel 8.4 (API RBI 581), dimana S_{VI} dari **Low Susceptibility**, adalah **1**.

d. Menentukan *in-service age* semenjak inspeksi level A,B, atau C terakhir dilakukan. Berdasarkan data yang di dapat, dapat ditentukan bahwa *in-service age* pada saat analisa dilakukan adalah **18 tahun.**

e. Menentukan inspeksi sebelumnya dan inspeksi yang sesuai menggunakan *Section 8.6.2* API RBI 581 Part 2 Annex 1. Berdasarkan data yang didapat, ada 2 inspeksi yang telah dilakukan sebelum analisa ini dilakukan dengan kategori efektif yakni E, dimana hasil inspeksi tersebut bersifat ***Ineffective.***

f. Menentukan basis *damage factor* untuk *sulfide stress cracking*, menggunakan tabel 6.3 API RBI 581 Annex 2. Penentuan *damage factor* untuk SCC dapat ditentukan dengan *inspection effectiveness* tertinggi dan jumlahnya, dimana berdasarkan langkah sebelumnya, didapat bahwa kategori dari inspeksi sebelumnya adalah E dan memiliki *severity index* sebesar 1. *Base damage factor* yang di dapat adalah **1**

g. Langkah terakhir ini dilakukan untuk menentukan *Damage Factor* dari *Stress Caustic Cracking – Sulfide Stress Cracking*, dimana untuk menentukan *Df* tersebut, dapat menggunakan equasi 2.27 API RBI 581. Dimana hasil yang di dapatkan untuk :

RBI Date

$$D_f^{SCC} = 5.8730947$$

RBI Plan Date

$$D_f^{SCC} = 13.980798$$

3. Perhitungan Damage Factor Stress Corrosion Cracking – HIC/SOHIC-H_2S.

HIC didefinisikan sebagai keretakan internal yang berdekatan dengan hydrogen blister di tingkatan yang berbeda pada metal, atau permukaan metal. Untuk menentukan *Damage Factor* HIC/SOHIC-H_2S, digunakan kalkulasi yang mengacu pada API RBI 581. Perhitungan lengkap dari HIC/SOHIC-H_2S Df dilampirkan pada lampiran 4

Langkah-langkah berikut digunakan untuk menentukan damage factor untuk HIC/SOHIC-H_2S

a. Menentukan *Enviromental Severity* untuk keretakan berdasarkan konten air dan pH dari H_2S menggunakan Tabel 8.2 (API 581). Dimana pH air adalah 5.52 dan konten air sebesar 1000 ppm, dapat di tentukan bahwa *environmental severity* dari HIC/SOHIC-H_2S adalah **Moderate.**

b. Menentukan kerentanan dari keretakan menggunakan *figure 8.1* dan tabel 9.3 (API RBI 581) berdasarkan dari *environmental severity* dari langkah 1, dengan kriteria dimana *Max Brinnel Hardness* bernilai <200 dan *Enviromental Severity* berada pada *Moderate*, dan tidak adanya PWHT pada equipment, maka didapatkan hasil **Low** untuk *susceptibility to SSC-SCC.*

c. Berdasarkan dari kerentanan yang di dapatkan pada langkah ke dua, ditentukan *severity index* (S_{vi}) menggunakan tabel 9.4 (API RBI 581), dengan S_{VI} dari **Low Susceptibility**, adalah **1**.

d. Menentukan *in-service age* semenjak inspeksi level A,B, atau C terakhir dilakukan. Berdasarkan data yang di dapat, dapat ditentukan bahwa *in-service age* pada saat analisa dilakukan adalah **18 tahun.**

e. Menentukan inspeksi sebelumnya dan inspeksi yang sesuai menggunakan *Section 8.6.2* API RBI 581 Part 2 Annex 1. Berdasarkan data yang didapat, ada 2 inspeksi yang telah dilakukan sebelum analisa ini dilakukan dengan kategori efektif yakni E, dimana hasil inspeksi tersebut bersifat ***Ineffective.***

f. Menentukan basis *damage factor* untuk *sulfide stress cracking*, menggunakan tabel 6.3 API RBI 581 Annex 2. Penentuan *damage factor* untuk HIC/SOHIC dapat ditentukan dengan *inspection effectiveness* tertinggi dan jumlahnya, dimana berdasarkan langkah sebelumnya, didapat bahwa kategori dari inspeksi sebelumnya adalah E dan memiliki *severity index* sebesar 1. *Base damage factor* yang di dapat adalah **1**

g. Menentukan *On-line adjustment factor* dengan menggunakan tabel 9.5 (API 581)

h. Menghitung *Df* akhir dengan memperkirakan kenaikan *Df* berdasarkan *in-service age* sejak inspeksi terakhir. Di asumsikan bahwa probabilitas untuk keretakan akan meningkat dengan waktu semenjak inspeksi terakhir akibat hasil dari peningkatan eksposur akibat kondisi normal ataupun tidak normal. Hasil akhir *Df* dapat dikalkulasikan sebagai berikut:

Damage Factor at RBI Date

$$D_f^{HIC\,SOHIC-H2S} = \frac{D_{fB}^{HIC\,SOHIC-H2S}.(Max[age,1.0])^{1.1}}{Fom}$$

$$D_f^{HIC\,SOHIC-H2S} = \frac{1.(Max[4,1.0])^{1.1}}{2}$$

$$D_f^{HIC\,SOHIC-H2S} = 4.594793$$

Damage Factor at RBI Plan Date

$$D_f^{HIC\,SOHIC-H2S} = \frac{D_{fB}^{HIC\,SOHIC-H2S}.(Max[age,1.0])^{1.1}}{Fom}$$

$$D_f^{HIC\,SOHIC-H2S} = \frac{1.(Max[9,1.0])^{1.1}}{2}$$

$$D_f^{HIC\,SOHIC-H2S} = 11.21158$$

Perhitungan General Failure Frequency (gff).

Untuk menentukan *General Failure Frequency* dapat mengacu pada Table 3.1 dari API RBI 581 yang berisi list rekomendasi *gff* untuk equipment yang di analisa. Perhitungan gff dilampirkan pada lampiran 4.

Tabel 4. 1 Suggested Component Generic Failure Frequencies

Equipment Type	Component Type	*gff* as a function of hole size (failures/yr)				gff_{total} *(failures/yr)*
		Small	Medium	Large	Rupture	
Vessel/FinFan	KODRUM, COLBTM, FINFAN, FILTER DRUM, REACTOR, COLTOP, COLMID,	8.00E-06	2.00E-05	2.00E-05	6.00E-07	3.06E-05

Dari tabel tersebut, dapat ditentukan bahwa *gfftotal* memiliki nilai 3.06E-05

4. **Perhitungan Management System Factor (Fms).**

Menentukan faktor *Fms* dapat menggunakan evaluasi majemen sistem yang disediakan pada *Part 2*, *Annex 2.A* RBI 581. Perhitungan fms dilampirkan pada lampiran 4.

Setelah mendapat percentage dari score, nilai *Fms* dapat dihitung dengan menggunakan rumus:

$$Fms = 10^{(-0;02.pscore+1)}$$

Maka didapat nilai *Fms* bernilai 0.182390.

5. **Perhitungan Probabiliy of Failure**

Setelah mendapatkan hasil *Df,gff,* dan *Fms*. Maka perhitungan PoF dilakukan dengan menggunakan rumus,

$$Pf\ (t) = gff\ .\ Fms\ .Df\ (t)$$

Dari rumus tersebut dapat dikalkulasikan bahwa PoF bernilai:

$$Pf\,(t)\ =\ gff\,.\,Fms\,.\,D\,f\,(t)$$
$$Pf\,(t)\ = 0.0124(RBI\ Date)$$
$$Pf\,(t)\ = 0.0837(RBI\ Plan\ Date)$$

Perhitungan dari probability of failure di lampirkan pada lampiran 4

4.3.1.2 Consequence of Failure

Consequence of Failure digunakan untuk menganalisa konsekuensi dari kegagalan sebuah equipment bertekanan yang berkemungkinan untuk menimbulkan kerusakan untuk equipment, loss dari produksi atau jalannya sistem, pencemaran, dan menimbulkan cedera fatal pada personel. Analisa CoF dapat dihitung sebagai konsekuensi area atau financial. Dalam API RBI 581, analisa konsekuense dibagi menjadi dua level, yakni *Level 1 Consequence of Failure*, dan *Level 2 Consequence of Failure*. Dalam analisa ini, perhitungan konsekuensi yang digunakan adalah perhitungan konsekuensi level 1. Perhitugan selengkapnya dari analisa konesekuense kegagalan dilampirkan pada lampiran 6.

Dalam beberapa tahap yang perlu dilakukan untuk melakukan analisa konsekuensi pada RBI, langkah langkah tersebut adalah sebagai berikut

1. Penentuan Fluida Representatif

Representative Liquid yang digunakan adalah H_2S atau Hydrogen Sulfide, dengan *properties*:

Liquid Density	:	993.033 Kg/m^3
NBP	:	-59.4 C°
Auto-Ignition temperature	:	500 F° / 260 C°

Dalam tabel 4.3 API RBI 581 Annex 3, dapat ditentukan bahwa fase liquid saat tersimpan adalah Liquid namun setelah terlepas adalah Gas.

2. Pemilihan Release Hole Size

Pemilihan release hole size didasarkan pada jenis peralatan. Pemilihan set ukuran lubang saat *release* untuk menentukan kemungkinan range dari konsekuensi yang dihasilkan. Untuk menentukan set ukuran lubang mengacu pada API RBI 581 Annex 3 Part 1, Tabel 4.4.

Tabel 4. 2. Release Hole Sizes and Areas Used in Level 1 and 2 Consequence Analysis.

Release Hole Number.	Release Hole Size.	Range of Hole Diameters (inch).	Release Hole Diameters, d_n, (inch).
1	Small	1 – ¼	$d_1 = 0.25$
2	Medium	>¼ - 2	$d_1 = 1$
3	Large	>2 – 6	$d_1 = 4$
4	Rupture	>6	$d_1 = min\ [D,16]$

3. Perhitungan Release Rate

Selanjutnya dihitung *theoretical release rate* dari scenario *release hole size (An)* yang sudah ditentukan pada langkah ke dua. Pada langkah ini, *release hole size* perlu di hitung menggunakan ekuasi 3.8.

$$An = \frac{\pi d_n^2}{4}$$

Dengan ekuasi tersebut didapatkan hasil:

Small Hole Size	:	3.00E-05	m^2
Medium Hole Size	:	5.00E-04	m^2
Large Hole Size	:	0.008	m^2
Rupture Hole Size	:	0.13	m^2

Setelah mendapatkan *release hole size* dari tiap scenario, langkah berikutnya adalah untuk menghitung *release rate* (W_n). didapatkan hasil *release rate* sebagai berikut:

Small Hole Size	:	0.001949	Kg/s
Medium Hole Size	:	0.093635	Kg/s
Large Hole Size	:	0.478570	Kg/s
Rupture Hole Size	:	23.96435	Kg/s

4. **Langkah ke empat adalah mengestimasikan masa maksimum yang ada saat release.**

Untuk menghitung masa yang ada atau *available mass* ($Mass_{avail}$), *group component* dan *equipment items* dari *inventory group* harus ditentukan terlebih dahulu, untuk menentukan *inventory groups*, dapat merujuk pada API RBI 581 Annex 3 Part 3, Tabel 3.A.3.2. Dapat disimpulkan bahwa equipment yang dianalisa memiliki *Default liquid volume percent* sebanyak 50% liquid.

Untuk penentuan massa komponen ($mass_{comp}$) diperlukan perhitungan massa fluida. massa fluida dihitung dengan rumus volume dari equipment yang dianalisa

$$Vcyl = \pi R^2 L$$
$$Vcyl = \pi .1.067.10{,}5$$
$$Vcyl = 37.5 \text{ m}^3$$

Untuk volume liquid dan volume vapour:

Liquid Volume: $\left(\frac{50}{100}\right) x\ Vcyl$ = 18,75 m^3

Vapour Volume: $(1 - \left(\frac{50}{100}\right) x\ Vcyl)$ = 18,75 m^3

Untuk massa komponen:

$Mass_{comp} = (V_l\, \rho_l) + (V_v\, \rho_v)$

$Mass_{comp} = 18728\ Kg$

Maka didapatkan massa inventory ($mass_{inv}$)

$$Mass_{inv} = \sum_{i=1}^{N} Masscomp$$

$$Mass_{inv} = 18639.3 \text{ Kg}$$

Perhitungan *flow rate* perlu dilakukan dengan cara meengkalkulasikan *flow rate* dari simulasi lubang dengan diameter 203mm (8 inch) dengan menggunakan ekuasi (3.3), (3.6), (3.7) API 581 Annex 3 sesuai dengan kebutuhan dengan $A_n = A_8 = 32{,}450 \text{ mm}^2$ ($50{,}3 \text{ inch}^2$).

$$W_{max.8} = \frac{Cd}{C2} \,.\, A8 \,.\, Ps \sqrt{\left(\frac{k\,.\,MW\,.\,gc}{R\,.\,Ts}\right)} \left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}$$

$$W_{max.8} = \frac{0.90}{1} \,.\, 32{,}450 \,.\, 1060 \sqrt{\left(\frac{1.27\,.\,34\,.\,1}{8.314\,.\,453.15}\right)} \left(\frac{2}{1.27+1}\right)^{\frac{1.27+1}{1.27-1}}$$

$$W_{max.8} = 0.221285458 \;\; Kg$$

Untuk setiap *hole size*, dikalkulasi massa fluida yang di tambah ($mass_{add,n}$). dihasilkan 3 menit *flow* berasal dari *inventory group* menggunakan ekuasi (3.10) API RBI 581, dimana W_n adalah lajur release dari tiap hole size.

$$Mass_{add,n} = 180 \,.\, \text{Min}\,[W_n \,,\, W_{max,8}]$$

Maka didapatkan hasil W_n

Small Hole Size : 0.3508 Kg/s
Medium Hole Size : 16,85 Kg/s
Large Hole Size : 84.17 Kg/s
Rupture Hole Size : 84.17 Kg/s

4 Penentuan Release Type.

Release type (*continuous/instantaneous*) untuk menentukan metoda yang akan digunakan untuk pemodelan *dispersion* dan *consequence*

a.Untuk setiap *hole size*, ditentukan waktu yang dibutuhkan untuk melepaskan 4536 Kg Liquid. Dengan menggunakan ekuasi:

$$tn = \frac{C3}{Wn}$$

Di dapatkan hasil t_n:

Small Hole Size : 2327052 s
Medium Hole Size : 48443.38 s
Large Hole Size : 9478.23 s
Rupture Hole Size : 189.27 s

b. Ditentukan *release type* apakah *continuous* atau *instantaneous* dengan menggunakan kriteria sebagai berikut:

- If the release hole size is 6.35 mm (0.25 inch) or less, then the release type is automatically continuous.

- If tn≤180 sec and the release mass is greater than 4536 kgs (10000 lbs.),then the release is instantaneous; otherwise, the release is continuous.

Dengan kriteria tersebut dapat di tentukan bahwa:

Small Hole Size : d_1 = 0.25 inch
t_1 = 2.33E+06 s
Continuous
Medium Hole Size: d_2 = 1 inch
t_2 = 48443.38 s
Continuous
Large Hole Size: d_3 = 4 inch
t_3 = 9478.235 s
Continuous
Rupture Hole Size: d_4 = 16 inch
t_4 = 189.2789 s
Continuous

5 **Estimasi impact dari sistem deteksi serta isolasi pada magnitude release**.

Menetapkan sistem deteksi dan isolasi yang ada pada unit, dengan menggunakan tabel 4.5 API RBI 581 Annex 3. Dimana klasifikasi yang dipilih adalah :

Detection System Classification: **C**
Isolation System Classification: **C**

Dengan menggunakan Tabel 4.6 API RBI 581, dan klasifikasi dari langkah 6.2 dan 6.3, ditentukan *release reduction factor* pada equipment.

$fact_{di}$: 0.00 (No adjustment to release rate or mass)

Dengan menggunakan tabel 4.7 dan klasifikasi yang telah ditetapkan pada langkah sebelumnya, ditentukan *total leak duration* pada setiap *release hole size, **Id** $_{max,n}$.*

Detection System : **C**
Isolation System : **C**
$Id_{max,1}$: 60 Minutes
$Id_{max.2}$: 40 Minutes
$Id_{max,3}$: 20 Minutes

6 **Penentuan release rate dan massa untuk analisa konsekuensi**.

Untuk setiap release hole size, dikalkulasi *adjusted release rate¸*$rate_n$ dengan menggunakan ekuasi (3.13) API RBI 581.

$$rate\ n = Wn\,(1 - factdi)$$

Small Hole Size : 0.00195 Kg/s
Medium Hole Size : 0.09364 Kg/s
Large Hole Size : 0.47857 Kg/s

Rupture Hole Size	:	23.9646	Kg/s

Untuk setiap hole size, ditentukan *leak duration*, Id_n dari release menggunakan ekuasi 3.15 API RBI Annex.

$$Idn = min\left[\left\{\frac{massavailn}{raten}\right\}, \{60.idmax, n\}\right]$$

Small Hole Size	:	3600	s
Medium Hole Size	:	1200	s
Large Hole Size	:	600	s
Rupture Hole Size	:	600	s

Untuk setiap hole size, dikalkulasi *release mass*, $mass_n$, menggunakna ekuasi (3.14) berdasarkan *release rate*¸ $rate_n$, dengan hasil dari langkah 3.2, Id_n dari langkah 7.2, dan *available mass*, $mass_{avail}$, dari langkah 4.6

$$mass_n = \min[\{rate_n .\ idn\},\ massav_{ailn}]$$

Small Hole Size	:	7.017	Kg/s
Medium Hole Size	:	112.362	Kg/s
Large Hole Size	:	287.142	Kg/s
Rupture Hole Size	:	14378.8	Kg/s

8. Penentuan konsekuensi flammable dan explosive pada equipment.

Langkah pertama dalam kalkulasi *flammable and explosive consequence analysis* adalah memilih reduction factor untuk mitigasi konsekuensi area Faktor mitigasi dapat ditentukan dengan menggunakan tabel 4.10 (API 581), dikarenakan tidak ada rujukan yang mencukupi dari data yang ada, mitigation system tidak dapat ditentukan, sehingga;

$Fact_{mit} = 0$

Untuk setiap release hole size, ditentukan koreksi dari effisiensi energy, atau en_{eff}. Dengan menggunakan ekuasi 3.18.

$$eneff_1 = 4.log_{10}[C_4.\ mass_1] - 15$$

Dengan ekuasi tersebut didapatkan hasil:

Small Hole Size	:	1.758311	Kg/s
Medium Hole Size	:	6.576113	Kg/s
Large Hole Size	:	8.206021	Kg/s
Rupture Hole Size	:	15.00452	Kg/s

Selanjutnya ditentukan tipe fluida, berdasar table 4.1 API RBI 581, Annex 3. Didapatkan hasil :

Representative Fluid	:	**H_2S**
Fluid type	:	***Type 0***

8.1 Untuk setiap *release hole size*¸dikalkulasi konsekuensi area untuk kerusakan komponen.

Dengan menggunakan table 4.8 API RBI 581 Annex 3, dapat di tentukan konstanta *a* dan *b*, dimana konstanta tersebut bernilai:

a= 32.0 *b= 1.00*

Dengan menggunakan ekuasi (3.31) didapatkan hasil:

$$CA_{cmd,n}^{AINL-CONT} = a\,(rate)^{b}\;.\;(1\;-factmil\,)$$

Small Hole Size : 0.062 m^2
Medium Hole Size : 2.996 m^2
Large Hole Size : 15.31 m^2
Rupture Hole Size : 766.9 m

8.2 Untuk setiap *release hole size*, dilakukan perhitungan untuk konsekuensi area dari kerusakan komponen untuk *Auto-ignition Likely Continuous Release (AIL-CONT).*

Dengan merujuk pada tabel 4.8 API RBI 581 Annex 3, dapat di tentukan konstanta *a* dan *b*, dimana konstanta tersebut bernilai

a= 203.0 *b= 0.89*

Dengan ekuasi (3.33) API RBI 581 Annex 3, dapat ditentukan hasil perhitungan Consequence Area:

Small Hole Size : 0.7861 m^2
Medium Hole Size: 24.665 m^2
Large Hole Size : 105.35 m^2
Rupture Hole Size: 3430.2 m^2

8.3 Untuk setiap *release hole size*, dilakukan perhitungan untuk konsekuensi area dari kerusakan komponen untuk *Auto-ignition Not-Likely Continuous Release (AINL-CONT)*

Dengan merujuk pada tabel 4.8 API RBI 581 Annex 3, dapat ditentukan konstanta *a* dan *b*, dimana konstanta tersebut bernilai

a= 148.0 *b= 0.63*

Dengan ekuasi (3.33) API RBI 581 Annex 3, dapat ditentukan hasil perhitungan Consequence Area:

Small Hole Size : 287.25 m^2
Medium Hole Size : 440.74 m^2
Large Hole Size : 637.87 m^2
Rupture Hole Size : 4105.9 m

8.4 Untuk setiap *release hole size*, dilakukan perhitungan untuk konsekuensi area dari kerusakan komponen untuk Auto-ignition Likely, Instantaneous Release (AIL-INST)

Dengan merujuk pada tabel 4.8 API RBI 581 Annex 3, dapat ditentukan konstanta *a* dan *b*, dimana konstanta tersebut bernilai

a= 357.0 *b= 0.61*

Dengan ekuasi (3.33) API RBI 581 Annex 3, dapat ditentukan hasil perhitungan Consequence Area:

Small Hole Size : 666.4 m^2
Medium Hole Size : 967.34 m^2
Large Hole Size : 1374 m^2
Rupture Hole Size : 8178.2 m

8.5 Untuk setiap *release hole size*, dilakukan perhitungan untuk konsekuensi area dari kerusakan komponen untuk Auto-ignition Not Likely, Continuous Release (AINL-CONT),

Dengan merujuk pada tabel 4.8 API RBI 581 Annex 3, dapat ditentukan konstanta *a* dan *b*, dimana konstanta tersebut bernilai

a= 52.0 *b= 1.00*

Dengan ekuasi (3.33) API RBI 581 Annex 3, dapat ditentukan hasil perhitungan Consequence Area:

Small Hole Size : 0.101 m^2
Medium Hole Size : 4.869 m^2
Large Hole Size : 24.89 m^2

8.6 Untuk setiap *release hole size*, dilakukan perhitungan untuk konsekuensi area dari kerusakan komponen untuk Auto-ignition Likely, Continuous Release (AIL-CONT)

Dengan merujuk pada tabel 4.8 API RBI 581 Annex 3, dapat ditentukan konstanta *a* dan *b*, dimana konstanta tersebut bernilai

a= 375.0 *b= 0.94*

Dengan ekuasi (3.33) API RBI 581 Annex 3, dapat ditentukan hasil perhitungan Consequence Area:

Small Hole Size : 1.063 m^2
Medium Hole Size : 40.47 m^2
Large Hole Size : 187.6 m^2

8.7 Untuk setiap *release hole size*, dilakukan perhitungan untuk konsekuensi area dari kerusakan komponen untuk Auto-ignition Not Likely, Instantaneous Release (AINL-INST)

Dengan merujuk pada tabel 4.8 API RBI 581 Annex 3, dapat ditentukan konstanta *a* dan *b*, dimana konstanta tersebut bernilai

a= 203.0 *b= 0.89*

Dengan ekuasi (3.33) API RBI 581 Annex 3, dapat ditentukan hasil perhitungan Consequence Area:

Small Hole Size : 527.72 m^2
Medium Hole Size : 440.74 m^2
Large Hole Size : 637.87 m^2

8.8 Untuk setiap *release hole size*, dilakukan perhitungan untuk konsekuensi area dari kerusakan komponen untuk Auto-ignition Likely, Instantaneous Release (AIL-INST)

Dengan merujuk pada tabel 4.8 API RBI 581 Annex 3, dapat ditentukan konstanta *a* dan *b*, dimana konstanta tersebut bernilai

a= 1253.0 *b= 0.63*

Dengan ekuasi (3.33) API RBI 581 Annex 3, dapat ditentukan hasil perhitungan Consequence Area:

Small Hole Size : 2431.9 m^2
Medium Hole Size : 3731.4 m^2
Large Hole Size : 5400.3 m^2
Rupture Hole Size : 34761 m

8.9 Untuk setiap *release hole size*, dikalkulasi konsekuensi area Instantaneous/Continuous dengan menggunakan ekuasi (3.19), (3.20) atau (3.26).

8.10 AIT *Blending factor*, *factAIT*, dikalkulasi menggunakan ekuasi (3.24), (3.25) atau (3.21).

$$Fact^{AIT} = 0 \qquad for\, Ts + C_6 \leq AIT$$

$$Fact^{AIT} = \frac{(Ts - AIT - C6)}{2.C6} \qquad for\, Ts + C_6 > AIT > Ts - C_6$$

$$Fact^{AIT} = 1 \qquad for\, Ts - C_6 \geq AIT$$

maka di dapatkan hasil:

AIT = 0

8.11 Perhitungan konsekuensi lengkung instan kontinu untuk komponen menggunakan persamaan (3.65) hingga (3.68) berdasarkan area konsekuensi yang dihitung dalam langkah 8.4, 8.5, 8.6, 8.7, 8.8, 8.9, 8.10, dan 8.11. dan faktor pencampuran kontinyu / instan.

Dengan menggunakan ekuasi (3.65) sampai dengan (3.68) di dapatkan hasil:

Small Hole size :
$CA^{ANIL}_{cmd,1}$ = 0.837585 m^2
$CA^{AIL}_{cmd,1}$ = 666.3495 m^2
$CA^{ANIL}_{inj,1}$ = 0.084589 m^2
$CA^{AIL}_{inj,1}$ = 1.250958 m^2

Medium Hole size :

$CA^{ANIL}_{cmd,2}$ = 28.1673 m^2
$CA^{AIL}_{cmd,2}$ = 4.62288 m^2
$CA^{ANIL}_{inj,2}$ = 28.1673 m^2
$CA^{AIL}_{inj,2}$ = 54.1889 m^2

Large Hole size :

$CA^{ANIL}_{cmd,3}$ = 651.845 m^2
$CA^{AIL}_{cmd,3}$ = 286.571 m^2
$CA^{ANIL}_{inj,3}$ = 27.1370 m^2
$CA^{AIL}_{inj,3}$ = 286.571 m^2

Rupture Hole size :

$CA^{ANIL}_{cmd,4}$ = 7978.54 m^2
$CA^{AIL}_{cmd,4}$ = 33258.3 m^2
$CA^{ANIL}_{inj,4}$ = 7777.26 m^2

$CA^{AIL}_{inj,4}$ = 7777.26m^2

8.12 Kalkulasi AIT *blended consequence area* untuk komponen dengan menggunakan ekuasi (3.57), (3.58) API RBI 581, berdasarkan CA pada langkah 8.14.

Small Hole size :

$CA_{cmd,1}^{flam}$ = 0.08458 m^2
$CA_{inj,1}^{flam}$ = 1.25095 m^2

Medium Hole size :

$CA_{cmd,2}^{flam}$ = 28.1673 m^2
$CA_{inj,2}^{flam}$ = 54.1889 m^2

Large Hole size :

$CA_{cmd,3}^{flam}$ = 27.1370 m^2
$CA_{inj,3}^{flam}$ = 286.571 m^2

Rupture Hole size :

$CA_{cmd,4}^{flam}$ = 33258.3 m^2
$CA_{inj,4}^{flam}$ = 7777.26 m^2

8.13 Penentuan *final consequence area* untuk kerusakan komponen dan cedera pada personel dengan menggunakan ekuasi (3.59) dan (3.60).

didapatkan hasil:

CA_{cmd}^{flam} = 652.124 m^2
CA_{inj}^{flam} = 223.046 m^2

9 Consequence Analysis Toxic

Untuk setiap *release hole size* yang dipilih pada langkah 2.2, tentukan durasi effektif dari *release* dengan menggunakan ekuasi (3.67)

$$Id_n^{tox} = min\left(3600,\ \left\{\frac{mass}{W}\right\},\ \{60\ .\ Idmax, n\}\right)$$

Maka didapatkan hasil:

Small Hole Size : 3.600 m^2
Medium Hole Size : 1200 m^2
Large Hole Size: 600 m^2
Rupture Hole Size : 600 m

Dimana persentase toxic dari component.

H_2S = 1.55%
Mfrac = 0.0155

9.1 Setiap *release hole size,* dikalkulasikan *release rate*, rate$_{tpx}$, and release mass, xmassntox to be used in toxic consequence analysis

Small Hole Size : 3E-05 Kg/s
Medium Hole Size : 0.0015 Kg/s
Large Hole Size : 0.0074` Kg/s
Rupture Hole Size : 0.3715 Kg/s

9.2 Untuk setiap release hole size, dikalkulasikan *konsekuensi toxic* pada setiap release hole size, untuk HF acid dan H_2S – tentukan $CA^{tox}_{inj,n}$ dengan menggunakan ekuasi (3.63) untuk *continuous release..*

Small Hole Size : -0.5573 Kg/s
Medium Hole Size : 0.5252 Kg/s
Large Hole Size : 0.8914 Kg/s
Rupture Hole Size : 2.4189 Kg/s

9.3 Final toxic consequences area for personnel injury.

$$CA^{tox}_{inj} = \left(\frac{\sum_{n=1}^{4} gffn \,.\, CA^{tox}_{inj,n}}{gfftotal}\right)$$

$$CA^{flam}_{inj} = 0.30324\ \mathrm{m}^2$$

10 CoA non-flam non-tox

Untuk setiap *release hole size,* dikalkulasikan non-flammable, non-toxic consequence area.

Didapatkan hasil:
Small Hole Size : 33.8 Kg/s
Medium Hole Size : 361 Kg/s
Large Hole Size : 0.8914 Kg/s

Untuk setiap *release hole size,* tentukan blending factor dari instantaneous/continuous, gunakan ekuasi (3.71)

$$fact^{IC}_{n} = min\left[\left\{\frac{Raten}{C5}\right\},\ 1.0\right]$$

Didapatkan hasil:
Small Hole Size : 7.73511E-05 Kg/s
Medium Hole Size : 0.00371568 Kg/s
Large Hole Size : 0.02 Kg/s
Rupture Hole Size : 0.02 Kg/s

S
Small Hole Size : 0 Kg/s
Medium Hole Size : 1.35 Kg/s

Large Hole Size : 355 Kg/s

Ca0=24.05882 m

11 Penentuan final consequence area

Penentuan area konsekuensi didapatkan dengan terlebih dahulu menentukan final omponent damage consequence area (CA cmd) dan personnel injury consequence area (CA imj)

Menentukan final component damage consequence area

$$CAcmd = CA_{cmd,}^{flam}$$

$CAcmd =$ 652.124

Menentukan final personnel injury consequence area

$CA_{inj} = max\left[CA_{inj}^{flam},\ CA_{inj}^{tox}\ ,\ CA_{inj}^{nfnt}\right]$

= 223m^2

Didapatkan hasil final consequence area, CA :

$CA = max\left[CA_{cmd}, CA_{inj}\right]$

= 652.1 m^2

4.3.1.3 Risk Analysis

Nilai risiko dari alat didapat dengan mengalikan PoF dan CoF. Risiko dihitung menggunakan persamaan (4.103) API RBI 581,:

$$Risk = PoF\ x\ CoF$$

Dimana :
PoF = Probabilitas kegagalan
CoF = Konsekuensi kegagalan

Penentuan tingkat risiko dilakukan dengan membandingkan nilai risiko yang didapatkan dengan *risk target.* Apabila hasil perbandingan menunjukkan bahwa risiko lebih besar dari *risk target*, maka akan dilakukan langkah mitigasi. Langkah mitigasi dapat dilakukan dengan cara melakukan inspeksi sesuai dengan jadwal dan metode yang diharapkan dapat meminimalkan nilai risiko tersebut.

Analisis risiko pada tugas akhir ini, untuk pressure vessel dilakukan perbandingan risiko pada RBI date dengan risk target. Menghitung besarnya risiko pada pressure vessel

a. Menghitung besarnya risiko pada RBI *date*

Besarnya risiko pada *pressure vessel* VS-80-001 adalah :

$$Risk = PoF\ x\ \max(CAinj, CAequip)$$

$$= 26.12641$$

Besarnya risiko pada *plan date* adalah :

$$Risk = PoF \, . \, max(CAinj, CAequip)$$

$$= 54.64667$$

b. Tingkat risiko

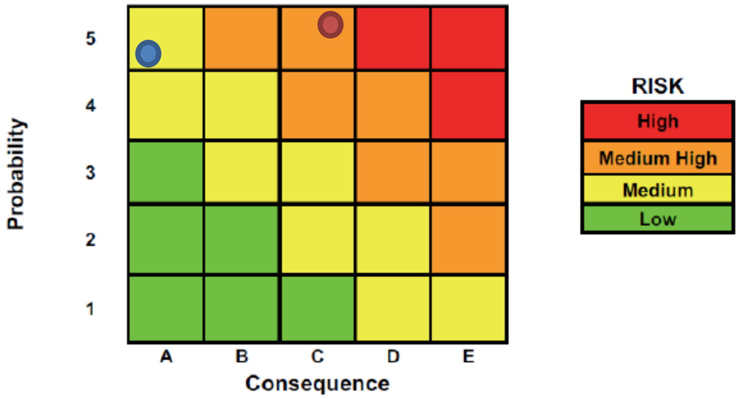
Kategori tingkat risiko ditentukan dari hasil PoF dan CoF. Dengan menggunakan Tabel 4.1M API RBI 581 Annex 1, maka tingkat risiko dapat dikategorikan.

Pada pressure vessel separator VS-80-001, VS-80-002, dan VS-80-003, hasil tingkat risiko yang didapat adalah:

Probability Range
5A – Medium

Damage Factor Range
5C – Medium High

Berdasarkan nilai tersebut maka didapatkan matriks risikonya yang ditunjukkan oleh gambar 4.1



Gambar 4. 1 Risk Matriks untuk VS-80-001

Tingkat risiko dapat di plotting sebagai table 4.3

Tabel 4. 3 Tabel Risiko VS-80-001

Tanggal	Keterangan	DF	CoF (m^2)	Risk Category	Definisi
02/12/2019	RBI date	46.15	652.1	5A	Medium

02/12/2023	Plan date	112.2		5C	Medium-High
*Note: Inspection effectiveness: 2E					

4.3.1.4 Inspection plan

Penjadwalan inspeksi adalah suatu kegiatan menentukan interval waktu antar-inspeksi yang akan diterapkan pada alat. Menurut API 581 penjadwalan inspeksi untuk pressure vessel dilakukan berdasarkan hasil dari risiko yang didapatkan, namun intervalnya sendiri tidak diberikan suatu perhitungan yang pasti. API 581 menyerahkan penjadwalan inspeksi kepada perusahaan sesuai dengan batasan risiko yang dapat diterima. Karena batasan risiko yang dapat diterima pada alat tidak diketahui, untuk membantu dalam melakukan penjadwalan maka dapat mengacu pada API 510 yang membahas mengenai pressure vessel inspection code.

API 510 menyatakan bahwa pressure vessel harus diinspeksi internal atau on-stream maksimal setiap 10 tahun atau pada saat umur pressure vessel telah mencapai setengah dari remaining life-nya, tergantung nilai mana yang lebih rendah.

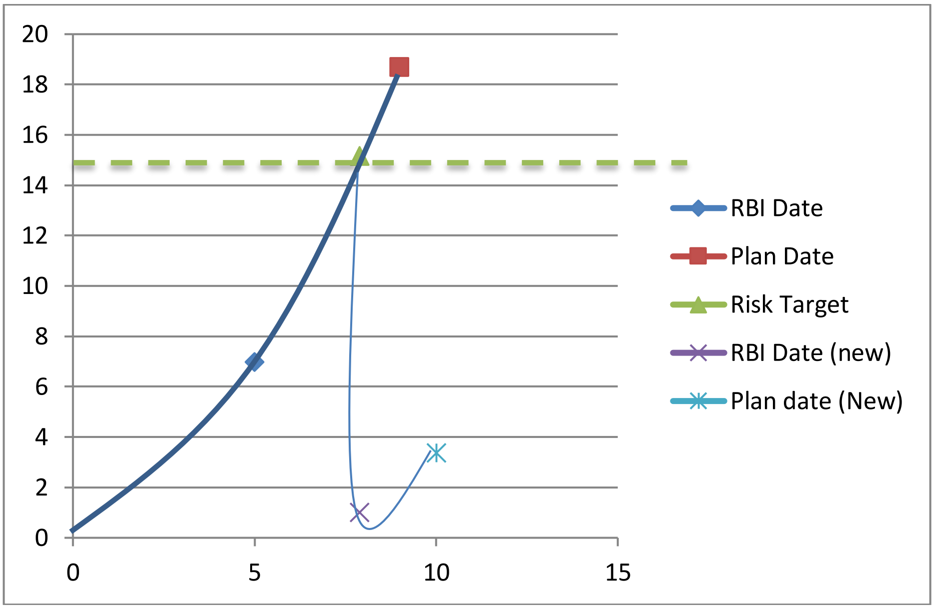
Analisis *inspection planning* dilakukan pada *pressure vessel*. Langkah-langkah dalam menentukan *inspection planning*:

1. Menghitung *target inspection date*

   Target date didapatkan dari perpotongan kurva risiko pada RBI *date* dengan kurva *risk target*.

Tabel 4. 4 Table kurva risiko berdasarkan risk area (VS-80-001)

Item	Date	Time since RBI Assessment	Risk Area (m^2/yr)
RBI Date	12/02/2019	5	20.45934724
Risk Target	05/12/2019	7.89	44.33273807
Plan Date	12/02/2023	9	54.64660042



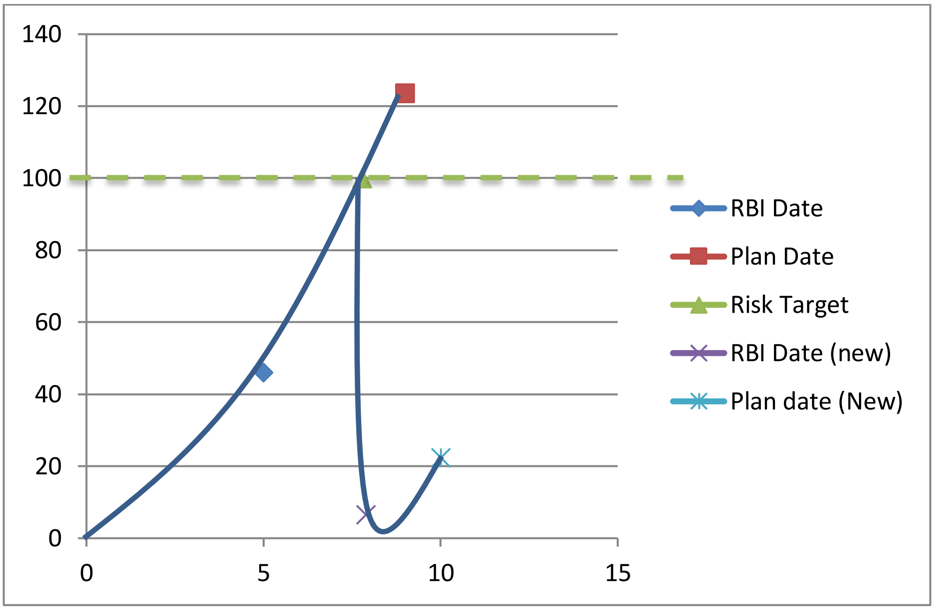
Gambar 4. 2 Grafik kurva risiko berdasarkan Risk area (VS-80-001)

Target date = 7.89 year after Assessment
= 11/22/2018

Tabel 4. 5 Tabel kurva risiko berdasarkan damage factor (VS-80-001)

Item	Date	Time since RBI Assessment	Damage Factor
RBI Date	12/02/2019	5	46.1495232
Risk Target	02/03/2022	7.25	100
Plan Date	12/02/2023	9	123.5288021

Target date = 7.25 Year after RBI Assessment
= 02/03/2022



Gambar 4. 3 Grafik kurva risiko beradasarkan Damage factor (VS-80-001)

Rekomendasi inspeksi yang ditawarkan dapat dilihat pada table 4.6.

Tabel 4. 6 Rekomendasi Inspeksi untuk VS-80-001

Damage factor	Efektivitas inspeksi	Inspeksi intrusif	Inspeksi non-intrusif	Tanggal inspeksi
Local Thinning	C	Untuk area permukaan total: • >50% pemeriksaan visual. • 100% follow up di area local thinning.	Untuk total area yang dicurigai: > cakupan 50% dari CML menggunakan ultrasonic scanning atau profile radiography.	Dilakukan pada tanggal 02-03-2022
Sulfide Stress Cracking	E	Dilakukannya teknik inspeksi/perencanaan yang tidak effektif	Dilakukannya teknik inspeksi/perencanaan yang tidak effektif	
SIC/SOHIC – H_2S	E	Dilakukannya teknik inspeksi/perencanaan yang tidak effektif	Dilakukannya teknik inspeksi/perencanaan yang tidak effektif	

4.3.2 Hasil RBI untuk VS-80-002

4.3.2.1 Probability of Failure

1. **Penentuan Thinning Damage Factor**

Setiap komponen perlu di periksa terhadap indicator kerusakan yang diakibatkan *ge factor* yang dapat diakibatkan oleh *general* dan *local thinning.* Untuk perhitungan selengkapnya dicantumkan pada lampiran 5.

Langkah-langkah berikut digunakan untuk menentukan damage factor untuk thinning adalah.

a. Menentukan furnished thickness dan umur dari equipment, ditentukan hasil dari furnished thickness adalah 28.85 dan umur dari equipment adalah 14 tahun.
b. Menentukan lajur korosi berdasarkan material dasar (C_{rbm}) berdasarkan material konstruksi serta lingkungan dan cladding/overlay. Berdasarkan penjelasan dari section 4.5.2 API RP 581, laju korosi dihitung dengan menggunakan pendekatan Annex 2B dari API RP 581, untuk menghitung laju korosi perlu ditentukan tipe korosi yang ada dengan menggunakan screening questions yang disediakan oleh tabel 2B.1.1. Dari screening question ditentukan bawha tipe korosi yang ada pada equipment adalah Sour water corrosion dan laju korosi yang telah disesuaikan adalah 0.287.
c. Menentukan waktu in-service,
d. Menentukan age_{rc} untuk komponen cladding/overlay, dikarenakan tidak adanya cladding, maka step ini dilewat.
e. Menentukan thickness minimum dari equipment, ada 4 metoda yang dapat digunakan untuk menentukan minimum thickness dari sebuah equipment, untuk perhitungan ini, metoda perhitungan pertama digunakan karena metoda ini digunakan komponen cylindrical, spherical, atau head. Hasil dari perhitungan didapatkan bahwa minimum thickness dari equipment adalah 25.91 mm atau 1.02" inch.
f. Menentukan parameter A_{rt}, dari perhitungan A_{rt} hasil yang didapatkan adalah 0.39820014 (calculated corrosion rate) dan 0.0013867 (berdasarkan data yang didapat).
g. Menentukan Flow stress dari equipment, dengan mengkalkulasikan Yield Strenght dan Tensile Strength, didapatkan hasil flow stress sebesar 35887
h. Menghitung parameter strength ratio dengan menggunakan equasi yang tepat, dimana didapatkan hasil 0.686
i. Menentukan jumlah inspeksi sebelumnya untuk inspection effectiveness dengan menggunakan section 4.5.6 dari API RP 581 Part 2, berdasarkan data sebelumnya, inspection effectiveness dari data yang didapat memiliki kategori E, dimana berdasarkan kategori

tersebut inspeksi yang dilakukan sangat tidak effective atau tidak dilakukan inspeksi sama sekali.

j. Menentukan inspection effective factor, tiap factor harus dihitung berdasarkan scenario damage state, dengan menggunakan Table 4.5 dan tabel 4.6 dari API RP 581, didapatkan hasil $I_1^{thin}, I_2^{thin}, I_3^{thin}$ senilai 0.50, 0.30, dan 0.20
k. Menentukan parameter $\beta_1, \beta_2, dan\ \beta_3$, dan didapatkan hasil 1.5390, 1.5390, 1.53056 dan 1.51375
l. Maka didapatkan hasil damage factor sebesar 0.200745959.

2. Perhitungan Damage Factor Stress Corrosion Cracking – Sulfide Stress Cracking.

Caustic cracking didefinisikan sebagai keretakan sebuah material dibawah campuran *tensile stress* dan korosi yang di akibatkan oleh sodium hydroxide (NaOH) pada temperatur yang tinggi. Untuk menentukan *Damage Factor* SCC-SSC, dapat digunakan kalkulasi yang mengacu pada API RBI 581. Perhitungan lengkap dari SCC-SSC Df dilampirkan pada lampiran 5

Langkah-langkah berikut di gunakan untuk menentukan damage factor untuk SCC-SSC.

a. Menentukan *Enviromental Severity* untuk keretakan berdasarkan konten air dan pH dari H_2S menggunakan Tabel 8.2 (API RBI 581). Dimana pH air adalah 5.52 dan konten air sebesar 1000 ppm, dapat di tentukan bahwa *environmental severity* dari SSC adalah **Moderate.**

b. Menentukan kerentanan dari keretakan menggunakan *figure 8.1* dan tabel 8.3 (API RBI 581) berdasarkan dari *environmental severity* dari langkah 1. Berdasarkan tabel tersebut, dengan kriteria dimana *Max Brinnel Hardness* bernilai <200 dan *Enviromental Severity* berada pada *Moderate*, dan tidak adanya PWHT pada equipment, maka didapatkan hasil **Low** untuk *susceptibility to SSC-SCC.*

c. Berdasarkan dari kerentanan yang di dapatkan pada langkah ke dua, ditentukan *severity index* (S_{vi}) menggunakan tabel 8.4 (API RBI 581), dimana S_{VI} dari **Low Susceptibility**, adalah **1**.

d. Menentukan *in-service age* semenjak inspeksi level A,B, atau C terakhir dilakukan. Berdasarkan data yang di dapat, dapat ditentukan bahwa *in-service age* pada saat analisa dilakukan adalah **18 tahun.**

e. Menentukan inspeksi sebelumnya dan inspeksi yang sesuai menggunakan *Section 8.6.2* API RBI 581 Part 2 Annex 1. Berdasarkan data yang didapat, ada 2 inspeksi yang telah dilakukan sebelum analisa ini dilakukan dengan kategori efektif yakni E, dimana hasil inspeksi tersebut bersifat ***Ineffective.***

f. Menentukan basis *damage factor* untuk *sulfide stress cracking*, menggunakan tabel 6.3 API RBI 581 Annex 2. Penentuan *damage factor* untuk SCC dapat ditentukan dengan *inspection effectiveness* tertinggi dan jumlahnya, dimana berdasarkan langkah sebelumnya, didapat bahwa kategori dari inspeksi sebelumnya adalah E dan memiliki *severity index* sebesar 1. *Base damage factor* yang di dapat adalah **1**

g. Langkah terakhir ini dilakukan untuk menentukan *Damage Factor* dari *Stress Caustic Cracking – Sulfide Stress Cracking*, dimana untuk menentukan *Df* tersebut, dapat menggunakan equasi 2.27 API RBI 581. Dimana hasil yang di dapatkan untuk :

RBI Date

$$D_f^{SCC} = 5.8730947$$

RBI Plan Date

$$D_f^{SCC} = 13.980798$$

3. Perhitungan Damage Factor Stress Corrosion Cracking – HIC/SOHIC-H_2S.

HIC didefinisikan sebagai keretakan internal yang berdekatan dengan hydrogen blister di tingkatan yang berbeda pada metal, atau permukaan metal. Untuk menentukan *Damage Factor* HIC/SOHIC-H_2S, digunakan kalkulasi yang mengacu pada API RBI 581. Perhitungan lengkap dari HIC/SOHIC-H_2S Df dilampirkan pada lampiran 5

Langkah-langkah berikut digunakan untuk menentukan damage factor untuk HIC/SOHIC-H_2S

i. Menentukan *Enviromental Severity* untuk keretakan berdasarkan konten air dan pH dari H_2S menggunakan Tabel 8.2 (API 581). Dimana pH air adalah 5.52 dan konten air sebesar 1000 ppm, dapat di tentukan bahwa *environmental severity* dari HIC/SOHIC-H_2S adalah **Moderate.**

j. Menentukan kerentanan dari keretakan menggunakan *figure 8.1* dan tabel 9.3 (API RBI 581) berdasarkan dari *environmental severity* dari langkah 1, dengan kriteria dimana *Max Brinnel Hardness* bernilai <200 dan *Enviromental Severity* berada pada *Moderate*, dan tidak adanya PWHT pada equipment, maka didapatkan hasil **Low** untuk *susceptibility to SSC-SCC.*

k. Berdasarkan dari kerentanan yang di dapatkan pada langkah ke dua, ditentukan *severity index* (S_{vi}) menggunakan tabel 9.4 (API RBI 581), dengan S_{VI} dari **Low Susceptibility**, adalah **1**.

l. Menentukan *in-service age* semenjak inspeksi level A,B, atau C terakhir dilakukan. Berdasarkan data yang di dapat, dapat ditentukan bahwa *in-service age* pada saat analisa dilakukan adalah **18 tahun.**

m. Menentukan inspeksi sebelumnya dan inspeksi yang sesuai menggunakan *Section 8.6.2* API RBI 581 Part 2 Annex 1. Berdasarkan data yang didapat, ada 2 inspeksi yang telah dilakukan sebelum analisa ini dilakukan dengan kategori efektif yakni E, dimana hasil inspeksi tersebut bersifat ***Ineffective.***

n. Menentukan basis *damage factor* untuk *sulfide stress cracking*, menggunakan tabel 6.3 API RBI 581 Annex 2. Penentuan *damage factor* untuk HIC/SOHIC dapat ditentukan dengan *inspection effectiveness* tertinggi dan jumlahnya, dimana berdasarkan langkah sebelumnya, didapat bahwa kategori dari inspeksi sebelumnya adalah E dan memiliki *severity index* sebesar 1. *Base damage factor* yang di dapat adalah **1**

o. Menentukan *On-line adjustment factor* dengan menggunakan tabel 9.5 (API 581)

p. Menghitung *Df* akhir dengan memperkirakan kenaikan *Df* berdasarkan *in-service age* sejak inspeksi terakhir. Di asumsikan bahwa probabilitas untuk keretakan akan meningkat dengan waktu semenjak inspeksi terakhir akibat hasil dari peningkatan eksposur akibat kondisi normal ataupun tidak normal. Hasil akhir *Df* dapat dikalkulasikan sebagai berikut:

Damage Factor at RBI Date

$$D_f^{HIC\,SOHIC-H2S} = \frac{D_{fB}^{HIC\,SOHIC-H2S}.(Max[age,1.0])^{1.1}}{Fom}$$

$$D_f^{HIC\,SOHIC-H2S} = \frac{1.(Max[4,1.0])^{1.1}}{2}$$

$$D_f^{HIC\,SOHIC-H2S} = 4.594793$$

Damage Factor at RBI Plan Date

$$D_f^{HIC\,SOHIC-H2S} = \frac{D_{fB}^{HIC\,SOHIC-H2S}.(Max[age,1.0])^{1.1}}{Fom}$$

$$D_f^{HIC\,SOHIC-H2S} = \frac{1.(Max[9,1.0])^{1.1}}{2}$$

$$D_f^{HIC\,SOHIC-H2S} = 11.21158$$

4. Perhitungan General Failure Frequency (gff).

Untuk menentukan *General Failure Frequency* dapat mengacu pada Table 3.1 dari API RBI 581 yang berisi list rekomendasi *gff* untuk equipment yang di analisa. Perhitungan gff dilampirkan pada lampiran 5.

Tabel 4. 7 Suggested Component Generic Failure Frequencies.

Equipment Type	Component Type	*gff* as a function of hole size (failures/yr)				gff_{total} *(failures/yr)*
		Small	Medium	Large	Rupture	
Vessel/FinFan	KODRUM, COLBTM, FINFAN, FILTER DRUM, REACTOR, COLTOP, COLMID,	8.00E-06	2.00E-05	2.00E-05	6.00E-07	3.06E-05

Dari tabel tersebut, dapat ditentukan bahwa *gfftotal* memiliki nilai 3.06E-05

5. Perhitungan Management System Factor (Fms).

Menentukan faktor *Fms* dapat menggunakan evaluasi majemen sistem yang disediakan pada *Part 2, Annex 2.A* RBI 581. Perhitungan fms dilampirkan pada lampiran 5.

Setelah mendapat percentage dari score, nilai *Fms* dapat dihitung dengan menggunakan rumus:

$$Fms = 10^{(-0;02.pscore+1)}$$

Maka didapat nilai *Fms* bernilai 0.182390.

6. Perhitungan *Probabiliy of Failure*

Setelah mendapatkan hasil *Df,gff,* dan *Fms*. Maka perhitungan PoF dilakukan dengan menggunakan rumus,

$$Pf\ (t) = gff\ .\ Fms\ .Df\ (t)$$

Dari rumus tersebut dapat dikalkulasikan bahwa PoF bernilai:

$$Pf\ (t)\ =\ gff\ .\ Fms\ .\ D\,f\ (t)$$
$$Pf\ (t)\ = 0.0124(RBI\ Date)$$
$$Pf\ (t)\ = 0.0837(RBI\ Plan\ Date)$$

Perhitungan dari probability of failure di lampirkan pada lampiran 5

4.3.2.2 Consequence of Failure

Consequence of Failure digunakan untuk menganalisa konsekuensi dari kegagalan sebuah equipment bertekanan yang berkemungkinan untuk menimbulkan kerusakan untuk equipment, loss dari produksi atau jalannya sistem, pencemaran, dan menimbulkan cedera fatal pada personel. Analisa CoF dapat dihitung sebagai konsekuensi area atau financial. Dalam API RBI 581, analisa konsekuense dibagi menjadi dua level, yakni *Level 1 Consequence of Failure*, dan *Level 2 Consequence of Failure*. Dalam analisa ini, perhitungan konsekuensi yang digunakan adalah perhitungan konsekuensi level 1. Perhitugan selengkapnya dari analisa konesekuense kegagalan dilampirkan pada lampiran 6.

Dalam beberapa tahap yang perlu dilakukan untuk melakukan analisa konsekuensi pada RBI, langkah langkah tersebut adalah sebagai berikut

1. Penentuan Fluida Representatif

Representative Liquid yang digunakan adalah H_2S atau Hydrogen Sulfide, dengan *properties*:

Liquid Density : 993.033 Kg/m^3

NBP : -59.4 C°
Auto-Ignition temperature : 500 F° / 260 C°

Dalam tabel 4.3 API RBI 581 Annex 3, dapat ditentukan bahwa fase liquid saat tersimpan adalah Liquid namun setelah terlepas adalah Gas.

2. Pemilihan Release Hole Size

Pemilihan release hole size didasarkan pada jenis peralatan. Pemilihan set ukuran lubang saat *release* untuk menentukan kemungkinan range dari konsekuensi yang dihasilkan. Untuk menentukan set ukuran lubang mengacu pada API RBI 581 Annex 3 Part 1, Tabel 4.4.

Tabel 4. 8 Release Hole Sizes and Areas Used in Level 1 and 2 Consequence Analysis

Release Hole Number.	Release Hole Size.	Range of Hole Diameters (inch).	Release Hole Diameters, d_n, (inch).
1	Small	1 – ¼	$d_1 = 0.25$
2	Medium	>¼ - 2	$d_1 = 1$
3	Large	>2 – 6	$d_1 = 4$
4	Rupture	>6	$d_1 = \min [D,16]$

3. Perhitungan Release Rate

Selanjutnya dihitung *theoretical release rate* dari scenario *release hole size (An)* yang sudah ditentukan pada langkah ke dua. Pada langkah ini, *release hole size* perlu di hitung menggunakan ekuasi 3.8.

$$An = \frac{\pi d_n^2}{4}$$

Dengan ekuasi tersebut didapatkan hasil:

Small Hole Size : 3.00E-05 m^2
Medium Hole Size : 5.00E-04 m^2
Large Hole Size : 0.008 m^2
Rupture Hole Size : 0.13 m^2

Setelah mendapatkan *release hole size* dari tiap scenario, langkah berikutnya adalah untuk menghitung *release rate* (W_n). didapatkan hasil *release rate* sebagai berikut:

Small Hole Size : 0.001949 Kg/s
Medium Hole Size : 0.093635 Kg/s
Large Hole Size : 0.478570 Kg/s
Rupture Hole Size : 23.96435 Kg/s

6. Langkah ke empat adalah mengestimasikan masa maksimum yang ada saat release.

Untuk menghitung masa yang ada atau *available mass* ($Mass_{avail}$), *group component* dan *equipment items* dari *inventory group* harus ditentukan terlebih dahulu, untuk menentukan *inventory groups*, dapat merujuk pada API RBI 581 Annex 3 Part 3, Tabel 3.A.3.2. Dapat disimpulkan bahwa equipment yang dianalisa memiliki *Default liquid volume percent* sebanyak 50% liquid.

Untuk penentuan massa komponen ($mass_{comp}$) diperlukan perhitungan massa fluida. massa fluida dihitung dengan rumus volume dari equipment yang dianalisa

$$Vcyl = \pi R^2 L$$
$$Vcyl = \pi . 1.067.10{,}5$$
$$Vcyl = 37.5 \text{ m}^3$$

Untuk volume liquid dan volume vapour:

Liquid Volume: $\left(\frac{50}{100}\right) x\ Vcyl$ = 18,75 m^3

Vapour Volume: $(1 - \left(\frac{50}{100}\right) x\ Vcyl)$ = 18,75 m^3

Untuk massa komponen:

$$Mass_{comp} = (V_l\ \rho_l) + (V_v\ \rho_v)$$
$$Mass_{comp} = 18728\ Kg$$

Maka didapatkan massa inventory ($mass_{inv}$)

$$Mass_{inv} = \sum_{i=1}^{N} Masscomp$$
$$Mass_{inv} = 18639.3 \text{ Kg}$$

Perhitungan *flow rate* perlu dilakukan dengan cara meengkalkulasikan *flow rate* dari simulasi lubang dengan diameter 203mm (8 inch) dengan menggunakan ekuasi (3.3), (3.6), (3.7) API 581 Annex 3 sesuai dengan kebutuhan dengan $A_n = A_8$ = 32,450 mm^2 (50,3 inch^2).

$$W_{max.8} = \frac{Cd}{C2} . A8 . Ps \sqrt{\left(\frac{k . MW . gc}{R . Ts}\right) \left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$
$$W_{max.8} = \frac{0.90}{1} . 32{,}450 . 1060 \sqrt{\left(\frac{1.27 . 34 . 1}{8.314 . 453.15}\right) \left(\frac{2}{1.27+1}\right)^{\frac{1.27+1}{1.27-1}}}$$
$$W_{max.8} = 0.221285458\ Kg$$

Untuk setiap *hole size*, dikalkulasi massa fluida yang di tambah ($mass_{add,n}$). dihasilkan 3 menit *flow* berasal dari *inventory group* menggunakan ekuasi (3.10) API RBI 581, dimana W_n adalah lajur release dari tiap hole size.

$$Mass_{add,n} = 180 . \text{Min} [W_n , W_{max,8}]$$

Maka didapatkan hasil W_n

Small Hole Size : 0.3508 Kg/s
Medium Hole Size : 16,85 Kg/s
Large Hole Size : 84.17 Kg/s
Rupture Hole Size : 84.17 Kg/s

7. Penentuan Release Type.

Release type (*continuous/instantaneous*) untuk menentukan metoda yang akan digunakan untuk pemodelan *dispersion* dan *consequence*

a.Untuk setiap *hole size*, ditentukan waktu yang dibutuhkan untuk melepaskan 4536 Kg Liquid. Dengan menggunakan ekuasi:

$$tn = \frac{C3}{Wn}$$

Di dapatkan hasil t_n:

Small Hole Size : 2327052 s
Medium Hole Size : 48443.38 s
Large Hole Size : 9478.23 s
Rupture Hole Size : 189.27 s

Ditentukan *release type* apakah *continuous* atau *instantaneous* dengan menggunakan kriteria sebagai berikut:

- If the release hole size is 6.35 mm (0.25 inch) or less, then the release type is automatically continuous.
- If tn≤180 sec and the release mass is greater than 4536 kgs (10000 lbs.),then the release is instantaneous; otherwise, the release is continuous.

Dengan kriteria tersebut dapat di tentukan bahwa:

Small Hole Size : d_1 = 0.25 inch
t_1 = 2.33E+06 s
Continuous
Medium Hole Size: d_2 = 1 inch
t_2 = 48443.38 s
Continuous
Large Hole Size: d_3 = 4 inch
t_3 = 9478.235 s
Continuous
Rupture Hole Size: d_4 = 16 inch
t_4 = 189.2789 s
Continuous

8. Estimasi impact dari sistem deteksi serta isolasi pada magnitude release.

Menetapkan sistem deteksi dan isolasi yang ada pada unit, dengan menggunakan tabel 4.5 API RBI 581 Annex 3. Dimana klasifikasi yang dipilih adalah :

Detection System Classification: **C**
Isolation System Classification: **C**

Dengan menggunakan Tabel 4.6 API RBI 581, dan klasifikasi dari langkah 6.2 dan 6.3, ditentukan *release reduction factor* pada equipment.

$fact_{di}$: 0.00 (No adjustment to release rate or mass)

Dengan menggunakan tabel 4.7 dan klasifikasi yang telah ditetapkan pada langkah sebelumnya, ditentukan *total leak duration* pada setiap *release hole size,* $\mathbf{Id}_{max,n}$.

Detection System : **C**
Isolation System : **C**
$Id_{max,1}$: 60 Minutes
$Id_{max.2}$: 40 Minutes
$Id_{max,3}$: 20 Minutes

9. Penentuan release rate dan massa untuk analisa konsekuensi.

Untuk setiap release hole size, dikalkulasi *adjusted release rate¸rate*$_n$ dengan menggunakan ekuasi (3.13) API RBI 581.

$$rate\ n = Wn\,(1 - factdi)$$

Small Hole Size : 0.00195 Kg/s
Medium Hole Size : 0.09364 Kg/s
Large Hole Size : 0.47857 Kg/s
Rupture Hole Size : 23.9646 Kg/s

Untuk setiap hole size, ditentukan *leak duration, Id*$_n$ dari release menggunakan ekuasi 3.15 API RBI Annex.

$$Idn = min\left[\left\{\frac{massavailn}{raten}\right\},\ \{60.\, idmax, n\}\right]$$

Small Hole Sizeq : 3600 s
Medium Hole Size : 1200 s
Large Hole Sizeq : 600 s
Rupture Hole Size : 600 s

Untuk setiap hole size, dikalkulasi *release mass, mass*$_n$, menggunakna ekuasi (3.14) berdasarkan *release rate¸rate*$_n$, dengan hasil dari langkah 3.2, *Id*$_n$ dari langkah 7.2, dan *available mass, mass*$_{avail}$, dari langkah 4.6

$$mass_n = \min[\{rate_n\,.\ idn\},\ massav_{ailn}]$$

Small Hole Size : 7.017 Kg/s
Medium Hole Size : 112.362 Kg/s
Large Hole Size : 287.142 Kg/s
Rupture Hole Size : 14378.8 Kg/s

10. Penentuan konsekuensi flammable dan explosive pada equipment.

Langkah pertama dalam kalkulasi *flammable and explosive consequence analysis* adalah memilih reduction factor untuk mitigasi konsekuensi area

Faktor mitigasi dapat ditentukan dengan menggunakan tabel 4.10 (API 581), dikarenakan tidak ada rujukan yang mencukupi dari data yang ada, mitigation system tidak dapat ditentukan, sehingga;

$Fact_{mit} = 0$

Untuk setiap release hole size, ditentukan koreksi dari effisiensi energy, atau en_{eff}. Dengan menggunakan ekuasi 3.18.

$$eneff_1 = 4.log_{10}[C_4.\ mass_1] - 15$$

Dengan ekuasi tersebut didapatkan hasil:

Small Hole Size : 1.758311 Kg/s
Medium Hole Size : 6.576113 Kg/s
Large Hole Size : 8.206021 Kg/s
Rupture Hole Size : 15.00452 Kg/s

Selanjutnya ditentukan tipe fluida, berdasar table 4.1 API RBI 581, Annex 3. Didapatkan hasil :

Representative Fluid : **H_2S**
Fluid type : ***Type 0***

Untuk setiap *release hole size*¸dikalkulasi konsekuensi area untuk kerusakan komponen.

Dengan menggunakan table 4.8 API RBI 581 Annex 3, dapat di tentukan konstanta *a* dan *b,* dimana konstanta tersebut bernilai:

a= 32.0 *b= 1.00*

Dengan menggunakan ekuasi (3.31) didapatkan hasil:

$$CA_{cmd,n}^{AINL-CONT} = a\,(rate)^b\ .\ (1\ - factmil\,)$$

Small Hole Size : 0.062 m^2
Medium Hole Size : 2.996 m^2
Large Hole Size : 15.31 m^2
Rupture Hole Size : 766.9 m

Untuk setiap *release hole size,* dilakukan perhitungan untuk konsekuensi area dari kerusakan komponen untuk *Auto-ignition Likely Continuous Release (AIL-CONT).*

Dengan merujuk pada tabel 4.8 API RBI 581 Annex 3, dapat di tentukan konstanta *a* dan *b,* dimana konstanta tersebut bernilai

a= 203.0 *b= 0.89*

Dengan ekuasi (3.33) API RBI 581 Annex 3, dapat ditentukan hasil perhitungan Consequence Area:

Small Hole Size : 0.7861 m^2
Medium Hole Size : 24.665 m^2
Large Hole Size : 105.35 m^2
Rupture Hole Size : 3430.2 m^2

Untuk setiap *release hole size*, dilakukan perhitungan untuk konsekuensi area dari kerusakan komponen untuk *Auto-ignition Not-Likely Continuous Release (AINL-CONT)*
Dengan merujuk pada tabel 4.8 API RBI 581 Annex 3, dapat ditentukan konstanta *a* dan *b*, dimana konstanta tersebut bernilai

a= 148.0 *b= 0.63*

Dengan ekuasi (3.33) API RBI 581 Annex 3, dapat ditentukan hasil perhitungan Consequence Area:

Small Hole Size : 287.25 m^2
Medium Hole Size : 440.74 m^2
Large Hole Size : 637.87 m^2
Rupture Hole Size : 4105.9 m

Untuk setiap *release hole size,* dilakukan perhitungan untuk konsekuensi area dari kerusakan komponen untuk Auto-ignition Likely, Instantaneous Release (AIL-INST)
Dengan merujuk pada tabel 4.8 API RBI 581 Annex 3, dapat ditentukan konstanta *a* dan *b*, dimana konstanta tersebut bernilai

a= 357.0 *b= 0.61*

Dengan ekuasi (3.33) API RBI 581 Annex 3, dapat ditentukan hasil perhitungan Consequence Area:

Small Hole Size : 666.4 m^2
Medium Hole Size : 967.34 m^2
Large Hole Size : 1374 m^2
Rupture Hole Size : 8178.2 m

Untuk setiap *release hole size,* dilakukan perhitungan untuk konsekuensi area dari kerusakan komponen untuk Auto-ignition Not Likely, Continuous Release (AINL-CONT),
Dengan merujuk pada tabel 4.8 API RBI 581 Annex 3, dapat ditentukan konstanta *a* dan *b*, dimana konstanta tersebut bernilai

a= 52.0 *b= 1.00*

Dengan ekuasi (3.33) API RBI 581 Annex 3, dapat ditentukan hasil perhitungan Consequence Area:

Small Hole Size : 0.101 m^2
Medium Hole Size : 4.869 m^2
Large Hole Size : 24.89 m^2

Untuk setiap *release hole size*, dilakukan perhitungan untuk konsekuensi area dari kerusakan komponen untuk Auto-ignition Likely, Continuous Release (AIL-CONT) Dengan merujuk pada tabel 4.8 API RBI 581 Annex 3, dapat ditentukan konstanta *a* dan *b*, dimana konstanta tersebut bernilai

$a= 375.0$ $b= 0.94$

Dengan ekuasi (3.33) API RBI 581 Annex 3, dapat ditentukan hasil perhitungan Consequence Area:

Small Hole Size : 1.063 m^2
Medium Hole Size : 40.47 m^2
Large Hole Size : 187.6 m^2

Untuk setiap *release hole size,* dilakukan perhitungan untuk konsekuensi area dari kerusakan komponen untuk Auto-ignition Not Likely, Instantaneous Release (AINL-INST)
Dengan merujuk pada tabel 4.8 API RBI 581 Annex 3, dapat ditentukan konstanta *a* dan *b,* dimana konstanta tersebut bernilai
$a= 203.0$ $b= 0.89$

Dengan ekuasi (3.33) API RBI 581 Annex 3, dapat ditentukan hasil perhitungan Consequence Area:

Small Hole Size : 527.72 m^2
Medium Hole Size : 440.74 m^2
Large Hole Size : 637.87 m^2

Untuk setiap *release hole size,* dilakukan perhitungan untuk konsekuensi area dari kerusakan komponen untuk Auto-ignition Likely, Instantaneous Release (AIL-INST)
Dengan merujuk pada tabel 4.8 API RBI 581 Annex 3, dapat ditentukan konstanta *a* dan *b,* dimana konstanta tersebut bernilai
$a= 1253.0$ $b= 0.63$

Dengan ekuasi (3.33) API RBI 581 Annex 3, dapat ditentukan hasil perhitungan Consequence Area:

Small Hole Size : 2431.9 m^2
Medium Hole Size : 3731.4 m^2
Large Hole Size : 5400.3 m^2
Rupture Hole Size : 34761 m

Untuk setiap *release hole size*, dikalkulasi konsekuensi area Instantaneous/Continuous dengan menggunakan ekuasi (3.19), (3.20) atau (3.26).

AIT *Blending factor, factAIT*, dikalkulasi menggunakan ekuasi (3.24), (3.25) atau (3.21).

$$Fact^{AIT} = 0 \qquad for\; Ts + C_6 \le AIT$$

$$Fact^{AIT} = \frac{(Ts - AIT - C6)}{2.C6} \qquad for\; Ts + C_6 > AIT > Ts - C_6$$

$$Fact^{AIT} = 1 \qquad for\; Ts - C_6 \ge AIT$$

maka di dapatkan hasil:

AIT = 0

Perhitungan konsekuensi lengkung instan kontinu untuk komponen menggunakan persamaan (3.65) hingga (3.68) berdasarkan area konsekuensi yang dihitung dalam langkah 8.4, 8.5, 8.6, 8.7, 8.8, 8.9, 8.10, dan 8.11. dan faktor pencampuran kontinyu / instan.

Dengan menggunakan ekuasi (3.65) sampai dengan (3.68) di dapatkan hasil:

Small Hole size :

$CA^{ANIL}_{cmd,1}$ = 0.837585 m^2

$CA^{AIL}_{cmd,1}$ = 666.3495 m^2

$CA^{ANIL}_{inj,1}$ = 0.084589 m^2

$CA^{AIL}_{inj,1}$ = 1.250958 m^2

Medium Hole size :

$CA^{ANIL}_{cmd,2}$ = 28.1673 m^2

$CA^{AIL}_{cmd,2}$ = 4.62288 m^2

$CA^{ANIL}_{inj,2}$ = 28.1673 m^2

$CA^{AIL}_{inj,2}$ = 54.1889 m^2

Large Hole size :

$CA^{ANIL}_{cmd,3}$ = 651.845 m^2

$CA^{AIL}_{cmd,3}$ = 286.571 m^2

$CA^{ANIL}_{inj,3}$ = 27.1370 m^2
$CA^{AIL}_{inj,3}$ = 286.571 m^2

Rupture Hole size :

$CA^{ANIL}_{cmd,4}$ = 7978.54 m^2
$CA^{AIL}_{cmd,4}$ = 33258.3 m^2
$CA^{ANIL}_{inj,4}$ = 7777.26 m^2

$CA^{AIL}_{inj,4}$ = 7777.26 m^2

Kalkulasi AIT *blended consequence area* untuk komponen dengan menggunakan ekuasi (3.57), (3.58) API RBI 581, berdasarkan CA pada langkah 8.14.

Small Hole size :
$CA^{flam}_{cmd,1}$ = 0.08458 m^2
$CA^{flam}_{inj,1}$ = 1.25095 m^2

Medium Hole size :
$CA^{flam}_{cmd,2}$ = 28.1673 m^2
$CA^{flam}_{inj,2}$ = 54.1889 m^2

Large Hole size :
$CA^{flam}_{cmd,3}$ = 27.1370 m^2
$CA^{flam}_{inj,3}$ = 286.571 m^2

Rupture Hole size :
$CA^{flam}_{cmd,4}$ = 33258.3 m^2
$CA^{flam}_{inj,4}$ = 7777.26 m^2

Penentuan *final consequence area* untuk kerusakan komponen dan cedera pada personel dengan menggunakan ekuasi (3.59) dan (3.60).
didapatkan hasil:
CA^{flam}_{cmd} = 652.124 m^2
CA^{flam}_{inj} = 223.046 m^2

11. Consequence Analysis Toxic

Untuk setiap *release hole size* yang dipilih pada langkah 2.2, tentukan durasi effektif dari *release* dengan menggunakan ekuasi (3.67)

$$Id_n^{tox} = min\left(3600,\ \left\{\frac{mass}{W}\right\},\ \{60\ .\ Idmax, n\}\right)$$

Maka didapatkan hasil:

Small Hole Size : 3.600 m^2
Medium Hole Size : 1200 m^2
Large Hole Size : 600 m^2
Rupture Hole Size : 600 m

Dimana persentase toxic dari component.

H_2S = 1.55%
Mfrac = 0.0155

Setiap *release hole size*, dikalkulasikan *release rate*, $rate_{tpx}$, and release mass, xmassntox to be used in toxic consequence analysis

Small Hole Size : 3E-05 Kg/s
Medium Hole Size : 0.0015 Kg/s
Large Hole Size : 0.0074` Kg/s
Rupture Hole Size : 0.3715 Kg/s

Untuk setiap release hole size, dikalkulasikan *konsekuensi toxic* pada setiap release hole size, untuk HF acid dan H_2S – tentukan $CA^{tox}_{inj,n}$ dengan menggunakan ekuasi (3.63) untuk *continuous release*..

Small Hole Size : -0.5573 Kg/s
Medium Hole Size : 0.5252 Kg/s
Large Hole Size : 0.8914 Kg/s
Rupture Hole Size : 2.4189 Kg/s

Final toxic consequences area for personnel injury.

$$CA_{inj}^{tox} = \left(\frac{\sum_{n=1}^{4} gffn\ .\ CA_{inj,n}^{tox}}{gfftotal}\right)$$

$$CA_{inj}^{flam} = 0.30324\ m^2$$

12. CoA non-flam non-tox

Untuk setiap *release hole size,* dikalkulasikan non-flammable, non-toxic consequence area.

Didapatkan hasil:

Small Hole Size	:	33.8	Kg/s
Medium Hole Size	:	361	Kg/s
Large Hole Size	:	0.8914	Kg/s

Untuk setiap *release hole size*, tentukan blending factor dari instantaneous/continuous, gunakan ekuasi (3.71)

$$fact_n^{IC} = min\left[\left\{\frac{Raten}{C5}\right\},\ 1.0\right]$$

Didapatkan hasil:

Small Hole Size	:	7.73511E-05	Kg/s
Medium Hole Size	:	0.00371568	Kg/s
Large Hole Size	:	0.02	Kg/s
Rupture Hole Size	:	0.02	Kg/s

Small Hole Size	:	0	Kg/s
Medium Hole Size	:	1.35	Kg/s
Large Hole Size	:	355	Kg/s

Ca0=24.05882 m

13. **Penentuan final consequence area**

Penentuan area konsekuensi didapatkan dengan terlebih dahulu menentukan final omponent damage consequence area (CA cmd) dan personnel injury consequence area (CA imj)

Menentukan final component damage consequence area

$$CAcmd = CA_{cmd,}^{flam}$$

$CAcmd =$ 652.124

Menentukan final personnel injury consequence area

CA_{inj} = max $\left[CA_{inj}^{flam},\ CA_{inj}^{tox},\ CA_{inj}^{nfnt}\right]$

= 223m^2

Didapatkan hasil final consequence area, CA :

CA=max$\left[CA_{cmd}, CA_{inj}\right]$

= 652.1 m^2

4.3.2.3 Risk Analysis

Nilai risiko dari alat didapat dengan mengalikan PoF dan CoF. Risiko dihitung menggunakan persamaan (4.103) API RBI 581,:

$$Risk = PoF\ x\ CoF$$

Dimana :

PoF = Probabilitas kegagalan
CoF = Konsekuensi kegagalan

Penentuan tingkat risiko dilakukan dengan membandingkan nilai risiko yang didapatkan dengan *risk target.* Apabila hasil perbandingan menunjukkan bahwa risiko lebih besar dari *risk target*, maka akan dilakukan langkah mitigasi. Langkah mitigasi dapat dilakukan dengan cara melakukan inspeksi sesuai dengan jadwal dan metode yang diharapkan dapat meminimalkan nilai risiko tersebut.

Analisis risiko pada tugas akhir ini, untuk pressure vessel dilakukan perbandingan risiko pada RBI date dengan risk target. Menghitung besarnya risiko pada pressure vessel

a. Menghitung besarnya risiko pada RBI *date*

Besarnya risiko pada *pressure vessel* VS-80-001 adalah :

$$Risk = PoF\ x\ \max(CAinj, CAequip)$$
$$= 26.12641$$

Besarnya risiko pada *plan date* adalah :

$$Risk = PoF\ .\ max(CAinj, CAequip)$$
$$= 54.64667$$

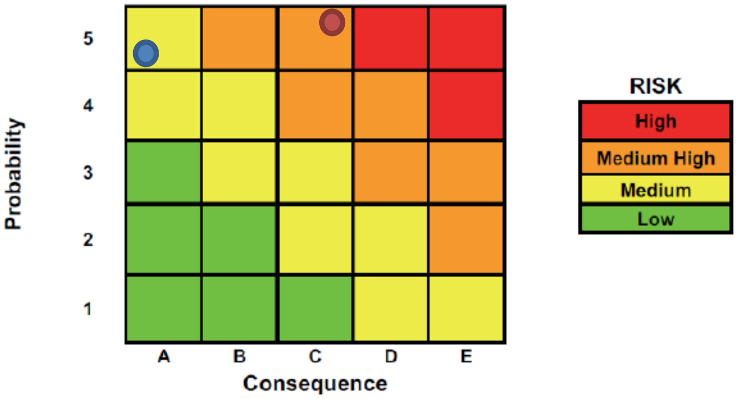
b. Tingkat risiko

Kategori tingkat risiko ditentukan dari hasil PoF dan CoF. Dengan menggunakan Tabel 4.1M API RBI 581 Annex 1, maka tingkat risiko dapat dikategorikan.

Pada pressure vessel separator VS-80-001, VS-80-002, dan VS-80-003, hasil tingkat risiko yang didapat adalah:

Probability Range	
5A – Medium	(Saat RBI Date)
5C – Medium High	(Saat Plan Date)

Berdasarkan nilai tersebut maka didapatkan matriks risikonya yang ditunjukkan oleh gambar 4.1



Gambar 4. 4 Risk Matrix untuk VS-80-002

Tingkat risiko dapat di plotting sebagai table 4.5

Tabel 4. 9 Tabel tingkat risiko untuk VS-80-002

Tanggal	Keterangan	DF	CoF (m^2)	Risk Category	Definisi
02/12/2019	RBI date	46.15	652.1	5A	Medium
02/12/2023	Plan date	112.2		5C	Medium-High
*Note: Inspection effectiveness: 2E					

4.3.2.4 Inspection plan

Penjadwalan inspeksi adalah suatu kegiatan menentukan interval waktu antar-inspeksi yang akan diterapkan pada alat. Menurut API 581 penjadwalan inspeksi untuk pressure vessel dilakukan berdasarkan hasil dari risiko yang didapatkan, namun intervalnya sendiri tidak diberikan suatu perhitungan yang pasti. API 581 menyerahkan penjadwalan inspeksi kepada perusahaan sesuai dengan batasan risiko yang dapat diterima. Karena batasan risiko yang dapat diterima pada alat tidak diketahui, untuk membantu dalam melakukan penjadwalan maka dapat mengacu pada API 510 yang membahas mengenai pressure vessel inspection code.

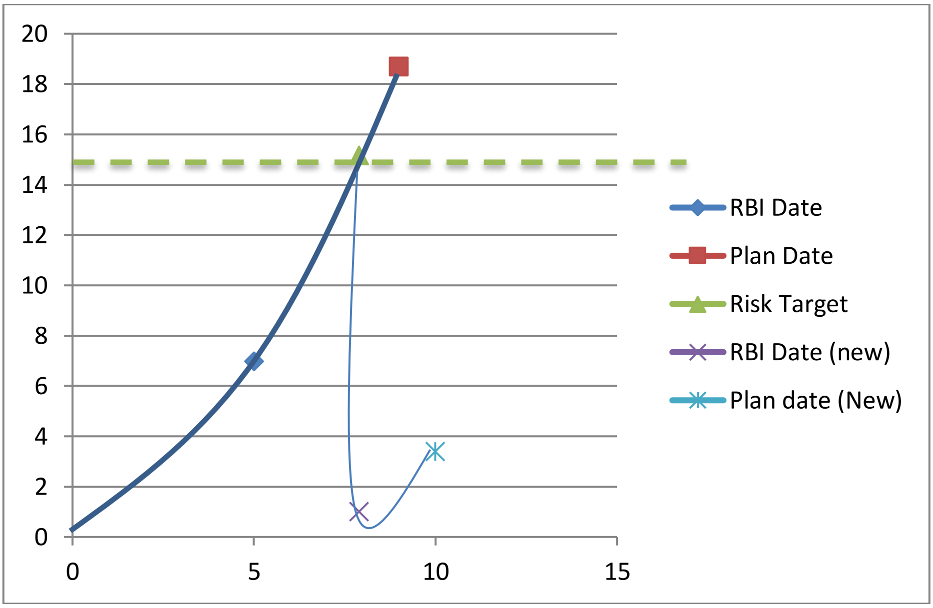
API 510 menyatakan bahwa pressure vessel harus diinspeksi internal atau on-stream maksimal setiap 10 tahun atau pada saat umur pressure vessel telah mencapai setengah dari remaining life-nya, tergantung nilai mana yang lebih rendah.
Analisis *inspection planning* dilakukan pada *pressure vessel*. Langkah-langkah dalam menentukan *inspection planning*:

2. Menghitung *target inspection date*

   Target date didapatkan dari perpotongan kurva risiko pada RBI *date* dengan kurva *risk target*.

Tabel 4. 10 Tabel kurva risiko berdasarkan Risk area (VS-80-002)

Item	Date	Time since RBI Assessment	Risk Area (m^2/yr)
RBI Date	12/02/2019	5	20.45934724
Risk Target	05/12/2019	7.89	44.33273807
Plan Date	12/02/2023	9	54.64660042



Gambar 4. 5 Grafik kurva risiko berdasarkan Risk area (VS-80-002)

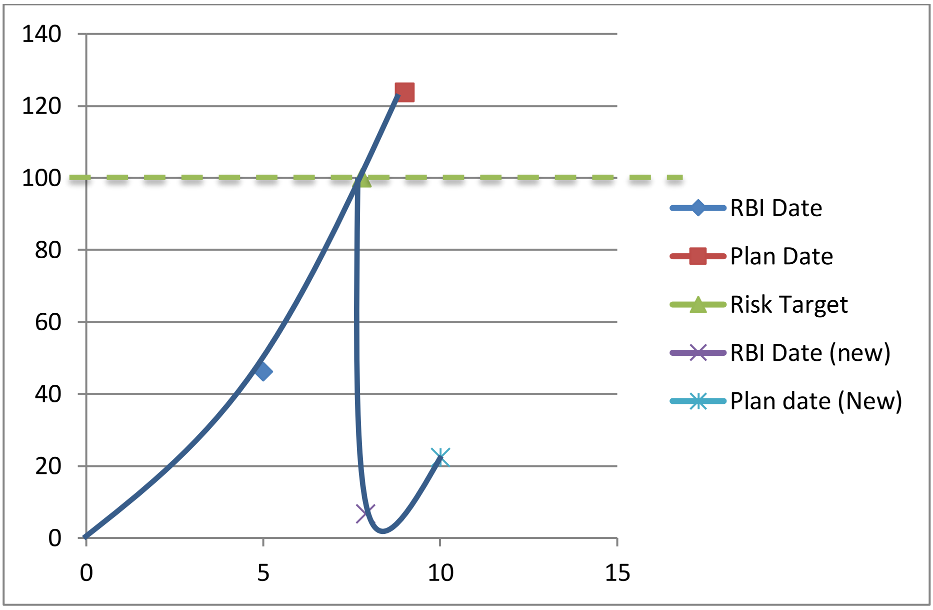
Target date = 7.89 year after Assessment
= 11/22/2018

Table 4.7 Table Kurva risiko berdasarkan damage factor

Tabel 4. 11 (Tabel kurva risiko berdasarkan Damage factor (VS-80-002)

Item	Date	Time since RBI Assessment	Damage Factor
RBI Date	12/02/2019	5	46.1495232
Risk Target	02/03/2022	7.25	100
Plan Date	12/02/2023	9	123.5288021

Target date = 7.25 Year after RBI Assessment
= 02/03/2022



Gambar 4. 6 Grafik Kurva risiko berdasarkan Damage factor

Dengan melihat hasil grafik laju risiko, dan melihat tingkatan risiko yang ada. Dapat ditentukan rekomendasi inspeksi, rekomendasi inspeksi dapat dilihat pada tabel 4.8

Tabel 4. 12 Rekomendasi Inspeksi untuk VS-80-002

Damage factor	Efektivitas inspeksi	Inspeksi intrusif	Inspeksi non-intrusif	Tanggal inspeksi
Local Thinning	C	Untuk area permukaan total: • >50% pemeriksaan visual. • 100% follow up di area local thinning.	Untuk total area yang dicurigai: > cakupan 50% dari CML menggunakan ultrasonic scanning atau profile radiography.	Dilakukan pada tanggal 02-03-2022
Sulfide Stress Cracking	E	Dilakukannya teknik inspeksi/perencana	Dilakukannya teknik inspeksi/perencana	

		an yang tidak effektif	an yang tidak effektif	
SIC/SOHIC – H_2S	E	Dilakukannya teknik inspeksi/perencanaan yang tidak effektif	Dilakukannya teknik inspeksi/perencanaan yang tidak effektif	

4.3.3 Hasil RBI analisi untuk VS-80-003

4.3.3.1 Probability of Failure

Penentuan Thinning Damage Factor

Setiap komponen perlu di periksa terhadap indicator kerusakan yang diakibatkan *ge factor* yang dapat diakibatkan oleh *general* dan *local thinning.* Untuk perhitungan selengkapnya dicantumkan pada lampiran 6.

Langkah-langkah berikut digunakan untuk menentukan damage factor untuk thinning adalah.

a. Menentukan furnished thickness dan umur dari equipment, ditentukan hasil dari furnished thickness adalah 28.85 dan umur dari equipment adalah 14 tahun.
b. Menentukan lajur korosi berdasarkan material dasar (C_{rbm}) berdasarkan material konstruksi serta lingkungan dan cladding/overlay. Berdasarkan penjelasan dari section 4.5.2 API RP 581, laju korosi dihitung dengan menggunakan pendekatan Annex 2B dari API RP 581, untuk menghitung laju korosi perlu ditentukan tipe korosi yang ada dengan menggunakan screening questions yang disediakan oleh tabel 2B.1.1. Dari screening question ditentukan bawha tipe korosi yang ada pada equipment adalah Sour water corrosion dan laju korosi yang telah disesuaikan adalah 0.287.
c. Menentukan waktu in-service,
d. Menentukan age_{rc} untuk komponen cladding/overlay, dikarenakan tidak adanya cladding, maka step ini dilewat.
e. Menentukan thickness minimum dari equipment, ada 4 metoda yang dapat digunakan untuk menentukan minimum thickness dari sebuah equipment, untuk perhitungan ini, metoda perhitungan pertama digunakan karena metoda ini digunakan komponen cylindrical, spherical, atau head. Hasil dari perhitungan didapatkan bahwa minimum thickness dari equipment adalah 25.91 mm atau 1.02” inch.
f. Menentukan parameter A_{rt}, dari perhitungan A_{rt} hasil yang didapatkan adalah 0.39820014 (calculated corrosion rate) dan 0.0013867 (berdasarkan data yang didapat).
g. Menentukan Flow stress dari equipment, dengan mengkalkulasikan Yield Strenght dan Tensile Strength, didapatkan hasil flow stress sebesar 35887

h. Menghitung parameter strength ratio dengan menggunakan equasi yang tepat, dimana didapatkan hasil 0.686
i. Menentukan jumlah inspeksi sebelumnya untuk inspection effectiveness dengan menggunakan section 4.5.6 dari API RP 581 Part 2, berdasarkan data sebelumnya, inspection effectiveness dari data yang didapat memiliki kategori E, dimana berdasarkan kategori tersebut inspeksi yang dilakukan sangat tidak effective atau tidak dilakukan inspeksi sama sekali.
j. Menentukan inspection effective factor, tiap factor harus dihitung berdasarkan scenario damage state, dengan menggunakan Table 4.5 dan tabel 4.6 dari API RP 581, didapatkan hasil $I_1^{thin}, I_2^{thin}, I_3^{thin}$ senilai 0.50, 0.30, dan 0.20
k. Menentukan parameter $\beta_1, \beta_2, dan\ \beta_3$, dan didapatkan hasil 1.5390, 1.5390, 1.53056 dan 1.51375
l. Maka didapatkan hasil damage factor sebesar 0.200745959.

1. Perhitungan Damage Factor Stress Corrosion Cracking – Sulfide Stress Cracking.

Caustic cracking didefinisikan sebagai keretakan sebuah material dibawah campuran *tensile stress* dan korosi yang di akibatkan oleh sodium hydroxide (NaOH) pada temperatur yang tinggi. Untuk menentukan *Damage Factor* SCC-SSC, dapat digunakan kalkulasi yang mengacu pada API RBI 581. Perhitungan lengkap dari SCC-SSC Df dilampirkan pada lampiran 6

Langkah-langkah berikut di gunakan untuk menentukan damage factor untuk SCC-SSC.

a. Menentukan *Enviromental Severity* untuk keretakan berdasarkan konten air dan pH dari H_2S menggunakan Tabel 8.2 (API RBI 581). Dimana pH air adalah 5.52 dan konten air sebesar 1000 ppm, dapat di tentukan bahwa *environmental severity* dari SSC adalah **Moderate.**

b. Menentukan kerentanan dari keretakan menggunakan *figure 8.1* dan tabel 8.3 (API RBI 581) berdasarkan dari *environmental severity* dari langkah 1. Berdasarkan tabel tersebut, dengan kriteria dimana *Max Brinnel Hardness* bernilai <200 dan *Enviromental Severity* berada pada *Moderate*, dan tidak adanya PWHT pada equipment, maka didapatkan hasil **Low** untuk *susceptibility to SSC-SCC.*

c. Berdasarkan dari kerentanan yang di dapatkan pada langkah ke dua, ditentukan *severity index* (S_{vi}) menggunakan tabel 8.4 (API RBI 581), dimana S_{VI} dari **Low Susceptibility**, adalah **1**.

d. Menentukan *in-service age* semenjak inspeksi level A,B, atau C terakhir dilakukan. Berdasarkan data yang di dapat, dapat ditentukan bahwa *in-service age* pada saat analisa dilakukan adalah **18 tahun.**

e. Menentukan inspeksi sebelumnya dan inspeksi yang sesuai menggunakan *Section 8.6.2* API RBI 581 Part 2 Annex 1. Berdasarkan data yang didapat, ada 2 inspeksi yang telah dilakukan sebelum analisa ini dilakukan dengan kategori efektif yakni E, dimana hasil inspeksi tersebut bersifat ***Ineffective.***

f. Menentukan basis *damage factor* untuk *sulfide stress cracking*, menggunakan tabel 6.3 API RBI 581 Annex 2. Penentuan *damage factor* untuk SCC dapat ditentukan dengan *inspection effectiveness* tertinggi dan jumlahnya, dimana berdasarkan langkah sebelumnya, didapat bahwa kategori dari inspeksi sebelumnya adalah E dan memiliki *severity index* sebesar 1. *Base damage factor* yang di dapat adalah **1**

g. Langkah terakhir ini dilakukan untuk menentukan *Damage Factor* dari *Stress Caustic Cracking – Sulfide Stress Cracking*, dimana untuk menentukan *Df* tersebut, dapat menggunakan equasi 2.27 API RBI 581. Dimana hasil yang di dapatkan untuk :

RBI Date

$$D_f^{SCC} = 5.8730947$$

RBI Plan Date:

$$D_f^{SCC} = 13.980798$$

2. Perhitungan Damage Factor Stress Corrosion Cracking – HIC/SOHIC-H_2S.

HIC didefinisikan sebagai keretakan internal yang berdekatan dengan hydrogen blister di tingkatan yang berbeda pada metal, atau permukaan metal. Untuk menentukan *Damage Factor* HIC/SOHIC-H_2S, digunakan kalkulasi yang mengacu pada API RBI 581. Perhitungan lengkap dari HIC/SOHIC-H_2S Df dilampirkan pada lampiran 6

Langkah-langkah berikut digunakan untuk menentukan damage factor untuk HIC/SOHIC-H_2S

a. Menentukan *Enviromental Severity* untuk keretakan berdasarkan konten air dan pH dari H_2S menggunakan Tabel 8.2 (API 581). Dimana pH air adalah 5.52 dan konten air sebesar 1000 ppm, dapat di tentukan bahwa *environmental severity* dari HIC/SOHIC-H_2S adalah **Moderate.**

b. Menentukan kerentanan dari keretakan menggunakan *figure 8.1* dan tabel 9.3 (API RBI 581) berdasarkan dari *environmental severity* dari langkah 1, dengan kriteria dimana *Max Brinnel Hardness* bernilai <200 dan *Enviromental Severity* berada pada *Moderate*, dan tidak adanya PWHT pada equipment, maka didapatkan hasil **Low** untuk *susceptibility to SSC-SCC.*

c. Berdasarkan dari kerentanan yang di dapatkan pada langkah ke dua, ditentukan *severity index* (S_{vi}) menggunakan tabel 9.4 (API RBI 581), dengan S_{VI} dari **Low Susceptibility**, adalah **1**.

d. Menentukan *in-service age* semenjak inspeksi level A,B, atau C terakhir dilakukan. Berdasarkan data yang di dapat, dapat ditentukan bahwa *in-service age* pada saat analisa dilakukan adalah **18 tahun.**

e. Menentukan inspeksi sebelumnya dan inspeksi yang sesuai menggunakan *Section 8.6.2* API RBI 581 Part 2 Annex 1. Berdasarkan data yang didapat, ada 2 inspeksi yang telah dilakukan sebelum analisa ini dilakukan dengan kategori efektif yakni E, dimana hasil inspeksi tersebut bersifat ***Ineffective.***

f. Menentukan basis *damage factor* untuk *sulfide stress cracking*, menggunakan tabel 6.3 API RBI 581 Annex 2. Penentuan *damage factor* untuk HIC/SOHIC dapat ditentukan dengan *inspection effectiveness* tertinggi dan jumlahnya, dimana berdasarkan langkah sebelumnya, didapat bahwa kategori dari inspeksi sebelumnya adalah E dan memiliki *severity index* sebesar 1. *Base damage factor* yang di dapat adalah **1**

g. Menentukan *On-line adjustment factor* dengan menggunakan tabel 9.5 (API 581)

h. Menghitung *Df* akhir dengan memperkirakan kenaikan *Df* berdasarkan *in-service age* sejak inspeksi terakhir. Di asumsikan bahwa probabilitas untuk keretakan akan meningkat dengan waktu semenjak inspeksi terakhir akibat hasil dari peningkatan eksposur akibat kondisi normal ataupun tidak normal. Hasil akhir *Df* dapat dikalkulasikan sebagai berikut:

Damage Factor at RBI Date

$$D_f^{HIC\,SOHIC-H2S} = \frac{D_{fB}^{HIC\,SOHIC-H2S}.(Max[age,1.0])^{1.1}}{Fom}$$

$$D_f^{HIC\,SOHIC-H2S} = \frac{1.(Max[4,1.0])^{1.1}}{2}$$

$$D_f^{HIC\,SOHIC-H2S} = 4.594793$$

Damage Factor at RBI Plan Date

$$D_f^{HIC\,SOHIC-H2S} = \frac{D_{fB}^{HIC\,SOHIC-H2S}.(Max[age,1.0])^{1.1}}{Fom}$$

$$D_f^{HIC\,SOHIC-H2S} = \frac{1.(Max[9,1.0])^{1.1}}{2}$$

$$D_f^{HIC\,SOHIC-H2S} = 11.21158$$

3. Perhitungan General Failure Frequency (gff).

Untuk menentukan *General Failure Frequency* dapat mengacu pada Table 3.1 dari API RBI 581 yang berisi list rekomendasi *gff* untuk equipment yang di analisa. Perhitungan gff dilampirkan pada lampiran 6.

Tabel 4. 13 Suggested Component Generic Failure Frequencies

Equipment Type	Component Type	*gff* as a function of hole size (failures/yr)				*gff_{total}* (failures/yr)
		Small	Medium	Large	Rupture	
Vessel/FinFan	KODRUM, COLBTM,	8.00E-06	2.00E-05	2.00E-05	6.00E-07	3.06E-05

	FINFAN, FILTER DRUM, REACTOR, COLTOP, COLMID,					

Dari tabel tersebut, dapat ditentukan bahwa *gfftotal* memiliki nilai 3.06E-05

4. Perhitungan Management System Factor (Fms).

Menentukan faktor *Fms* dapat menggunakan evaluasi majemen sistem yang disediakan pada *Part 2, Annex 2.A* RBI 581. Perhitungan fms dilampirkan pada lampiran 4.

Setelah mendapat percentage dari score, nilai *Fms* dapat dihitung dengan menggunakan rumus:

$$Fms = \ 10^{(-0;02.pscore+1)}$$

Maka didapat nilai *Fms* bernilai 0.182390.

Perhitungan *Probabiliy of Failure*

Setelah mendapatkan hasil *Df,gff,* dan *Fms*. Maka perhitungan PoF dilakukan dengan menggunakan rumus,

$$Pf\ (t) = gff\ .\ Fms\ .Df\ (t)$$

Dari rumus tersebut dapat dikalkulasikan bahwa PoF bernilai:

$$Pf\ (t)\ =\ gff\ .\ Fms\ .\ D\ f\ (t)$$

$$Pf\ (t)\ = 0.0124(RBI\ Date)$$

$$Pf\ (t)\ = 0.0837(RBI\ Plan\ Date)$$

Perhitungan dari probability of failure di lampirkan pada lampiran 4

4.3.3.2 Consequence of Failure

Consequence of Failure digunakan untuk menganalisa konsekuensi dari kegagalan sebuah equipment bertekanan yang berkemungkinan untuk menimbulkan kerusakan untuk equipment, loss dari produksi atau jalannya sistem, pencemaran, dan menimbulkan cedera fatal pada personel. Analisa CoF dapat dihitung sebagai konsekuensi area atau financial. Dalam API RBI 581, analisa konsekuense dibagi menjadi dua level, yakni *Level 1 Consequence of Failure,* dan *Level 2 Consequence* *of Failure*. Dalam analisa ini, perhitungan konsekuensi yang digunakan adalah perhitungan konsekuensi level 1. Perhitugan selengkapnya dari analisa konesekuense kegagalan dilampirkan pada lampiran 6.

Dalam beberapa tahap yang perlu dilakukan untuk melakukan analisa konsekuensi pada RBI, langkah langkah tersebut adalah sebagai berikut

1. Penentuan Fluida Representatif

Representative Liquid yang digunakan adalah H_2S atau Hydrogen Sulfide, dengan *properties*:

Liquid Density	:	993.033 Kg/m^3
NBP	:	-59.4 C°
Auto-Ignition temperature	:	500 F° / 260 C°

Dalam tabel 4.3 API RBI 581 Annex 3, dapat ditentukan bahwa fase liquid saat tersimpan adalah Liquid namun setelah terlepas adalah Gas.

2. Pemilihan Release Hole Size

Pemilihan release hole size didasarkan pada jenis peralatan. Pemilihan set ukuran lubang saat *release* untuk menentukan kemungkinan range dari konsekuensi yang dihasilkan. Untuk menentukan set ukuran lubang mengacu pada API RBI 581 Annex 3 Part 1, Tabel 4.4.

Tabel 4. 14 Release Hole Sizes and Areas Used in Level 1 and 2 Consequence Analysis

Release Hole Number.	Release Hole Size.	Range of Hole Diameters (inch).	Release Hole Diameters, d_n, (inch).
1	Small	1 – ¼	$d_1 = 0.25$
2	Medium	>¼ - 2	$d_1 = 1$
3	Large	>2 – 6	$d_1 = 4$
4	Rupture	>6	$d_1 = \min [D,16]$

3. Perhitungan Release Rate

Selanjutnya dihitung *theoretical release rate* dari scenario *release hole size (An)* yang sudah ditentukan pada langkah ke dua. Pada langkah ini, *release hole size* perlu di hitung menggunakan ekuasi 3.8.

$$An = \frac{\pi d_n^2}{4}$$

Dengan ekuasi tersebut didapatkan hasil:

Small Hole Size	:	3.00E-05	m^2
Medium Hole Size	:	5.00E-04	m^2
Large Hole Size	:	0.008	m^2
Rupture Hole Size	:	0.13	m^2

Setelah mendapatkan *release hole size* dari tiap scenario, langkah berikutnya adalah untuk menghitung *release rate* (W_n). didapatkan hasil *release rate* sebagai berikut:

Small Hole Size : 0.001949 Kg/s
Medium Hole Size : 0.093635 Kg/s
Large Hole Size : 0.478570 Kg/s
Rupture Hole Size : 23.96435 Kg/s

4. **Langkah ke empat adalah mengestimasikan masa maksimum yang ada saat release.**

Untuk menghitung masa yang ada atau *available mass* ($Mass_{avail}$), *group component* dan *equipment items* dari *inventory group* harus ditentukan terlebih dahulu, untuk menentukan *inventory groups*, dapat merujuk pada API RBI 581 Annex 3 Part 3, Tabel 3.A.3.2. Dapat disimpulkan bahwa equipment yang dianalisa memiliki *Default liquid volume percent* sebanyak 50% liquid.

Untuk penentuan massa komponen ($mass_{comp}$) diperlukan perhitungan massa fluida. massa fluida dihitung dengan rumus volume dari equipment yang dianalisa

$$Vcyl = \pi R^2 L$$
$$Vcyl = \pi.1.067.10{,}5$$
$$Vcyl = 37.5 \text{ m}^3$$

Untuk volume liquid dan volume vapour:

Liquid Volume: $\left(\frac{50}{100}\right) x\ Vcyl$ $= 18{,}75 \text{ m}^3$

Vapour Volume: $(1 - \left(\frac{50}{100}\right) x\ Vcyl)$ $= 18{,}75 \text{ m}^3$

Untuk massa komponen:

$$Mass_{comp} = (V_l\, \rho_l) + (V_v\, \rho_v)$$
$$Mass_{comp} = 18728\ Kg$$

Maka didapatkan massa inventory ($mass_{inv}$)

$$Mass_{inv} = \sum_{i=1}^{N} Masscomp$$
$$Mass_{inv} = 18639.3 \text{ Kg}$$

Perhitungan *flow rate* perlu dilakukan dengan cara meengkalkulasikan *flow rate* dari simulasi lubang dengan diameter 203mm (8 inch) dengan menggunakan ekuasi (3.3), (3.6), (3.7) API 581 Annex 3 sesuai dengan kebutuhan dengan $A_n = A_8 = 32{,}450 \text{ mm}^2$ ($50{,}3 \text{ inch}^2$).

$$W_{max.8} = \frac{Cd}{C2} \,.\, A8 \,.\, Ps \sqrt{\left(\frac{k \,.\, MW \,.\, gc}{R \,.\, Ts}\right)} \left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}$$

$$W_{max.8} = \frac{0.90}{1} \, . \, 32{,}450 \, . \, 1060 \sqrt{\left(\frac{1.27 \, . \, 34 \, . \, 1}{8.314 \, . \, 453.15}\right)} \left(\frac{2}{1.27+1}\right)^{\frac{1.27+1}{1.27-1}}$$

$$W_{max.8} = 0.221285458 \;\; Kg$$

Untuk setiap *hole size*, dikalkulasi massa fluida yang di tambah ($mass_{add,n}$). dihasilkan 3 menit *flow* berasal dari *inventory group* menggunakan ekuasi (3.10) API RBI 581, dimana W_n adalah lajur release dari tiap hole size.

$$Mass_{add,n} = 180 \, . \, \text{Min} \, [W_n \, , \, W_{max,8}]$$

Maka didapatkan hasil W_n

Small Hole Size : 0.3508 Kg/s
Medium Hole Size : 16,85 Kg/s
Large Hole Size : 84.17 Kg/s
Rupture Hole Size : 84.17 Kg/s

5 Penentuan Release Type.

Release type (*continuous/instantaneous*) untuk menentukan metoda yang akan digunakan untuk pemodelan *dispersion* dan *consequence*

a.Untuk setiap *hole size*, ditentukan waktu yang dibutuhkan untuk melepaskan 4536 Kg Liquid. Dengan menggunakan ekuasi:

$$tn = \frac{C3}{Wn}$$

Di dapatkan hasil t_n:

Small Hole Size : 2327052 s
Medium Hole Size : 48443.38 s
Large Hole Size : 9478.23 s
Rupture Hole Size : 189.27 s

b. Ditentukan *release type* apakah *continuous* atau *instantaneous* dengan menggunakan kriteria sebagai berikut:

- If the release hole size is 6.35 mm (0.25 inch) or less, then the release type is automatically continuous.
- If tn≤180 sec and the release mass is greater than 4536 kgs (10000 lbs.),then the release is instantaneous; otherwise, the release is continuous.

Dengan kriteria tersebut dapat di tentukan bahwa:

Small Hole Size : d_1 = 0.25 inch
t_1 = 2.33E+06 s
Continuous
Medium Hole Size: d_2 = 1 inch
t_2 = 48443.38 s
Continuous
Large Hole Size: d_3 = 4 inch

t_3 = 9478.235 s

Continuous

Rupture Hole Size: d_4 = 16 inch

t_4 = 189.2789 s

Continuous

6 Estimasi impact dari sistem deteksi serta isolasi pada magnitude release.

Menetapkan sistem deteksi dan isolasi yang ada pada unit, dengan menggunakan tabel 4.5 API RBI 581 Annex 3. Dimana klasifikasi yang dipilih adalah :

Detection System Classification: **C**
Isolation System Classification: **C**

Dengan menggunakan Tabel 4.6 API RBI 581, dan klasifikasi dari langkah 6.2 dan 6.3, ditentukan *release reduction factor* pada equipment.

$fact_{di}$: 0.00 (No adjustment to release rate or mass)

Dengan menggunakan tabel 4.7 dan klasifikasi yang telah ditetapkan pada langkah sebelumnya, ditentukan *total leak duration* pada setiap *release hole size,* $\boldsymbol{Id}_{max,n}$.

Detection System : **C**
Isolation System : **C**
$Id_{max,1}$: 60 Minutes
$Id_{max.2}$: 40 Minutes
$Id_{max,3}$: 20 Minutes

7 Penentuan release rate dan massa untuk analisa konsekuensi.

Untuk setiap release hole size, dikalkulasi *adjusted release rate¸*$rate_n$ dengan menggunakan ekuasi (3.13) API RBI 581.

$$rate\ n = Wn\,(1 - factdi)$$

Small Hole Size : 0.00195 Kg/s
Medium Hole Size : 0.09364 Kg/s
Large Hole Size : 0.47857 Kg/s
Rupture Hole Size : 23.9646 Kg/s

Untuk setiap hole size, ditentukan *leak duration,* Id_n dari release menggunakan ekuasi 3.15 API RBI Annex.

$$Idn = min\left[\left\{\frac{massavailn}{raten}\right\},\ \{60.idmax,n\}\right]$$

Small Hole Size : 3600 s
Medium Hole Size : 1200 s
Large Hole Size : 600 s
Rupture Hole Size : 600 s

Untuk setiap hole size, dikalkulasi *release mass*, $mass_n$, menggunakna ekuasi (3.14) berdasarkan *release rate¸*$rate_n$, dengan hasil dari langkah 3.2, Id_n dari langkah 7.2, dan *available mass*, $mass_{avail}$, dari langkah 4.6

$$mass_n = \min[\{rate_n \, . \, idn\}, \, massav_{ailn}]$$

Small Hole Size	:	7.017	Kg/s
Medium Hole Size	:	112.362	Kg/s
Large Hole Size	:	287.142	Kg/s
Rupture Hole Size	:	14378.8	Kg/s

8 Penentuan konsekuensi flammable dan explosive pada equipment.

Langkah pertama dalam kalkulasi *flammable and explosive consequence analysis* adalah memilih reduction factor untuk mitigasi konsekuensi area Faktor mitigasi dapat ditentukan dengan menggunakan tabel 4.10 (API 581), dikarenakan tidak ada rujukan yang mencukupi dari data yang ada, mitigation system tidak dapat ditentukan, sehingga;

$Fact_{mit} = 0$

Untuk setiap release hole size, ditentukan koreksi dari effisiensi energy, atau en_{eff}. Dengan menggunakan ekuasi 3.18.

$$eneff_1 = 4. log_{10}[C_4. \, mass_1] - 15$$

Dengan ekuasi tersebut didapatkan hasil:

Small Hole Size	:	1.758311	Kg/s
Medium Hole Size	:	6.576113	Kg/s
Large Hole Size	:	8.206021	Kg/s
Rupture Hole Size	:	15.00452	Kg/s

Selanjutnya ditentukan tipe fluida, berdasar table 4.1 API RBI 581, Annex 3. Didapatkan hasil :

Representative Fluid	:	***H_2S***
Fluid type	:	***Type 0***

Untuk setiap *release hole size¸*dikalkulasi konsekuensi area untuk kerusakan komponen.

Dengan menggunakan table 4.8 API RBI 581 Annex 3, dapat di tentukan konstanta *a* dan *b*, dimana konstanta tersebut bernilai:

$a = 32.0$ $\qquad b = 1.00$

Dengan menggunakan ekuasi (3.31) didapatkan hasil:

$$CA_{cmd,n}^{AINL-CONT} = a\,(rate)^b \,.\, (1 \, - factmil\,)$$

Small Hole Size	:	0.062	m^2
Medium Hole Size	:	2.996	m^2
Large Hole Size	:	15.31	m^2

Rupture Hole Size	:	766.9	m

Untuk setiap *release hole size*, dilakukan perhitungan untuk konsekuensi area dari kerusakan komponen untuk *Auto-ignition Likely Continuous Release (AIL-CONT).*

Dengan merujuk pada tabel 4.8 API RBI 581 Annex 3, dapat di tentukan konstanta *a* dan *b*, dimana konstanta tersebut bernilai

a= 203.0 *b= 0.89*

Dengan ekuasi (3.33) API RBI 581 Annex 3, dapat ditentukan hasil perhitungan Consequence Area:

Small Hole Size	:	0.7861	m^2
Medium Hole Size	:	24.665	m^2
Large Hole Size	:	105.35	m^2
Rupture Hole Size	:	3430.2	m^2

Untuk setiap *release hole size,* dilakukan perhitungan untuk konsekuensi area dari kerusakan komponen untuk *Auto-ignition Not-Likely Continuous Release (AINL-CONT)*

Dengan merujuk pada tabel 4.8 API RBI 581 Annex 3, dapat ditentukan konstanta *a* dan *b*, dimana konstanta tersebut bernilai

a= 148.0 *b= 0.63*

Dengan ekuasi (3.33) API RBI 581 Annex 3, dapat ditentukan hasil perhitungan Consequence Area:

Small Hole Size	:	287.25	m^2
Medium Hole Size	:	440.74	m^2
Large Hole Size	:	637.87	m^2
Rupture Hole Size	:	4105.9	m

Untuk setiap *release hole size*, dilakukan perhitungan untuk konsekuensi area dari kerusakan komponen untuk Auto-ignition Likely, Instantaneous Release (AIL-INST)

Dengan merujuk pada tabel 4.8 API RBI 581 Annex 3, dapat ditentukan konstanta *a* dan *b*, dimana konstanta tersebut bernilai

a= 357.0 *b= 0.61*

Dengan ekuasi (3.33) API RBI 581 Annex 3, dapat ditentukan hasil perhitungan Consequence Area:

Small Hole Size	:	666.4	m^2
Medium Hole Size	:	967.34	m^2

Large Hole Size : 1374 m^2
Rupture Hole Size : 8178.2 m

Untuk setiap *release hole size*, dilakukan perhitungan untuk konsekuensi area dari kerusakan komponen untuk Auto-ignition Not Likely, Continuous Release (AINL-CONT),

Dengan merujuk pada tabel 4.8 API RBI 581 Annex 3, dapat ditentukan konstanta *a* dan *b*, dimana konstanta tersebut bernilai

a= 52.0 *b= 1.00*

Dengan ekuasi (3.33) API RBI 581 Annex 3, dapat ditentukan hasil perhitungan Consequence Area:

Small Hole Size : 0.101 m^2
Medium Hole Size : 4.869 m^2
Large Hole Size : 24.89 m^2

Untuk setiap *release hole size*, dilakukan perhitungan untuk konsekuensi area dari kerusakan komponen untuk Auto-ignition Likely, Continuous Release (AIL-CONT)

Dengan merujuk pada tabel 4.8 API RBI 581 Annex 3, dapat ditentukan konstanta *a* dan *b*, dimana konstanta tersebut bernilai

a= 375.0 *b= 0.94*

Dengan ekuasi (3.33) API RBI 581 Annex 3, dapat ditentukan hasil perhitungan Consequence Area:

Small Hole Size : 1.063 m^2
Medium Hole Size : 40.47 m^2
Large Hole Size : 187.6 m^2

Untuk setiap *release hole size*, dilakukan perhitungan untuk konsekuensi area dari kerusakan komponen untuk Auto-ignition Not Likely, Instantaneous Release (AINL-INST)

Dengan merujuk pada tabel 4.8 API RBI 581 Annex 3, dapat ditentukan konstanta *a* dan *b*, dimana konstanta tersebut bernilai

a= 203.0 *b= 0.89*

Dengan ekuasi (3.33) API RBI 581 Annex 3, dapat ditentukan hasil perhitungan Consequence Area:

Small Hole Size : 527.72 m^2
Medium Hole Size : 440.74 m^2

Large Hole Size : 637.87 m^2

Untuk setiap *release hole size*, dilakukan perhitungan untuk konsekuensi area dari kerusakan komponen untuk Auto-ignition Likely, Instantaneous Release (AIL-INST)

Dengan merujuk pada tabel 4.8 API RBI 581 Annex 3, dapat ditentukan konstanta *a* dan *b*, dimana konstanta tersebut bernilai

$a = 1253.0$ $b = 0.63$

Dengan ekuasi (3.33) API RBI 581 Annex 3, dapat ditentukan hasil perhitungan Consequence Area:

Small Hole Size : 2431.9 m^2
Medium Hole Size : 3731.4 m^2
Large Hole Size : 5400.3 m^2
Rupture Hole Size : 34761 m

Untuk setiap *release hole size*, dikalkulasi konsekuensi area Instantaneous/Continuous dengan menggunakan ekuasi (3.19), (3.20) atau (3.26).

AIT *Blending factor, factAIT,* dikalkulasi menggunakan ekuasi (3.24), (3.25) atau (3.21).

$$Fact^{AIT} = 0 \qquad for\, Ts + C_6 \leq AIT$$

$$Fact^{AIT} = \frac{(Ts - AIT - C6)}{2.C6} \qquad for\, Ts + C_6 > AIT > Ts - C_6$$

$$Fact^{AIT} = 1 \qquad for\, Ts - C_6 \geq AIT$$

maka di dapatkan hasil:

AIT = 0

Perhitungan konsekuensi lengkung instan kontinu untuk komponen menggunakan persamaan (3.65) hingga (3.68) berdasarkan area konsekuensi yang dihitung dalam langkah 8.4, 8.5, 8.6, 8.7, 8.8, 8.9, 8.10, dan 8.11. dan faktor pencampuran kontinyu / instan.

Dengan menggunakan ekuasi (3.65) sampai dengan (3.68) di dapatkan hasil:

Small Hole size :

$CA^{ANIL}_{cmd,1}$ = 0.837585 m^2

$CA^{AIL}_{cmd,1}$ = 666.3495 m^2

$CA_{inj,1}^{ANIL}$ = 0.084589 m^2
$CA_{inj,1}^{AIL}$ = 1.250958 m^2

Medium Hole size :

$CA_{cmd,2}^{ANIL}$ = 28.1673 m^2
$CA_{cmd,2}^{AIL}$ = 4.62288 m^2
$CA_{inj,2}^{ANIL}$ = 28.1673 m^2
$CA_{inj,2}^{AIL}$ = 54.1889 m^2

Large Hole size :

$CA_{cmd,3}^{ANIL}$ = 651.845 m^2
$CA_{cmd,3}^{AIL}$ = 286.571 m^2
$CA_{inj,3}^{ANIL}$ = 27.1370 m^2
$CA_{inj,3}^{AIL}$ = 286.571 m^2

Rupture Hole size :

$CA_{cmd,4}^{ANIL}$ = 7978.54 m^2
$CA_{cmd,4}^{AIL}$ = 33258.3 m^2
$CA_{inj,4}^{ANIL}$ = 7777.26 m^2

$CA_{inj,4}^{AIL}$ = 7777.26m^2

Kalkulasi AIT *blended consequence area* untuk komponen dengan menggunakan ekuasi (3.57), (3.58) API RBI 581, berdasarkan CA pada langkah 8.14.

Small Hole size :
$CA_{cmd,1}^{flam}$ = 0.08458 m^2
$CA_{inj,1}^{flam}$ = 1.25095 m^2

Medium Hole size :
$CA_{cmd,2}^{flam}$ = 28.1673 m^2
$CA_{inj,2}^{flam}$ = 54.1889 m^2

Large Hole size :

$CA^{flam}_{cmd,3}$ = 27.1370 m^2
$CA^{flam}_{inj,3}$ = 286.571 m^2

Rupture Hole size :
$CA^{flam}_{cmd,4}$ = 33258.3 m^2
$CA^{flam}_{inj,4}$ = 7777.26 m^2

Penentuan *final consequence area* untuk kerusakan komponen dan cedera pada personel dengan menggunakan ekuasi (3.59) dan (3.60).
didapatkan hasil:
CA^{flam}_{cmd} = 652.124 m^2
CA^{flam}_{inj} = 223.046 m^2

9 Consequence Analysis Toxic

Untuk setiap *release hole size* yang dipilih pada langkah 2.2, tentukan durasi effektif dari *release* dengan menggunakan ekuasi (3.67)

$$Id^{tox}_{n} = min\left(3600,\ \left\{\frac{mass}{W}\right\},\ \{60\ .\ Idmax, n\}\right)$$

Maka didapatkan hasil:
Small Hole Size : 3.600 m^2
Medium Hole Size : 1200 m^2
Large Hole Size : 600 m^2
Rupture Hole Size : 600 m

Dimana persentase toxic dari component.
H_2S = 1.55%
Mfrac = 0.0155

Setiap *release hole size*, dikalkulasikan *release rate*, $rate_{tpx}$, and release mass, xmassntox to be used in toxic consequence analysis

Small Hole Size : 3E-05 Kg/s
Medium Hole Size : 0.0015 Kg/s
Large Hole Size : 0.0074` Kg/s
Rupture Hole Size : 0.3715 Kg/s

Untuk setiap release hole size, dikalkulasikan *konsekuensi toxic* pada setiap release hole size, untuk HF acid dan H_2S – tentukan $CA^{tox}_{inj,n}$ dengan menggunakan ekuasi (3.63) untuk *continuous release*..

Small Hole Size : -0.5573 Kg/s
Medium Hole Size : 0.5252 Kg/s
Large Hole Size : 0.8914 Kg/s
Rupture Hole Size : 2.4189 Kg/s

Final toxic consequences area for personnel injury.

$$CA_{inj}^{tox} = \left(\frac{\sum_{n=1}^{4} gffn \, . \, CA_{inj,n}^{tox}}{gfftotal}\right)$$

$$CA_{inj}^{flam} = 0.30324 \text{ m}^2$$

10 CoA non-flam non-tox

Untuk setiap *release hole size*, dikalkulasikan non-flammable, non-toxic consequence area.

Didapatkan hasil:

Small Hole Size : 33.8 Kg/s
Medium Hole Size : 361 Kg/s
Large Hole Size : 0.8914 Kg/s

Untuk setiap *release hole size*, tentukan blending factor dari instantaneous/continuous, gunakan ekuasi (3.71)

$$fact_n^{IC} = min\left[\left\{\frac{Raten}{C5}\right\},\ 1.0\right]$$

Didapatkan hasil:

Small Hole Size : 7.73511E-05 Kg/s
Medium Hole Size : 0.00371568 Kg/s
Large Hole Size : 0.02 Kg/s
Rupture Hole Size : 0.02 Kg/s

S

Small Hole Size : 0 Kg/s
Medium Hole Size : 1.35 Kg/s
Large Hole Size : 355 Kg/s

Ca0=24.05882 m

11 Penentuan final consequence area

Penentuan area konsekuensi didapatkan dengan terlebih dahulu menentukan final omponent damage consequence area (CA cmd) dan personnel injury consequence area (CA imj)

Menentukan final component damage consequence area

$$CAcmd = CA_{cmd,}^{flam}$$

$$CAcmd = 652.124$$

Menentukan final personnel injury consequence area
$CA_{inj} = max\left[CA_{inj}^{flam},\ CA_{inj}^{tox},\ CA_{inj}^{nfnt}\right]$
= 223m^2

Didapatkan hasil final consequence area, CA :
$CA=max\left[CA_{cmd}, CA_{inj}\right]$
= 652.1 m^2

4.3.3.3 Risk Analysis

Nilai risiko dari alat didapat dengan mengalikan PoF dan CoF. Risiko dihitung menggunakan persamaan (4.103) API RBI 581,:

$$Risk = PoF\ x\ CoF$$

Dimana :
PoF = Probabilitas kegagalan
CoF = Konsekuensi kegagalan

Penentuan tingkat risiko dilakukan dengan membandingkan nilai risiko yang didapatkan dengan *risk target.* Apabila hasil perbandingan menunjukkan bahwa risiko lebih besar dari *risk target*, maka akan dilakukan langkah mitigasi. Langkah mitigasi dapat dilakukan dengan cara melakukan inspeksi sesuai dengan jadwal dan metode yang diharapkan dapat meminimalkan nilai risiko tersebut.

Analisis risiko pada tugas akhir ini, untuk pressure vessel dilakukan perbandingan risiko pada RBI date dengan risk target. Menghitung besarnya risiko pada pressure vessel

a. Menghitung besarnya risiko pada RBI *date*

Besarnya risiko pada *pressure vessel* VS-80-001 adalah :

$$Risk = PoF\ x\ \max(CAinj, CAequip)$$
$$= 26.12641$$

Besarnya risiko pada *plan date* adalah :

$$Risk = PoF\ .\ max(CAinj, CAequip)$$
$$= 54.64667$$

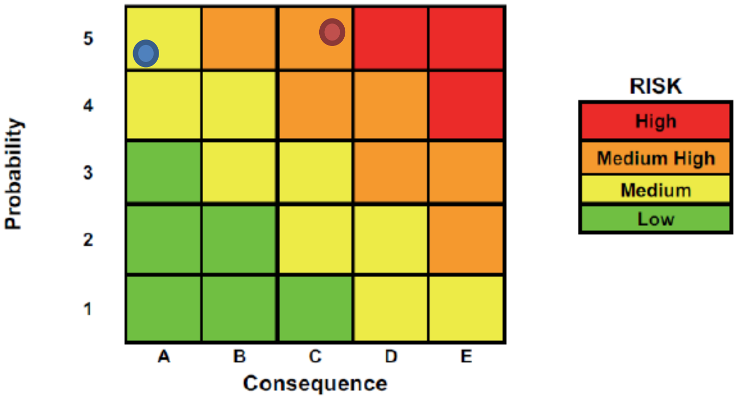
b. Tingkat risiko

Kategori tingkat risiko ditentukan dari hasil PoF dan CoF. Dengan menggunakan Tabel 4.1M API RBI 581 Annex 1, maka tingkat risiko dapat dikategorikan.

Pada pressure vessel separator VS-80-001, VS-80-002, dan VS-80-003, hasil tingkat risiko yang didapat adalah:

Probability Range
5A – Medium (Saat RBI Date)
5D – High (Saat Plan Date)

Berdasarkan nilai tersebut maka didapatkan matriks risikonya yang ditunjukkan oleh gambar 4.7



Gambar 4. 7 Risk Matrix untuk VS-80-003

Tingkat risiko dapat di plotting sebagai table 4.15

Tabel 4. 15 Tabel Tingkat Risiko VS-80-003

Tanggal	Keterangan	DF	CoF (m^2)	Risk Category	Definisi
02/12/2019	RBI date	46.15	652.1	5A	Medium
02/12/2023	Plan date	112.2		5C	Medium-High
*Note: Inspection effectiveness: 2E					

4.3.3.4 Inspection plan

Penjadwalan inspeksi adalah suatu kegiatan menentukan interval waktu antar-inspeksi yang akan diterapkan pada alat. Menurut API 581 penjadwalan inspeksi untuk pressure vessel dilakukan berdasarkan hasil dari risiko yang didapatkan, namun intervalnya sendiri tidak diberikan suatu perhitungan yang pasti. API 581 menyerahkan penjadwalan inspeksi kepada perusahaan sesuai dengan batasan risiko yang dapat diterima. Karena batasan risiko yang dapat diterima pada alat tidak diketahui, untuk membantu dalam melakukan penjadwalan maka dapat mengacu pada API 510 yang membahas mengenai pressure vessel inspection code.

API 510 menyatakan bahwa pressure vessel harus diinspeksi internal atau on-stream maksimal setiap 10 tahun atau pada saat umur pressure vessel telah mencapai setengah dari remaining life-nya, tergantung nilai mana yang lebih rendah.

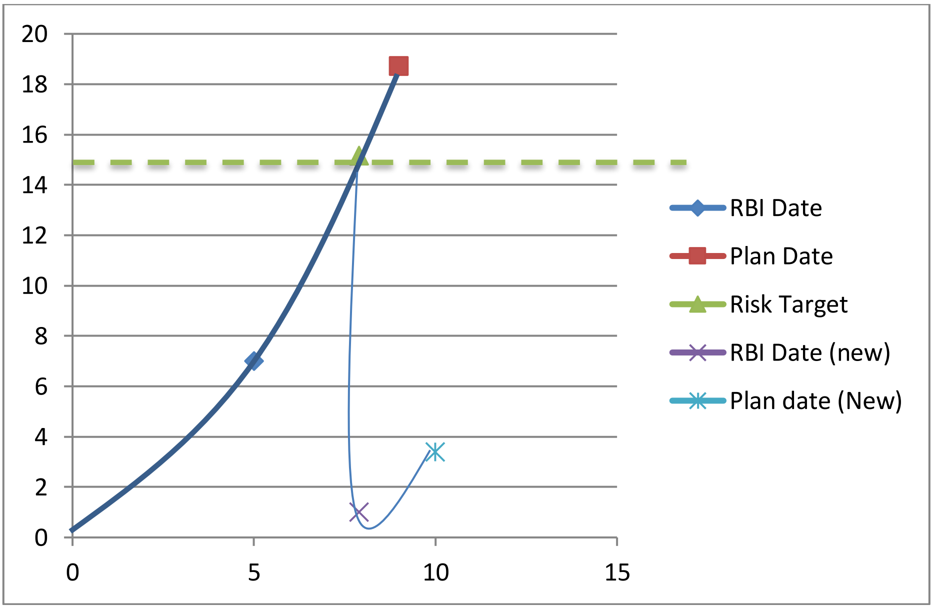
Analisis *inspection planning* dilakukan pada *pressure vessel*. Langkah-langkah dalam menentukan *inspection planning*:

12 Menghitung *target inspection date*

Target date didapatkan dari perpotongan kurva risiko pada RBI *date* dengan kurva *risk target*.

Tabel 4. 16 Table kurva risiko berdasarkan risk area (VS-80-003)

Item	Date	Time since RBI Assessment	Risk Area (m^2/yr)
RBI Date	12/02/2019	5	20.45934724
Risk Target	05/12/2019	7.89	44.33273807
Plan Date	12/02/2023	9	54.64660042



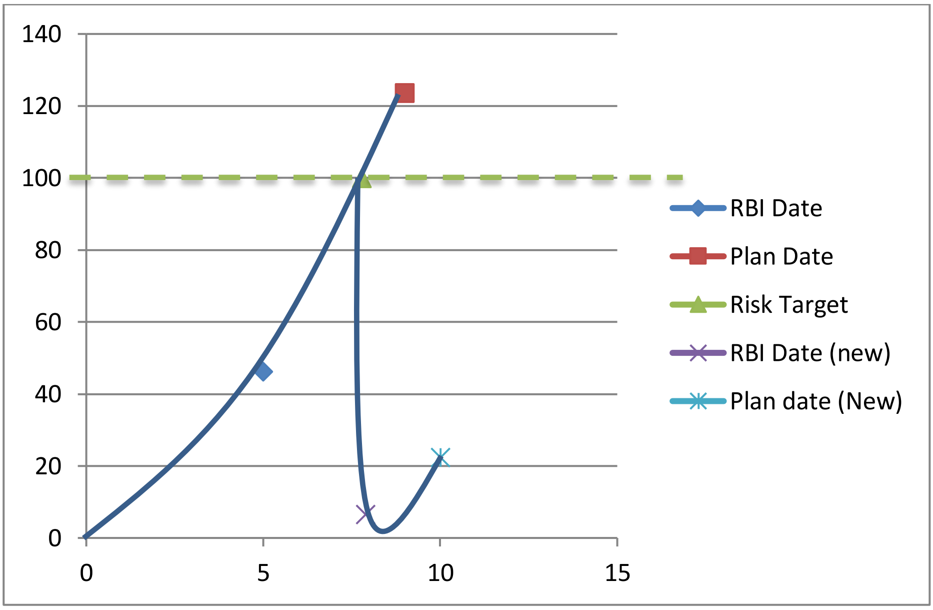
Gambar 4. 8 Grafik Kurva risiko berdasarkan risk area (VS-80-003)

Target date = 7.89 year after Assessment
= 11/22/2018

Tabel 4. 17 Tabel Kurva risiko berdasarkan damage factor (VS-80-003)

Item	Date	Time since RBI Assessment	Damage Factor
RBI Date	12/02/2019	5	46.1495232
Risk Target	02/03/2022	7.25	100
Plan Date	12/02/2023	9	123.5288021

Target date = 7.25 Year after RBI Assessment
= 02/03/2022



Gambar 4. 9 Grafik kurva risiko berdasarkan damage factor (VS-80-003)

Rekomendasi dengan mengacu pada hasil penelitian ini adalah:

- Perlunya maintenance overhaul pada pressure vessel, dikarenakan pada tahun ini semenjak inspeksi belum di lakukan inspeksi total atau maintenance total.
- Peningkatan *inspection effectiveness* pada pressure vessel, dikarenakan berdasarkan *inspection report* yang digunakan sebagai acuan, *inspection effectiveness* pada pressure vessel berada pada kategori E atau Ineffective.

Dengan melihat hasil grafik laju risiko, dan melihat tingkatan risiko yang ada. Dapat ditentukan rekomendasi inspeksi seperti tabel 4.18.

Tabel 4. 18 Rekomendasi Inspeksi untuk VS-80-003

Damage factor	Efektivitas inspeksi	Inspeksi intrusif	Inspeksi non-intrusif	Tanggal inspeksi
Local Thinning	C	Untuk area permukaan total: • >50% pemeriksaan visual. • 100% follow up di area local thinning.	Untuk total area yang dicurigai: > cakupan 50% dari CML menggunakan ultrasonic scanning atau profile radiography.	Dilakukan pada tanggal 02-03-2022
Sulfide Stress Cracking	E	Dilakukannya teknik inspeksi/perencanaan yang tidak effektif	Dilakukannya teknik inspeksi/perencanaan yang tidak effektif	
SIC/SOHIC – H_2S	E	Dilakukannya teknik inspeksi/perencanaan yang tidak effektif permukaan.	Dilakukannya teknik inspeksi/perencanaan yang tidak effektif	

4.3.4 Hasil RBI analisi untuk MD-5 Pipeline

4.3.4.1 Probability of Failure

Penentuan Thinning Damage Factor

Setiap komponen perlu di periksa terhadap indicator kerusakan yang diakibatkan *ge factor* yang dapat diakibatkan oleh *general* dan *local thinning.* Untuk perhitungan selengkapnya dicantumkan pada lampiran 7.

Langkah-langkah berikut digunakan untuk menentukan damage factor untuk thinning adalah.

a. Menentukan furnished thickness dan umur dari equipment, ditentukan hasil dari furnished thickness adalah 28.85 dan umur dari equipment adalah 14 tahun.
b. Menentukan lajur korosi berdasarkan material dasar (C_{rbm}) berdasarkan material konstruksi serta lingkungan dan cladding/overlay. Berdasarkan penjelasan dari section 4.5.2 API RP 581, laju korosi dihitung dengan menggunakan pendekatan Annex 2B dari API RP 581, untuk menghitung laju korosi perlu ditentukan tipe korosi yang ada dengan menggunakan screening questions yang

disediakan oleh tabel 2B.1.1. Dari screening question ditentukan bawha tipe korosi yang ada pada equipment adalah Sour water corrosion dan laju korosi yang telah disesuaikan adalah 0.287.

c. Menentukan waktu in-service,
d. Menentukan age_{rc} untuk komponen cladding/overlay, dikarenakan tidak adanya cladding, maka step ini dilewat.
e. Menentukan thickness minimum dari equipment, ada 4 metoda yang dapat digunakan untuk menentukan minimum thickness dari sebuah equipment, untuk perhitungan ini, metoda perhitungan pertama digunakan karena metoda ini digunakan komponen cylindrical, spherical, atau head. Hasil dari perhitungan didapatkan bahwa minimum thickness dari equipment adalah 25.91 mm atau 1.02" inch.
f. Menentukan parameter A_{rt}, dari perhitungan A_{rt} hasil yang didapatkan adalah 0.39820014 (calculated corrosion rate) dan 0.0013867 (berdasarkan data yang didapat).
g. Menentukan Flow stress dari equipment, dengan mengkalkulasikan Yield Strenght dan Tensile Strength, didapatkan hasil flow stress sebesar 35887
h. Menghitung parameter strength ratio dengan menggunakan equasi yang tepat, dimana didapatkan hasil 0.686
i. Menentukan jumlah inspeksi sebelumnya untuk inspection effectiveness dengan menggunakan section 4.5.6 dari API RP 581 Part 2, berdasarkan data sebelumnya, inspection effectiveness dari data yang didapat memiliki kategori E, dimana berdasarkan kategori tersebut inspeksi yang dilakukan sangat tidak effective atau tidak dilakukan inspeksi sama sekali.
j. Menentukan inspection effective factor, tiap factor harus dihitung berdasarkan scenario damage state, dengan menggunakan Table 4.5 dan tabel 4.6 dari API RP 581, didapatkan hasil $I_1^{thin}, I_2^{thin}, I_3^{thin}$ senilai 0.50, 0.30, dan 0.20
k. Menentukan parameter $\beta_1, \beta_2, dan\ \beta_3$, dan didapatkan hasil 1.5390, 1.5390, 1.53056 dan 1.51375
l. Maka didapatkan hasil damage factor sebesar 0.200745959.

Perhitungan Damage Factor Stress Corrosion Cracking – Sulfide Stress Cracking.

Caustic cracking didefinisikan sebagai keretakan sebuah material dibawah campuran *tensile stress* dan korosi yang di akibatkan oleh sodium hydroxide (NaOH) pada temperatur yang tinggi. Untuk menentukan *Damage Factor* SCC-SSC, dapat digunakan kalkulasi yang mengacu pada API RBI 581. Perhitungan lengkap dari SCC-SSC Df dilampirkan pada lampiran 7

Langkah-langkah berikut di gunakan untuk menentukan damage factor untuk SCC-SSC.

- **a.** Menentukan *Enviromental Severity* untuk keretakan berdasarkan konten air dan pH dari H_2S menggunakan Tabel 8.2 (API RBI 581). Dimana pH air adalah 5.52 dan konten air sebesar 1000 ppm, dapat di tentukan bahwa *environmental severity* dari SSC adalah **Moderate.**
- **b.** Menentukan kerentanan dari keretakan menggunakan *figure 8.1* dan tabel 8.3 (API RBI 581) berdasarkan dari *environmental severity* dari langkah 1. Berdasarkan tabel tersebut, dengan kriteria dimana *Max Brinnel Hardness* bernilai <200 dan *Enviromental Severity* berada pada *Moderate*, dan tidak adanya PWHT pada equipment, maka didapatkan hasil **Low** untuk *susceptibility to SSC-SCC.*
- **c.** Berdasarkan dari kerentanan yang di dapatkan pada langkah ke dua, ditentukan *severity index* (S_{vi}) menggunakan tabel 8.4 (API RBI 581), dimana S_{VI} dari **Low Susceptibility**, adalah **1**.
- **d.** Menentukan *in-service age* semenjak inspeksi level A,B, atau C terakhir dilakukan. Berdasarkan data yang di dapat, dapat ditentukan bahwa *in-service age* pada saat analisa dilakukan adalah **18 tahun.**
- **e.** Menentukan inspeksi sebelumnya dan inspeksi yang sesuai menggunakan *Section 8.6.2* API RBI 581 Part 2 Annex 1. Berdasarkan data yang didapat, ada 2 inspeksi yang telah dilakukan sebelum analisa ini dilakukan dengan kategori efektif yakni E, dimana hasil inspeksi tersebut bersifat ***Ineffective.***
- **f.** Menentukan basis *damage factor* untuk *sulfide stress cracking*, menggunakan tabel 6.3 API RBI 581 Annex 2. Penentuan *damage factor* untuk SCC dapat ditentukan dengan *inspection effectiveness* tertinggi dan jumlahnya, dimana berdasarkan langkah sebelumnya, didapat bahwa kategori dari inspeksi sebelumnya adalah E dan memiliki *severity index* sebesar 1. *Base damage factor* yang di dapat adalah **1**
- **g.** Langkah terakhir ini dilakukan untuk menentukan *Damage Factor* dari *Stress Caustic Cracking – Sulfide Stress Cracking*, dimana untuk menentukan *Df* tersebut, dapat menggunakan equasi 2.27 API RBI 581. Dimana hasil yang di dapatkan untuk :

  RBI Date

  $$D_f^{SCC} = 5.8730947$$

  RBI Plan Date

  $$D_f^{SCC} = 13.980798$$

1. Perhitungan Damage Factor Stress Corrosion Cracking – HIC/SOHIC-H_2S.

HIC didefinisikan sebagai keretakan internal yang berdekatan dengan hydrogen blister di tingkatan yang berbeda pada metal, atau permukaan metal. Untuk menentukan *Damage Factor* HIC/SOHIC-H_2S, digunakan kalkulasi yang mengacu pada API RBI 581. Perhitungan lengkap dari HIC/SOHIC-H_2S Df dilampirkan pada lampiran 7

Langkah-langkah berikut digunakan untuk menentukan damage factor untuk HIC/SOHIC-H_2S

a. Menentukan *Enviromental Severity* untuk keretakan berdasarkan konten air dan pH dari H_2S menggunakan Tabel 8.2 (API 581). Dimana pH air adalah 5.52 dan konten air sebesar 1000 ppm, dapat di tentukan bahwa *environmental severity* dari HIC/SOHIC-H_2S adalah **Moderate.**

b. Menentukan kerentanan dari keretakan menggunakan *figure 8.1* dan tabel 9.3 (API RBI 581) berdasarkan dari *environmental severity* dari langkah 1, dengan kriteria dimana *Max Brinnel Hardness* bernilai <200 dan *Enviromental Severity* berada pada *Moderate*, dan tidak adanya PWHT pada equipment, maka didapatkan hasil **Low** untuk *susceptibility to SSC-SCC.*

c. Berdasarkan dari kerentanan yang di dapatkan pada langkah ke dua, ditentukan *severity index* (S_{vi}) menggunakan tabel 9.4 (API RBI 581), dengan S_{VI} dari **Low Susceptibility**, adalah **1**.

d. Menentukan *in-service age* semenjak inspeksi level A,B, atau C terakhir dilakukan. Berdasarkan data yang di dapat, dapat ditentukan bahwa *in-service age* pada saat analisa dilakukan adalah **18 tahun.**

e. Menentukan inspeksi sebelumnya dan inspeksi yang sesuai menggunakan *Section 8.6.2* API RBI 581 Part 2 Annex 1. Berdasarkan data yang didapat, ada 2 inspeksi yang telah dilakukan sebelum analisa ini dilakukan dengan kategori efektif yakni E, dimana hasil inspeksi tersebut bersifat ***Ineffective.***

f. Menentukan basis *damage factor* untuk *sulfide stress cracking*, menggunakan tabel 6.3 API RBI 581 Annex 2. Penentuan *damage factor* untuk HIC/SOHIC dapat ditentukan dengan *inspection effectiveness* tertinggi dan jumlahnya, dimana berdasarkan langkah sebelumnya, didapat bahwa kategori dari inspeksi sebelumnya adalah E dan memiliki *severity index* sebesar 1. *Base damage factor* yang di dapat adalah **1**

g. Menentukan *On-line adjustment factor* dengan menggunakan tabel 9.5 (API 581)

h. Menghitung *Df* akhir dengan memperkirakan kenaikan *Df* berdasarkan *in-service age* sejak inspeksi terakhir. Di asumsikan bahwa probabilitas untuk keretakan akan meningkat dengan waktu semenjak inspeksi terakhir akibat hasil dari peningkatan eksposur akibat kondisi normal ataupun tidak normal. Hasil akhir *Df* dapat dikalkulasikan sebagai berikut:
Damage Factor at RBI Date

$$D_f^{HIC\,SOHIC-H2S} = \frac{D_{fB}^{HIC\,SOHIC-H2S}.(Max[age,1.0])^{1.1}}{Fom}$$

$$D_f^{HIC\,SOHIC-H2S} = \frac{1.(Max[4,1.0])^{1.1}}{2}$$

$$D_f^{HIC\,SOHIC-H2S} = 4.594793$$

Damage Factor at RBI Plan Date

$$D_f^{HIC\,SOHIC-H2S} = \frac{D_{fB}^{HIC\,SOHIC-H2S}.(Max[age,1.0])^{1.1}}{Fom}$$

$$D_f^{HIC\,SOHIC-H2S} = \frac{1.(Max[9,1.0])^{1.1}}{2}$$

$$D_f^{HIC\,SOHIC-H2S} = 11.21158$$

2. Perhitungan General Failure Frequency (gff).

Untuk menentukan *General Failure Frequency* dapat mengacu pada Table 3.1 dari API RBI 581 yang berisi list rekomendasi *gff* untuk equipment yang di analisa. Perhitungan gff dilampirkan pada lampiran 7.

Tabel 4. 19 Suggested Component Generic Failure Frequencies

Equipment Type	Component Type	*gff* as a function of hole size (failures/yr)				gff_{total} *(failures/yr)*
		Small	Medium	Large	Rupture	
Vessel/FinFan	KODRUM, COLBTM, FINFAN, FILTER DRUM, REACTOR, COLTOP, COLMID,	8.00E-06	2.00E-05	2.00E-05	6.00E-07	3.06E-05

Dari tabel tersebut, dapat ditentukan bahwa *gfftotal* memiliki nilai 3.06E-05

3. Perhitungan Management System Factor (Fms).

Menentukan faktor *Fms* dapat menggunakan evaluasi majemen sistem yang disediakan pada *Part 2, Annex 2.A* RBI 581. Perhitungan fms dilampirkan pada lampiran 7.

Setelah mendapat percentage dari score, nilai *Fms* dapat dihitung dengan menggunakan rumus:

$$Fms = 10^{(-0;02.pscore+1)}$$

Maka didapat nilai *Fms* bernilai 0.182390.

Perhitungan *Probabiliy of Failure*

Setelah mendapatkan hasil *Df,gff,* dan *Fms*. Maka perhitungan PoF dilakukan dengan menggunakan rumus,

$$Pf\ (t) = gff\ .\ Fms\ .Df\ (t)$$

Dari rumus tersebut dapat dikalkulasikan bahwa PoF bernilai:

$$Pf\ (t)\ =\ gff\ .\ Fms\ .\ D\,f\ (t)$$

$$Pf\ (t)\ = 0.0042(RBI\ Date)$$
$$Pf\ (t)\ = 0.019(RBI\ Plan\ Date)$$

Perhitungan dari probability of failure di lampirkan pada lampiran 7

4.3.4.3 Consequence of Failure

Consequence of Failure digunakan untuk menganalisa konsekuensi dari kegagalan sebuah equipment bertekanan yang berkemungkinan untuk menimbulkan kerusakan untuk equipment, loss dari produksi atau jalannya sistem, pencemaran, dan menimbulkan cedera fatal pada personel. Analisa CoF dapat dihitung sebagai konsekuensi area atau financial. Dalam API RBI 581, analisa konsekuense dibagi menjadi dua level, yakni *Level 1 Consequence of Failure*, dan *Level 2 Consequence of Failure*. Dalam analisa ini, perhitungan konsekuensi yang digunakan adalah perhitungan konsekuensi level 1. Perhitugan selengkapnya dari analisa konesekuense kegagalan dilampirkan pada lampiran 6.

Dalam beberapa tahap yang perlu dilakukan untuk melakukan analisa konsekuensi pada RBI, langkah langkah tersebut adalah sebagai berikut

1. Penentuan Fluida Representatif

Representative Liquid yang digunakan adalah H_2S atau Hydrogen Sulfide, dengan *properties*:

Liquid Density	:	993.033 Kg/m^3
NBP	:	-59.4 C°
Auto-Ignition temperature	:	500 F° / 260 C°

Dalam tabel 4.3 API RBI 581 Annex 3, dapat ditentukan bahwa fase liquid saat tersimpan adalah Liquid namun setelah terlepas adalah Gas.

2. Pemilihan Release Hole Size

Pemilihan release hole size didasarkan pada jenis peralatan. Pemilihan set ukuran lubang saat *release* untuk menentukan kemungkinan range dari konsekuensi yang dihasilkan. Untuk menentukan set ukuran lubang mengacu pada API RBI 581 Annex 3 Part 1, Tabel 4.4.

Tabel 4. 20 Release Hole Sizes and Areas Used in Level 1 and 2 Consequence Analyses

Release Hole Number.	Release Hole Size.	Range of Hole Diameters (inch).	Release Hole Diameters, d_n, (inch).
1	Small	1 – ¼	$d_1 = 0.25$
2	Medium	>¼ - 2	$d_1 = 1$
3	Large	>2 – 6	$d_1 = 4$
4	Rupture	>6	$d_1 = \min [D,16]$

3. Perhitungan Release Rate

Selanjutnya dihitung *theoretical release rate* dari scenario *release hole size (An)* yang sudah ditentukan pada langkah ke dua. Pada langkah ini, *release hole size* perlu di hitung menggunakan ekuasi 3.8.

$$An = \frac{\pi d_n^2}{4}$$

Dengan ekuasi tersebut didapatkan hasil:

Small Hole Size	:	3.00E-05	m^2
Medium Hole Size	:	5.00E-04	m^2
Large Hole Size	:	0.008	m^2
Rupture Hole Size	:	0.13	m^2

Setelah mendapatkan *release hole size* dari tiap scenario, langkah berikutnya adalah untuk menghitung *release rate* (W_n). didapatkan hasil *release rate* sebagai berikut:

Small Hole Size	:	0.001949	Kg/s
Medium Hole Size	:	0.093635	Kg/s
Large Hole Size	:	0.478570	Kg/s
Rupture Hole Size	:	23.96435	Kg/s

4. **Langkah ke empat adalah mengestimasikan masa maksimum yang ada saat release.**

Untuk menghitung masa yang ada atau *available mass* ($Mass_{avail}$), *group component* dan *equipment items* dari *inventory group* harus ditentukan terlebih dahulu, untuk menentukan *inventory groups*, dapat merujuk pada API RBI 581 Annex 3 Part 3, Tabel 3.A.3.2. Dapat disimpulkan bahwa equipment yang dianalisa memiliki *Default liquid volume percent* sebanyak 100% liquid.

Untuk penentuan massa komponen ($mass_{comp}$) diperlukan perhitungan massa fluida. massa fluida dihitung dengan rumus volume dari equipment yang dianalisa

$$Vcyl = \pi R^2 L$$
$$Vcyl = 2.0511 \text{ m}^3$$

Untuk volume liquid dan volume vapour:

Liquid Volume: $(100\%) x\ Vcyl$ = 1.026 m^3

Untuk massa komponen:

$$Mass_{comp} = (V_l\,\rho_l) + (V_v\,\rho_v)$$
$$Mass_{comp} = 1024.4\ Kg$$

Maka didapatkan massa inventory ($mass_{inv}$)

$$Mass_{inv} = \sum_{i=1}^{N} Masscomp$$
$$Mass_{inv} = 1024.4 \text{ Kg}$$

Perhitungan *flow rate* perlu dilakukan dengan cara meengkalkulasikan *flow rate* dari simulasi lubang dengan diameter 203mm (8 inch) dengan menggunakan ekuasi (3.3), (3.6), (3.7) API 581 Annex 3 sesuai dengan kebutuhan dengan $A_n = A_8 = 32{,}450 \text{ mm}^2$ (50,3 inch^2).

$$W_{max.8} = \frac{Cd}{C2} \,.\, A8 \,.\, Ps \sqrt{\left(\frac{k \,.\, MW \,.\, gc}{R \,.\, Ts}\right)} \left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}$$

$$W_{max.8} = \frac{0.90}{1} \,.\, 32{,}450 \,.\, 1060 \sqrt{\left(\frac{1.27 \,.\, 34 \,.\, 1}{8.314 \,.\, 453.15}\right)} \left(\frac{2}{1.27+1}\right)^{\frac{1.27+1}{1.27-1}}$$

$$W_{max.8} = 0.221285458 \;\; Kg$$

Untuk setiap *hole size*, dikalkulasi massa fluida yang di tambah ($mass_{add,n}$). dihasilkan 3 menit *flow* berasal dari *inventory group* menggunakan ekuasi (3.10) API RBI 581, dimana W_n adalah lajur release dari tiap hole size.

$$Mass_{add,n} = 180 \,.\, \text{Min}\,[W_n \,,\, W_{max,8}]$$

Maka didapatkan hasil W_n

Small Hole Size	:	0.3508	Kg/s
Medium Hole Size	:	16,85	Kg/s
Large Hole Size	:	84.17	Kg/s
Rupture Hole Size	:	84.17	Kg/s

Penentuan Release Type.

Release type (*continuous/instantaneous*) untuk menentukan metoda yang akan digunakan untuk pemodelan *dispersion* dan *consequence*

a.Untuk setiap *hole size*, ditentukan waktu yang dibutuhkan untuk melepaskan 4536 Kg Liquid. Dengan menggunakan ekuasi:

$$tn = \frac{C3}{Wn}$$

Di dapatkan hasil t_n:

Small Hole Size	:	2327052	s
Medium Hole Size	:	48443.38	s
Large Hole Size	:	9478.23	s
Rupture Hole Size	:	189.27	s

b. Ditentukan *release type* apakah *continuous* atau *instantaneous* dengan menggunakan kriteria sebagai berikut:

- If the release hole size is 6.35 mm (0.25 inch) or less, then the release type is automatically continuous.
- If tn≤180 sec and the release mass is greater than 4536 kgs (10000 lbs.),then the release is instantaneous; otherwise, the release is continuous.

Dengan kriteria tersebut dapat di tentukan bahwa:

Small Hole Size : d_1 = 0.25 inch
t_1 = 2.33E+06 s
<u>Continuous</u>
Medium Hole Size: d_2 = 1 inch
t_2 = 48443.38 s
<u>Continuous</u>
Large Hole Size: d_3 = 4 inch
t_3 = 9478.235 s
<u>Continuous</u>
Rupture Hole Size: d_4 = 16 inch
t_4 = 189.2789 s
<u>Continuous</u>

Estimasi impact dari sistem deteksi serta isolasi pada magnitude release.

Menetapkan sistem deteksi dan isolasi yang ada pada unit, dengan menggunakan tabel 4.5 API RBI 581 Annex 3. Dimana klasifikasi yang dipilih adalah :

Detection System Classification: **<u>C</u>**
Isolation System Classification: **<u>C</u>**

Dengan menggunakan Tabel 4.6 API RBI 581, dan klasifikasi dari langkah 6.2 dan 6.3, ditentukan *release reduction factor* pada equipment.

$fact_{di}$: 0.00 (No adjustment to release rate or mass)

Dengan menggunakan tabel 4.7 dan klasifikasi yang telah ditetapkan pada langkah sebelumnya, ditentukan *total leak duration* pada setiap *release hole size*, ***Id*** ***max,n.***

Detection System : **<u>C</u>**
Isolation System : **<u>C</u>**
$Id_{max,1}$: <u>60 Minutes</u>
$Id_{max.2}$: <u>40 Minutes</u>
$Id_{max,3}$: <u>20 Minutes</u>

Penentuan release rate dan massa untuk analisa konsekuensi.

Untuk setiap release hole size, dikalkulasi *adjusted release rate¸*$rate_n$ dengan menggunakan ekuasi (3.13) API RBI 581.

$rate\ n = Wn\ (1 - factdi)$

Small Hole Size : 0.00195 Kg/s
Medium Hole Size : 0.09364 Kg/s
Large Hole Size : 0.47857 Kg/s
Rupture Hole Size : 23.9646 Kg/s

Untuk setiap hole size, ditentukan *leak duration*, Id_n dari release menggunakan ekuasi 3.15 API RBI Annex.

$$Idn = min\left[\left\{\frac{massavailn}{raten}\right\}, \{60.idmax, n\}\right]$$

Small Hole Size	:	3600	s
Medium Hole Size	:	1200	s
Large Hole Size	:	600	s
Rupture Hole Size	:	600	s

Untuk setiap hole size, dikalkulasi *release mass*, $mass_n$, menggunakna ekuasi (3.14) berdasarkan *release rate*¸$rate_n$, dengan hasil dari langkah 3.2, Id_n dari langkah 7.2, dan *available mass*, $mass_{avail}$, dari langkah 4.6

$$mass_n = \min[\{rate_n . idn\}, massav_{ailn}]$$

Small Hole Size	:	7.017	Kg/s
Medium Hole Size	:	112.362	Kg/s
Large Hole Size	:	287.142	Kg/s
Rupture Hole Size	:	14378.8	Kg/s

Penentuan konsekuensi flammable dan explosive pada equipment.

Langkah pertama dalam kalkulasi *flammable and explosive consequence analysis* adalah memilih reduction factor untuk mitigasi konsekuensi area Faktor mitigasi dapat ditentukan dengan menggunakan tabel 4.10 (API 581), dikarenakan tidak ada rujukan yang mencukupi dari data yang ada, mitigation system tidak dapat ditentukan, sehingga;

$Fact_{mit} = 0$

Untuk setiap release hole size, ditentukan koreksi dari effisiensi energy, atau en_{eff}. Dengan menggunakan ekuasi 3.18.

$$eneff_1 = 4.log_{10}[C_4. mass_1] - 15$$

Dengan ekuasi tersebut didapatkan hasil:

Small Hole Size	:	1.758311	Kg/s
Medium Hole Size	:	6.576113	Kg/s
Large Hole Size	:	8.206021	Kg/s
Rupture Hole Size	:	15.00452	Kg/s

Selanjutnya ditentukan tipe fluida, berdasar table 4.1 API RBI 581, Annex 3. Didapatkan hasil :

Representative Fluid : ***H_2S***
Fluid type : ***Type 0***

Untuk setiap *release hole size*¸dikalkulasi konsekuensi area untuk kerusakan komponen.

Dengan menggunakan table 4.8 API RBI 581 Annex 3, dapat di tentukan konstanta *a* dan *b,* dimana konstanta tersebut bernilai:

$a = 32.0$ $b = 1.00$

Dengan menggunakan ekuasi (3.31) didapatkan hasil:

$$CA_{cmd,n}^{AINL-CONT} = a\,(rate)^{b}\ .\ (1\ - factmil\,)$$

Small Hole Size : 0.0.468 m^2
Medium Hole Size : 2.2472 m^2
Large Hole Size : 11.486 m^2
Rupture Hole Size : 575.15 m

Untuk setiap *release hole size,* dilakukan perhitungan untuk konsekuensi area dari kerusakan komponen untuk *Auto-ignition Likely Continuous Release (AIL-CONT).*

Dengan merujuk pada tabel 4.8 API RBI 581 Annex 3, dapat di tentukan konstanta *a* dan *b,* dimana konstanta tersebut bernilai

$a = 203.0$ $b = 0.89$

Dengan ekuasi (3.33) API RBI 581 Annex 3, dapat ditentukan hasil perhitungan Consequence Area:

Small Hole Size : 0.5896 m^2
Medium Hole Size: 18.499 m^2
Large Hole Size : 79.015 m^2
Rupture Hole Size: 2572.6 m^2

Untuk setiap *release hole size,* dilakukan perhitungan untuk konsekuensi area dari kerusakan komponen untuk *Auto-ignition Not-Likely Continuous Release (AINL-CONT)*

Dengan merujuk pada tabel 4.8 API RBI 581 Annex 3, dapat ditentukan konstanta *a* dan *b,* dimana konstanta tersebut bernilai

$a = 148.0$ $b = 0.63$

Dengan ekuasi (3.33) API RBI 581 Annex 3, dapat ditentukan hasil perhitungan Consequence Area:

Small Hole Size : 215.43 m^2
Medium Hole Size : 330.56 m^2
Large Hole Size : 478.4 m^2
Rupture Hole Size : 1163.8 m

Untuk setiap *release hole size,* dilakukan perhitungan untuk konsekuensi area dari kerusakan komponen untuk Auto-ignition Likely, Instantaneous Release (AIL-INST)

Dengan merujuk pada tabel 4.8 API RBI 581 Annex 3, dapat ditentukan konstanta *a* dan *b*, dimana konstanta tersebut bernilai

a= 357.0 *b= 0.61*

Dengan ekuasi (3.33) API RBI 581 Annex 3, dapat ditentukan hasil perhitungan Consequence Area:

Small Hole Size : 499.8 m^2
Medium Hole Size : 725.5 m^2
Large Hole Size : 1030.5 m^2
Rupture Hole Size : 2410.3 m

Untuk setiap *release hole size,* dilakukan perhitungan untuk konsekuensi area dari kerusakan komponen untuk Auto-ignition Not Likely, Continuous Release (AINL-CONT),

Dengan merujuk pada tabel 4.8 API RBI 581 Annex 3, dapat ditentukan konstanta *a* dan *b*, dimana konstanta tersebut bernilai

a= 52.0 *b= 1.00*

Dengan ekuasi (3.33) API RBI 581 Annex 3, dapat ditentukan hasil perhitungan Consequence Area:

Small Hole Size : 0.08 m^2
Medium Hole Size : 3.65 m^2
Large Hole Size : 18.7 m^2

Untuk setiap *release hole size,* dilakukan perhitungan untuk konsekuensi area dari kerusakan komponen untuk Auto-ignition Likely, Continuous Release (AIL-CONT)

Dengan merujuk pada tabel 4.8 API RBI 581 Annex 3, dapat ditentukan konstanta *a* dan *b*, dimana konstanta tersebut bernilai

a= 375.0 *b= 0.94*

Dengan ekuasi (3.33) API RBI 581 Annex 3, dapat ditentukan hasil perhitungan Consequence Area:

Small Hole Size : 0.8 m^2
Medium Hole Size : 30.4 m^2
Large Hole Size : 141 m^2

Untuk setiap *release hole size,* dilakukan perhitungan untuk konsekuensi area dari kerusakan komponen untuk Auto-ignition Not Likely, Instantaneous Release (AINL-INST)

Dengan merujuk pada tabel 4.8 API RBI 581 Annex 3, dapat ditentukan konstanta *a* dan *b,* dimana konstanta tersebut bernilai

a= 203.0 *b= 0.89*

Dengan ekuasi (3.33) API RBI 581 Annex 3, dapat ditentukan hasil perhitungan Consequence Area:

Small Hole Size : 395.79 m^2
Medium Hole Size : 330.56 m^2
Large Hole Size : 478.4 m^2

Untuk setiap *release hole size,* dilakukan perhitungan untuk konsekuensi area dari kerusakan komponen untuk Auto-ignition Likely, Instantaneous Release (AIL-INST)

Dengan merujuk pada tabel 4.8 API RBI 581 Annex 3, dapat ditentukan konstanta *a* dan *b,* dimana konstanta tersebut bernilai

a= 1253.0 *b= 0.63*

Dengan ekuasi (3.33) API RBI 581 Annex 3, dapat ditentukan hasil perhitungan Consequence Area:

Small Hole Size : 1823.9 m^2
Medium Hole Size : 2798.6 m^2
Large Hole Size : 4050.2 m^2
Rupture Hole Size : 9853.1 m

Untuk setiap *release hole size,* dikalkulasi konsekuensi area Instantaneous/Continuous dengan menggunakan ekuasi (3.19), (3.20) atau (3.26).

AIT *Blending factor, factAIT,* dikalkulasi menggunakan ekuasi (3.24), (3.25) atau (3.21).

$$Fact^{AIT} = 0 \qquad for\, Ts + C_6 \leq AIT$$

$$Fact^{AIT} = \frac{(Ts - AIT - C6)}{2.C6} \qquad for\, Ts + C_6 > AIT > Ts - C_6$$

$$Fact^{AIT} = 1 \qquad for\, Ts - C_6 \geq AIT$$

maka di dapatkan hasil:

AIT = 0

Perhitungan konsekuensi lengkung instan kontinu untuk komponen menggunakan persamaan (3.65) hingga (3.68) berdasarkan area konsekuensi yang dihitung dalam langkah 8.4, 8.5, 8.6, 8.7, 8.8, 8.9, 8.10, dan 8.11. dan faktor pencampuran kontinyu / instan.

Dengan menggunakan ekuasi (3.65) sampai dengan (3.68) di dapatkan hasil:

Small Hole size :

$CA_{cmd,1}^{ANIL}$ = 0.628 m^2

$CA_{cmd,1}^{AIL}$ = 449.76 m^2

$CA_{inj,1}^{ANIL}$ = 0.06344 m^2

$CA_{inj,1}^{AIL}$ = 0.93821 m^2

Medium Hole size :

$CA_{cmd,2}^{ANIL}$ = 28.1673 m^2

$CA_{cmd,2}^{AIL}$ = 4.62288 m^2

$CA_{inj,2}^{ANIL}$ = 28.1673 m^2

$CA_{inj,2}^{AIL}$ = 54.1889 m^2

Large Hole size :

$CA_{cmd,3}^{ANIL}$ = 488.884 m^2

$CA_{cmd,3}^{AIL}$ = 214.928 m^2

$CA_{inj,3}^{ANIL}$ = 20.3527 m^2

$CA_{inj,3}^{AIL}$ = 214.9288 m^2

Rupture Hole size :

$CA_{cmd,4}^{ANIL}$ = 2349.23 m^2

$CA_{cmd,4}^{AIL}$ = 9427.11 m^2

$CA_{inj,4}^{ANIL}$ = 2292.186 m^2

$CA_{inj,4}^{AIL}$ = 2292.186 m^2

Kalkulasi AIT *blended consequence area* untuk komponen dengan menggunakan ekuasi (3.57), (3.58) API RBI 581, berdasarkan CA pada langkah 8.14.

Small Hole size :

$CA_{cmd,1}^{flam}$ = 0.06344 m^2

$CA_{inj,1}^{flam}$ = 0.93821 m^2

Medium Hole size :

$CA_{cmd,2}^{flam}$ = 21.1255 m^2

$CA_{inj,2}^{flam}$ = 40.6417 m^2

Large Hole size :

$CA_{cmd,3}^{flam}$ = 20.3527 m^2

$CA_{inj,3}^{flam}$ = 214.928 m^2

Rupture Hole size :

$CA_{cmd,4}^{flam}$ = 9427.110 m^2

$CA_{inj,4}^{flam}$ = 2292.186 m^2

Penentuan *final consequence area* untuk kerusakan komponen dan cedera pada personel dengan menggunakan ekuasi (3.59) dan (3.60).

didapatkan hasil:

CA_{cmd}^{flam} = 184.845 m^2

CA_{inj}^{flam} = 167.284 m^2

Consequence Analysis Toxic

Untuk setiap *release hole size* yang dipilih pada langkah 2.2, tentukan durasi effektif dari *release* dengan menggunakan ekuasi (3.67)

$$Id_n^{tox} = min\left(3600,\ \left\{\frac{mass}{W}\right\},\ \{60\ .\ Idmax, n\}\right)$$

Maka didapatkan hasil:

Small Hole Size : 3.600 m^2

Medium Hole Size : 1200 m^2

Large Hole Size : 600 m^2

Rupture Hole Size : 600 m

Dimana persentase toxic dari component.

H_2S = 1.55%

Mfrac = 0.0155

Setiap *release hole size*, dikalkulasikan *release rate*, $rate_{tpx}$, and release mass, xmassntox to be used in toxic consequence analysis

Small Hole Size	:	3E-05	Kg/s
Medium Hole Size	:	0.001	Kg/s
Large Hole Size	:	0.007`	Kg/s
Rupture Hole Size	:	0.371	Kg/s

Untuk setiap release hole size, dikalkulasikan *konsekuensi toxic* pada setiap release hole size, untuk HF acid dan H_2S – tentukan $CA^{tox}_{inj,n}$ dengan menggunakan ekuasi (3.63) untuk *continuous release*..

Small Hole Size	:	-0.5573	Kg/s
Medium Hole Size	:	0.52	Kg/s
Large Hole Size	:	0.89	Kg/s
Rupture Hole Size	:	1.657	Kg/s

Final toxic consequences area for personnel injury.

$$CA^{tox}_{inj} = \left(\frac{\sum_{n=1}^{4} gffn \, . \, CA^{tox}_{inj,n}}{gfftotal} \right)$$

$$CA^{flam}_{inj} = 0.28 \text{ m}^2$$

CoA non-flam non-tox

Untuk setiap *release hole size,* dikalkulasikan non-flammable, non-toxic consequence area.

Didapatkan hasil:

Small Hole Size	:	33.8	Kg/s
Medium Hole Size	:	361	Kg/s
Large Hole Size	:	0.8914	Kg/s

Untuk setiap *release hole size*, tentukan blending factor dari instantaneous/continuous, gunakan ekuasi (3.71)

$$fact^{IC}_{n} = min\left[\left\{\frac{Raten}{C5}\right\},\ 1.0\right]$$

Didapatkan hasil:

Small Hole Size	:	7.73511E-05	Kg/s
Medium Hole Size	:	0.00371568	Kg/s
Large Hole Size	:	0.02	Kg/s
Rupture Hole Size	:	0.02	Kg/s

S

Small Hole Size	:	0	Kg/s
Medium Hole Size	:	1.35	Kg/s
Large Hole Size	:	355	Kg/s

Ca0=24.05882 m

Penentuan final consequence area

Penentuan area konsekuensi didapatkan dengan terlebih dahulu menentukan final omponent damage consequence area (CA cmd) dan personnel injury consequence area (CA imj)

Menentukan final component damage consequence area

$$CAcmd = CA_{cmd,}^{flam}$$

$CAcmd =$ 184.84

Menentukan final personnel injury consequence area

$CA_{inj} = max\left[CA_{inj}^{flam},\ CA_{inj}^{tox}\ ,\ CA_{inj}^{nfnt}\right]$

= 167.28 m^2

Didapatkan hasil final consequence area, CA :

$CA=max\left[CA_{cmd}, CA_{inj}\right]$

= 184.8 m^2

4.3.4.4 Risk Analysis

Nilai risiko dari alat didapat dengan mengalikan PoF dan CoF. Risiko dihitung menggunakan persamaan (4.103) API RBI 581,:

$$Risk = PoF\ x\ CoF$$

Dimana :

PoF = Probabilitas kegagalan

CoF = Konsekuensi kegagalan

Penentuan tingkat risiko dilakukan dengan membandingkan nilai risiko yang didapatkan dengan *risk target*. Apabila hasil perbandingan menunjukkan bahwa risiko lebih besar dari *risk target*, maka akan dilakukan langkah mitigasi. Langkah mitigasi dapat dilakukan dengan cara melakukan inspeksi sesuai dengan jadwal dan metode yang diharapkan dapat meminimalkan nilai risiko tersebut.

Analisis risiko pada tugas akhir ini, untuk well pipes dilakukan perbandingan risiko pada RBI date dengan risk target. Menghitung besarnya risiko pada well pipes

c. Menghitung besarnya risiko pada RBI *date*

Besarnya risiko pada *Pipe* MD-5 adalah :

$$Risk = PoF\ x\ \max(CAinj, CAequip)$$

$$= 2.304\ m^2$$

Besarnya risiko pada *plan date* adalah :

$$Risk = PoF\ .\ max(CAinj, CAequip)$$

$= 21.5 \text{ m}^2$

d. Tingkat risiko

Kategori tingkat risiko ditentukan dari hasil PoF dan CoF. Dengan menggunakan Tabel 4.1M API RBI 581 Annex 1, maka tingkat risiko dapat dikategorikan.

Pada pipa MD-5 hasil tingkat risiko yang didapat adalah:

Probability Range

3B– Medium	(Saat RBI Date)
3C- Medium	(Saat Plan Date)

Berdasarkan nilai tersebut maka didapatkan matriks risikonya yang ditunjukkan oleh gambar 4.10

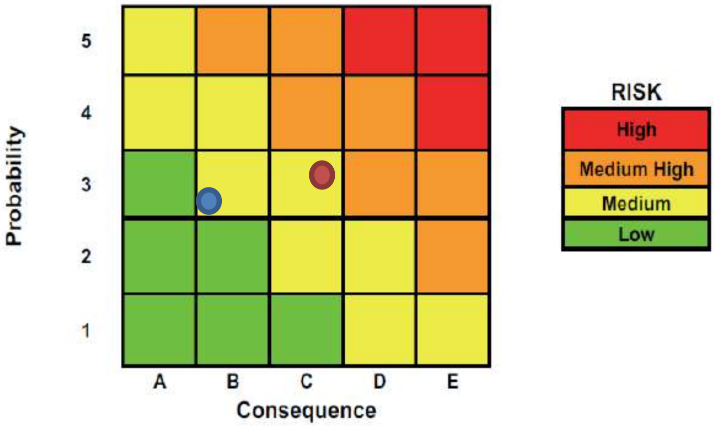


Figure 4.3 – Balanced Risk Matrix Example

Gambar 4. 10 Risk Matrix untuk MD-5 Pipeline

Tingkat risiko dapat di plotting sebagai table 4.21

Tabel 4. 21 Tabel Tingkat Risiko (MD-5 Pipeline)

Tanggal	Keterangan	DF	CoF (m^2)	Risk Category	Definisi
02/12/2019	RBI date	0.0042	184.8	3B	Medium
02/12/2023	Plan date	0.019		3C	Medium
*Note: Inspection effectiveness: 2E					

4.3.4.5 Inspection plan

Penjadwalan inspeksi adalah suatu kegiatan menentukan interval waktu antar-inspeksi yang akan diterapkan pada alat. Menurut API 581 penjadwalan inspeksi untuk well pipes dilakukan berdasarkan hasil dari risiko yang didapatkan, namun intervalnya sendiri tidak diberikan suatu perhitungan yang pasti. API 581 menyerahkan penjadwalan inspeksi kepada perusahaan sesuai dengan batasan risiko yang dapat diterima. Karena batasan risiko yang dapat diterima pada alat tidak diketahui, untuk membantu dalam melakukan penjadwalan maka dapat mengacu pada API 510 yang membahas mengenai well pipes inspection code.

Analisis *inspection planning* dilakukan well pipes.

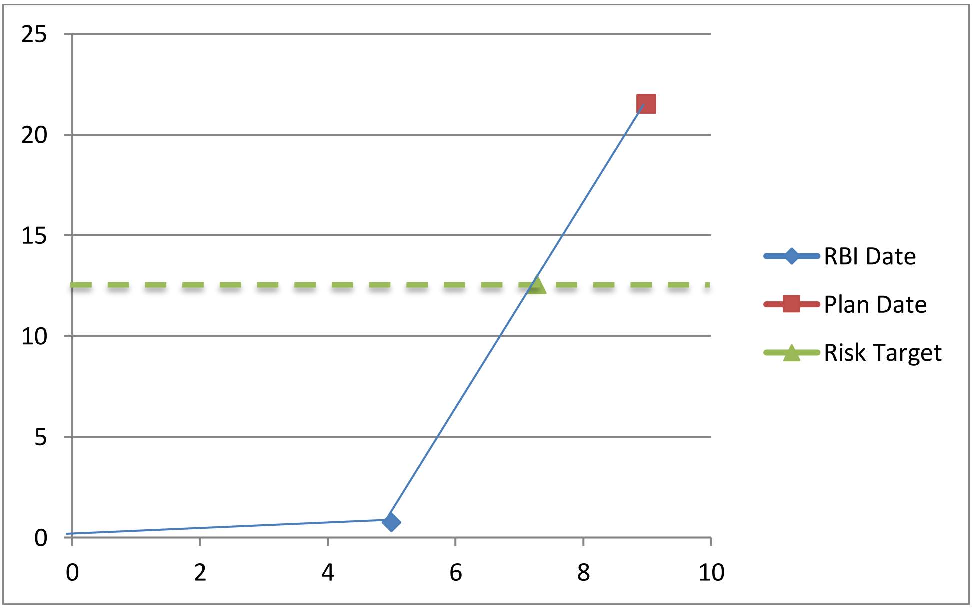
Langkah-langkah dalam menentukan *inspection planning*:

Menghitung *target inspection date*

Target date didapatkan dari perpotongan kurva risiko pada RBI *date* dengan kurva *risk target*.

Tabel 4. 22. Tabel Kurva risiko berdasarkan risiko area (MD-5 Pipeline)

Item	Date	Time since RBI Assessment	Risk Area (m^2/yr)
RBI Date	12/02/2019	5	0.768
Risk Target	05/12/2019	7.27	12.566
Plan Date	12/02/2023	9	21.5



Dengan melihat hasil grafik laju risiko, dan melihat tingkatan risiko yang ada. Dapat ditentukan rekomendasi inspeksi seperti tabel 4.23.

Tabel 4. 23 Rekomendasi Inspeksi untuk MD-5 Pipeline

Damage factor	Efektivitas inspeksi	Inspeksi intrusif	Inspeksi non-intrusif	Tanggal inspeksi
Local Thinning	C	Untuk area permukaan total: • >50% pemeriksaan visual. • 100% follow up di area local thinning.	Untuk total area yang dicurigai: > cakupan 50% dari CML menggunakan ultrasonic scanning atau profile radiography.	Dilakukan pada tanggal 02-03-2022
Sulfide Stress Cracking	E	Dilakukannya teknik inspeksi/perencanaan yang tidak effektif	Dilakukannya teknik inspeksi/perencanaan yang tidak effektif	
SIC/SOHIC – H_2S	E	Dilakukannya teknik inspeksi/perencanaan yang tidak effektif	Dilakukannya teknik inspeksi/perencanaan yang tidak effektif	

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BAB V
KESIMPULAN DAN SARAN

1.1. Kesimpulan

Kesimpulan yang dapat diambil dari hasil analisis dalam tugas akhir ini adalah :

1. Besarnya risiko pada *pressure vessel* VS-80-001, VS-80-002, dan, VS-80-003 adalah 26.126 m^2/yr. Besarnya risiko pada masing-masing *pressure vessel* adalah sama, hal ini dikarenakan data serta kondisi pada masing-masing *pressure vessel* sama.
2. Besarnya risiko pada MD-5 Well pipes adalah 0.768 m^2/yr pada tanggal saat RBI dilakukan dan 3.511 m^2/yr pada plan date.
3. Hasil Consequence of Area equipment yang di analisa adalah:
    a. MD-5 Well Pipes adalah: 184.8 m^2
    b. Pressure Vessel VS-80-001 adalah: 652.1 m^2
4. Inspection planning untuk *pressure vessel* VS-80-001, VS-80-002, dan, VS-80-003 disarankan untuk berjalan pada tahun ini, dikarenakan Risk area pertahun melebihi Target risk yang ada.
    a. Jadwal inspeksi
    Jadwal inspeksi berdasarkan analisis RBI ini berada pada tahun 12-02-2023.
5. Inspection planning untuk MD-5 Well Pipes adalah sebagai berikut:
    a. Jadwal inspeksi
    Jadwal inspeksi berdasarkan analisis RBI ini berada pada tahun 12-02-2023.

3. Berdasarkan hasil analisa, tingkatan risiko pada *risk matrix* dari VS-80-001, VS-80-002, VS-80-003, berada pada:
    a. Probability Range

5A – Medium	(RBI date)
5C – Medium High	(Plan Date

4. Berdasarkan hasil analisa, tingkatan risiko pada *risk matrix* dari MD-5 Well Pipes, berada pada:
    a. Probability Range

3B – Medium	(RBI Date)
3C – Medium	(Plan Date)

DAFTAR PUSTAKA

American Petroleum Institute (API). 2016. *Risk Based Inspection Technology API RP 581*. Washington, D.C: API Publishing Services

American Petroleum Institute (API). 2009. *Risk Based Inspection API RP 580*. Washington, D.C: API Publishing Services

American Petroleum Institute (API). 2009. *Inspection Practice for Pressure Vessel Based Resource Document API 572*. Washington, D.C: API Publishing Services

American Petroleum Institute (API). 2006. *Pressure Vessel Inspection Code: In-Service Inspection, Rating, Repair, and Alteration API 510*. Washington, D.C: API Publishing Services

ASME B31.1, 2004. Power Piping. The American Society of Mechanical Engineer.

Andritsos N, Ungemach P, Koutsoukos P. Chapter 9: **Corrosion and Scaling**.

Baticci, Francesca, Albert Genter , Petra Huttenloch ,Roman Zorn, 2010. **Corrosion and Scaling Detection in the Soultz EGS Power Plant**, Upper Rhine Graben, France. Proceedings World Geothermal Congress 2010 Bali, Indonesia, 25-29 April 2010

Kusmono., Khasani.2017. **Analysis of a Failed Pipe Elbow in Geothermal Production Facility. Case Studies in Engineering Failure Analysis**, Elsevier 9 , hal. 71–77.

Lichti K.A., Firth D.M., Wilson P.T. 1993. **Lifetime Predictions for Critical Plant In Geothermal Energy System**. Industrial Research Limited, LowerHutt.

Lichti K,A. 2002. Risk **Management and Risk Based Inspection of Aging Geothermal Energy plant**. .

Lichti K.A, Cruz R.P.V, Fernandez N.A., 2003. **Risk Based Inpection of a Turbine Inlet Steam Pipeline**. Geothermal Resource Council Transactions

Ompusunggu BHM Goldy, Mahesa Ryan Pamuji, Gede Wibawa, Kuswandi Kuswandi. 2017. Studi Perencanaan Pembangunan Pembangkit Listrik Tenaga Panas Bumi Sebesar 120 MW di Blok Sarulla. **Jurnal Teknik ITS**, Vol 5 (2)

Purnanto M.H., Purwakusumah A.2015. Fifteen Year (Mid-life Time) of Wayang Windu Geothermal Power Station Unit-1: An Operational Review. **Proceedings World Geothermal Congress Melbourne**, Australia.

Rød, Bjarte, 2015. Evaluation of Probability of Failure of Static Equipment in Pressurized Mud Systems on an Offshore Drilling Installation. ***Master's thesis in Energy, Climate and Environment*** . The Arctic University of Norway.

Tomarov , Grigory V., Dmitry V. Kolesnikov, Valery N. Semenov, Viktor M. Podverbny and Andrey A. Shipkov, 2015., **Prevention of Corrosion and Scaling in Geothermal Power Plants Equipment**. Proceedings World Geothermal Congress 2015 Melbourne, Australia, 19-25 April 2015

Van den Heuvel D.B., Gunnlaugsson E., Gunnarson I., Stawski T.M., Peacock C.L., Benning L.G. 2018. Understanding amorphous silica scaling under well-constrained conditions inside geothermal pipelines. **Geothermics**, hal.231–241.

Vinod G, Shamra P.K, Santosh T.V, Prasad M.H, Vaze K.K., 2014. New Approach For Risk Based Inspection Of H2S Based Process Plants. **Annals of Nuclear Energy**. Hal. 13–19

Zarrouk, S.J. Moon H, 2014. **Efficiency of geothermal power plants: A worldwide review**. Geothermics 51. Hal. 142-153.

Lampiran 1

General Data

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Basic Data	Value	Unit	Comments
Start Date	01/01/2000		The date the component was placed in service.
Thickness	30.47	mm	The thickness used for DF calculation that is either the furnished thickness or the measured thickness.
Corrosion Allowance	3.00	mm	The corrosion allowance is the specified design or actual corrosion allowance upon being placed in the current servicce.
Design Tempearture	5-265	^{o}C	The design temperature, shell side and tube side for heat exchanger.
Design Pressure	7100	Kpa	The design pressure, shell side and tubbe side for heat exchanger.
Operating Tempearture	196.6	^{o}C	The highest expected operating temperature expected during operation including normal and unusual operating conditions, shell side and tube side for heat exchanger.
Operating Pressure	1060	Kpa	The highest expected operating pressure expected during operation including normal and unusual operating conditions, shell side and tube side for heat exchanger.
Design Code	ANSI B31.1		The designing of the component containing the component.
Equipment Type	Pipe		The type of equipment.
Component Type	API-5L-Gr B		The type of component.
Geometry Data			Component geometry data depending on the type of component.
Material Specification			The specification of the material of construction, the ASME SA or SB specification for pressure vessel components or for ASTM specification for piping and tankage components. Data entry is based on the material specification, grade, year, UNS Number, class/condition/temper/size/thickness; this data is readdily available in the ASME Code.
Yield Strength	415,000	Kpa	The design yield strength of the material based on material specification.
Tensile Strength	245,000	Kpa	The design tensile strength of the material based on material specification.
Weld Joint Efficiency	1.00	mm	Weld joint efficiency per the Code of construction.
Heat Tracing	Yes		Is the component heat traced? (Yes or No)

Basic Data	Value	Unit	Comments
Start Date	01/01/2000		The date the component was placed in service.
Thickness	28.85	mm	The thickness used for DF calculation that is either the furnished thickness or the measured thickness.
Corrosion Allowance	3.00	mm	The corrosion allowance is the specified design or actual corrosion allowance upon being placed in the current servicce.
Design Tempearture	50-200	°C	The design temperature, shell side and tube side for heat exchanger.
Design Pressure	1450	Kpa	The design pressure, shell side and tubbe side for heat exchanger.
Operating Tempearture	187	°C	The highest expected operating temperature expected during operation including normal and unusual operating conditions, shell side and tube side for heat exchanger.
Operating Pressure	1060	Kpa	The highest expected operating pressure expected during operation including normal and unusual operating conditions, shell side and tube side for heat exchanger.
Design Code	ASME Section VIII Division I Ed. 2015		The designing of the component containing the component.
Equipment Type	Separator (Pressure Vessel)		The type of equipment.
Component Type	Filter		The type of component.
Geometry Data	ELL (Elliptical Head)		Component geometry data depending on the type of component.
Material Specification			The specification of the material of construction, the ASME SA or SB specification for pressure vessel components or for ASTM specification for piping and tankage components. Data entry is based on the material specification, grade, year, UNS Number, class/condition/temper/size/thickness; this data is readdily available in the ASME Code.
Yield Strength	510000/650000	Kpa	The design yield strength of the material based on material specification.
Tensile Strength	335000	Kpa	The design tensile strength of the material based on material specification.
Weld Joint Efficiency	1.00	mm	Weld joint efficiency per the Code of construction.
Heat Tracing	Yes		Is the component heat traced? (Yes or No)

Lampiran 2
P&ID Data

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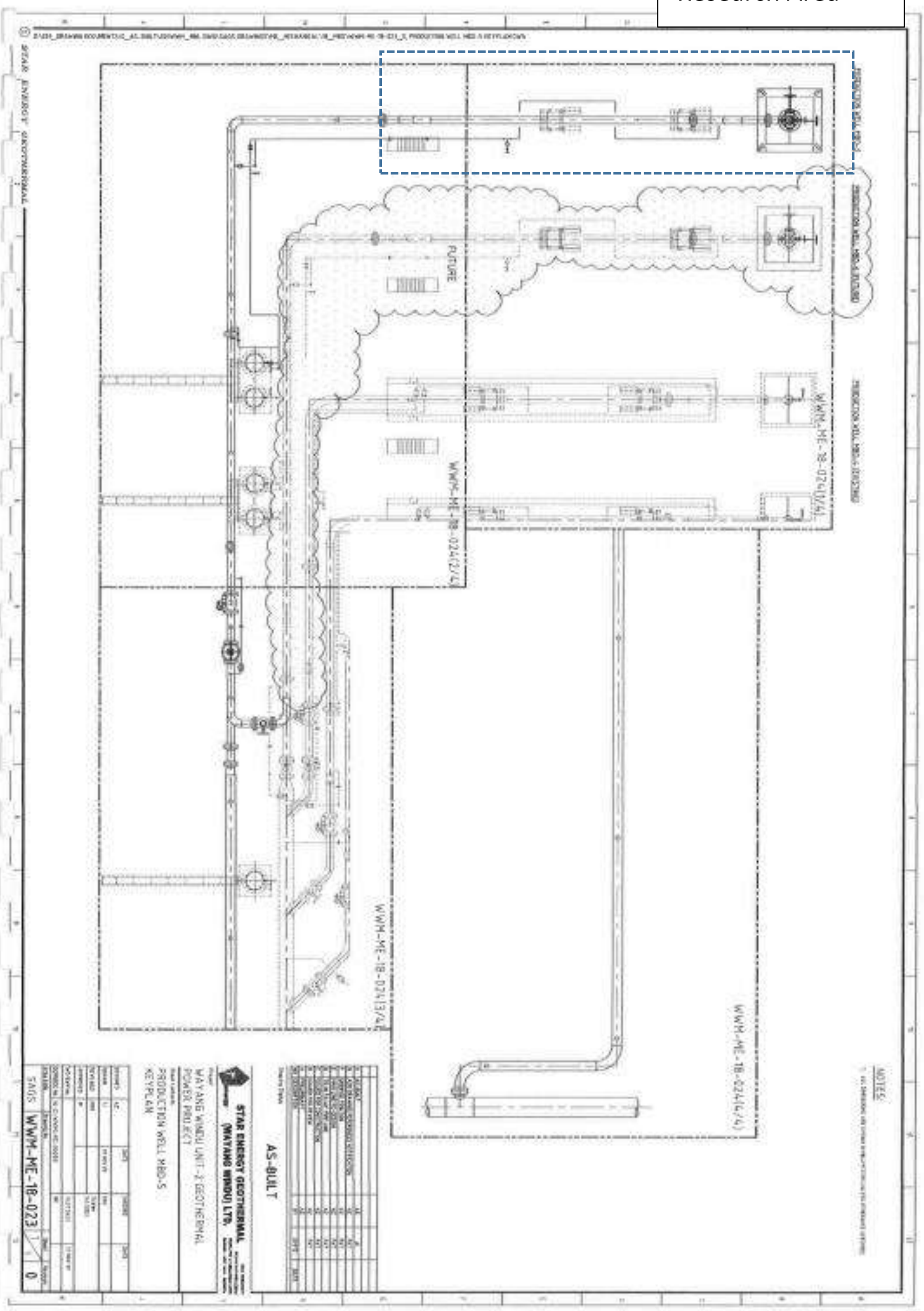
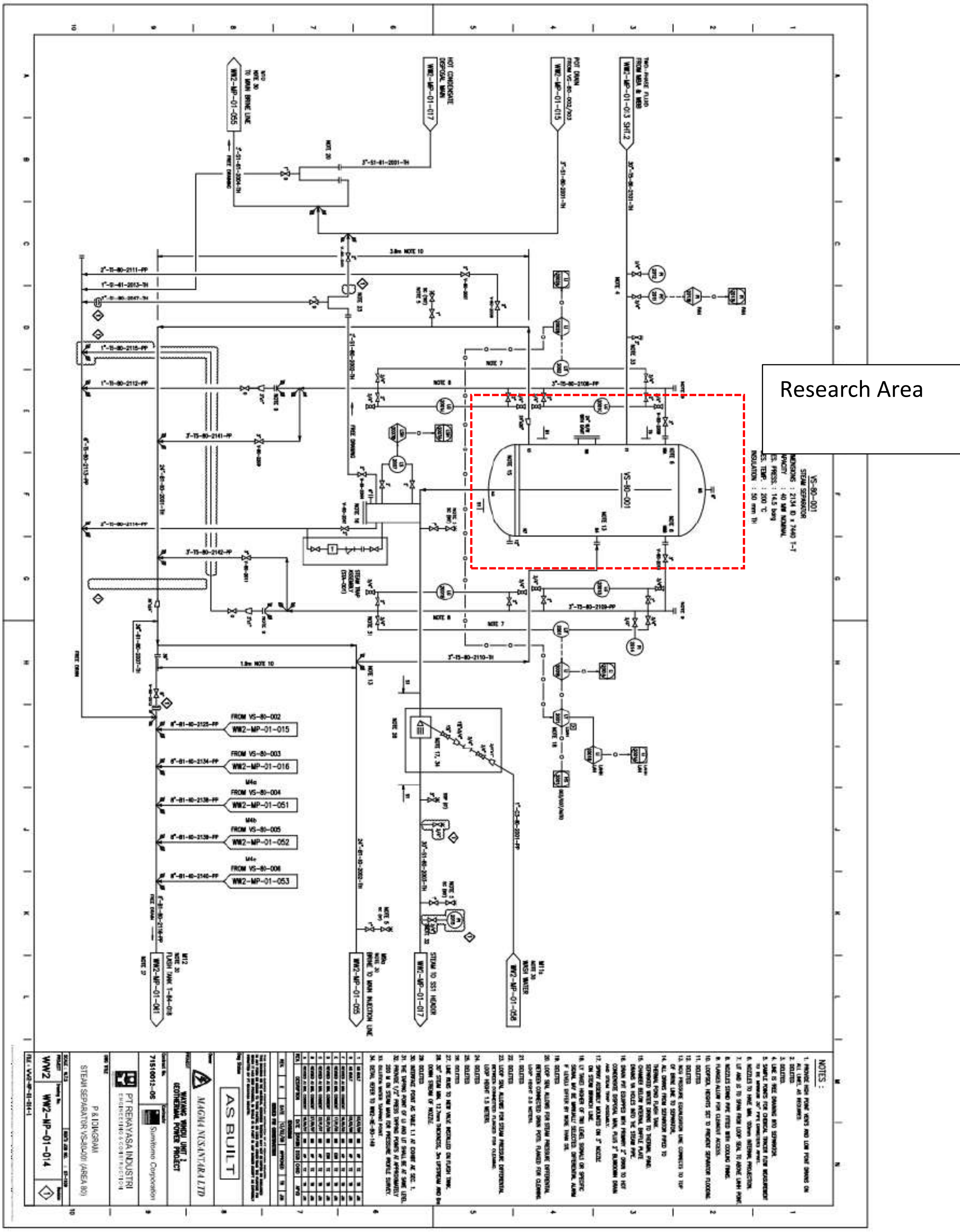

Research Area


Research Area
VS-80-001
STEAM SEPARATOR
AS BUILT
MAGMA NUSANTARA LTD
WAYANG WINDU UNIT 2 GEOTHERMAL POWER PROJECT
PT REKAYASA INDUSTRI
Sumitomo Corporation
P&ID DIAGRAM
STEAM SEPARATOR VS-80-001 (AREA 80)
WW2-MP-01-014
NOTES:

Lampiran 3
Chemical Analysis

Location	Date	WHP	Gas Lab No.	Dry gas (mole %)								mmole/100 mole H2O								Gas in Steam (weight %)									Ratio	Remark
				CO_2	H_2S	NH_3	N_2	CH_4	He	H_2	Ar	CO_2	H_2S	NH_3	N_2	CH_4	He	H_2	Ar	CO_2	H_2S	NH_3	N_2	CH_4	He	H_2	Ar	TGC	CO_2/H_2S	
MBA-1	13-Sep-18	13.7	13169	84.073	7.936	0.158	7.099	0.065	0.005	0.658	0.006	92.79	8.758	0.175	7.834	0.072	0.005	0.726	0.006	0.227	0.017	1.65E-04	1.22E-02	6.39E-05	1.19E-06	0.000	0.00	0.26	10.59	
MBA-2	13-Sep-18	12.9	13173	76.720	6.562	0.243	15.606	0.139	0.002	0.714	0.015	52.37	4.479	0.166	10.653	0.095	0.001	0.487	0.010	0.128	0.008	1.57E-04	1.66E-02	8.44E-05	2.36E-07	0.000	0.00	0.15	11.69	
MBA-3	13-Sep-18	15.1	13177	85.381	3.699	0.188	9.959	0.148	0.001	0.616	0.008	108.13	4.685	0.238	12.613	0.188	0.001	0.780	0.010	0.264	0.009	2.25E-04	1.96E-02	1.67E-04	2.78E-07	0.000	0.00	0.29	23.08	
MBA-4	13-Sep-18	13.0	13181	81.225	2.093	0.027	16.249	0.089	0.010	0.295	0.013	243.87	6.285	0.080	48.784	0.268	0.031	0.885	0.039	0.596	0.012	7.53E-05	7.59E-02	2.39E-04	6.84E-06	0.000	0.00	0.68	38.80	
MBA-5	13-Sep-18	14.8	13186	75.241	2.118	0.043	22.543	0.000	0.000	0.051	0.003	139.81	3.936	0.080	41.889	0.000	0.001	0.095	0.005	0.342	0.007	7.58E-05	6.52E-02	0.00E+00	1.56E-07	0.000	0.00	0.41	35.52	
MBB-1	13-Sep-18	12.6	13191	86.970	0.830	0.118	11.418	0.225	0.001	0.431	0.006	322.52	3.079	0.439	42.341	0.836	0.004	1.598	0.023	0.789	0.006	4.16E-04	6.59E-02	7.45E-04	7.87E-07	0.000	0.00	0.86	104.73	
MBB-2																														shut in
MBB-3	13-Sep-18	12.7	13195	89.363	1.452	0.107	8.344	0.087	0.222	0.420	0.006	213.97	3.476	0.257	19.980	0.208	0.531	1.005	0.013	0.523	0.007	2.43E-04	3.11E-02	1.85E-04	1.18E-04	0.000	0.00	0.56	61.57	
MBB-4	13-Sep-18	13.0	13199	90.970	0.688	0.142	7.909	0.154	0.001	0.532	0.004	465.00	3.515	0.726	38.383	0.787	0.005	2.721	0.019	1.137	0.007	6.87E-04	5.97E-02	7.01E-04	1.06E-06	0.000	0.00	1.21	132.29	
MBB-5	13-Sep-18	13.0	13203	82.111	1.045	0.119	16.206	0.194	0.007	0.306	0.012	287.54	3.659	0.415	56.751	0.679	0.024	1.073	0.043	0.703	0.007	3.93E-04	8.83E-02	6.06E-04	5.36E-06	0.000	0.00	0.80	78.58	
MBD-1	6-Sep-18	12.4	13122	85.136	2.847	0.265	11.104	0.000	0.280	0.360	0.008	106.70	3.568	0.332	13.917	0.000	0.351	0.452	0.010	0.261	0.007	3.14E-04	2.17E-02	0.00E+00	7.80E-05	0.000	0.00	0.29	29.90	
MBD-2	6-Sep-18	13.0	13126	93.317	2.068	0.214	3.995	0.090	0.012	0.300	0.003	225.80	5.004	0.518	9.666	0.217	0.029	0.727	0.008	0.552	0.009	4.91E-04	1.50E-02	1.94E-04	6.42E-06	0.000	0.00	0.58	45.13	
MBD-3	6-Sep-18	12.1	13130	87.205	1.008	0.184	10.932	0.324	0.001	0.339	0.006	162.78	1.882	0.343	20.407	0.604	0.002	0.633	0.011	0.398	0.004	3.25E-04	3.18E-02	5.39E-04	4.41E-07	0.000	0.00	0.43	86.50	
MBD-4	6-Sep-18	12.4	13134	80.086	3.853	0.289	15.016	0.000	0.012	0.730	0.015	57.64	2.773	0.208	10.808	0.000	0.008	0.525	0.011	0.141	0.005	1.97E-04	1.68E-02	0.00E+00	1.89E-06	0.000	0.00	0.16	20.79	
MBD-5	6-Sep-18	15.9	13138	90.203	1.839	0.162	7.183	0.208	0.001	0.400	0.005	169.10	3.447	0.303	13.465	0.390	0.002	0.749	0.009	0.413	0.007	2.87E-04	2.10E-02	3.47E-04	3.66E-07	0.000	0.00	0.44	49.05	
MBD-6	6-Sep-18	17.0	13142	88.585	1.829	0.144	8.864	0.205	0.016	0.351	0.007	155.73	3.215	0.253	15.583	0.360	0.028	0.617	0.012	0.381	0.006	2.40E-04	2.43E-02	3.21E-04	6.16E-06	0.000	0.00	0.41	48.44	
MBE-3	16-Sep-18	11.7	13231	85.536	6.056	0.175	7.263	0.103	0.001	0.858	0.007	127.07	8.996	0.261	10.790	0.153	0.001	1.275	0.010	0.311	0.017	2.47E-04	1.68E-02	1.36E-04	3.20E-07	0.000	0.00	0.35	14.12	
MBE-4	16-Sep-18	11.8	13235	87.859	5.099	0.164	6.243	0.080	0.001	0.549	0.005	161.95	9.398	0.301	11.508	0.148	0.001	1.012	0.010	0.396	0.018	2.85E-04	1.79E-02	1.32E-04	2.16E-07	0.000	0.00	0.43	17.23	
MBE-5	16-Sep-18	15.0	13239	93.837	0.383	0.000	5.477	0.095	0.067	0.136	0.005	612.83	2.503	0.000	35.771	0.618	0.436	0.889	0.031	1.498	0.005	0.00E+00	5.57E-02	5.51E-04	9.70E-05	0.000	0.00	1.56	244.86	
WWA-4																														Shut-in
WWA-6	12-Sep-18	14.0	13149	90.771	2.370	0.011	5.981	0.395	0.059	0.409	0.004	668.89	17.465	0.080	44.071	2.907	0.436	3.015	0.032	1.635	0.033	7.54E-05	6.86E-02	2.59E-03	9.70E-05	0.000	0.00	1.74	38.30	
WWD-1	12-Sep-18	11.7	13164	79.446	9.737	0.046	10.222	0.041	0.182	0.281	0.046	136.24	16.697	0.079	17.530	0.071	0.312	0.482	0.077	0.333	0.032	7.51E-05	2.73E-02	6.29E-05	6.93E-05	0.000	0.00	0.39	8.16	
WWQ-2	16-Sep-18	16.8	13210	64.177	1.488	0.104	32.151	0.484	0.012	1.427	0.157	130.76	3.032	0.212	65.504	0.987	0.024	2.907	0.321	0.320	0.006	2.01E-04	1.02E-01	8.80E-04	5.29E-06	0.000	0.00	0.43	43.13	
WWQ-3	16-Sep-18	15.7	13214	90.651	2.440	0.000	6.277	0.178	0.001	0.450	0.003	162.84	4.383	0.000	11.275	0.320	0.002	0.809	0.005	0.398	0.008	0.00E+00	1.75E-02	2.85E-04	3.52E-07	0.000	0.00	0.42	37.15	
WWQ-4	16-Sep-18	14.9	13218	95.829	1.035	0.055	2.728	0.195	0.000	0.155	0.002	346.42	3.743	0.199	9.863	0.703	0.002	0.560	0.006	0.847	0.007	1.89E-04	1.54E-02	6.27E-04	3.82E-07	0.000	0.00	0.87	92.55	
WWQ-5	16-Sep-18	11.7	13222	84.344	4.255	0.040	10.416	0.163	0.022	0.752	0.010	166.57	8.407	0.079	20.582	0.322	0.043	1.486	0.019	0.408	0.016	7.51E-05	3.20E-02	2.87E-04	9.50E-06	0.000	0.00	0.46	19.82	
WWQ-6	16-Sep-18	15.4	13227	87.228	2.161	0.192	9.720	0.181	0.001	0.510	0.007	134.85	3.341	0.296	15.028	0.280	0.002	0.788	0.011	0.330	0.006	2.80E-04	2.34E-02	2.49E-04	4.06E-07	0.000	0.00	0.36	40.36	
WWT-2	12-Sep-18	14.1	13159	89.164	5.067	0.019	4.977	0.075	0.003	0.692	0.003	376.59	21.402	0.080	21.019	0.318	0.013	2.922	0.013	0.921	0.041	7.55E-05	3.27E-02	2.83E-04	2.86E-06	0.000	0.00	0.99	17.60	
WWA-7	12-Sep-18	11.8	13154	88.904	5.242	0.011	5.081	0.109	0.008	0.643	0.003	647.68	38.188	0.080	37.012	0.792	0.058	4.685	0.020	1.584	0.072	7.53E-05	5.76E-02	7.06E-04	1.28E-05	0.001	0.00	1.71	16.96	

Lampiran 4

Calculation for VS-80-001

“Halaman ini sengaja dikosongkan”

Calculation of Thinning Damage Factor

Basic Data	Value	Unit	Comments
Start Date	01/01/2000		The date the component was placed in service.
Thickness	28.85	mm	The thickness used for DF calculation that is either the furnished thickness or the measured thickness.
Corrosion Allowance	3.00	mm	The corrosion allowance is the specified design or actual corrosion allowance upon being placed in the current servicce.
Design Tempearture	50-200	^{o}C	The design temperature, shell side and tube side for heat exchanger.
Design Pressure	1450	Kpa	The design pressure, shell side and tubbe side for heat exchanger.
Operating Tempearture	187	^{o}C	The highest expected operating temperature expected during operation including normal and unusual operating conditions, shell side and tube side for heat exchanger.
Operating Pressure	1060	Kpa	The highest expected operating pressure expected during operation including normal and unusual operating conditions, shell side and tube side for heat exchanger.
Design Code	ASME Section VIII Division I Ed. 2015		The designing of the component containing the component.
Equipment Type	Separator (Pressure Vessel)		The type of equipment.
Component Type	Filter		The type of component.
Geometry Data	ELL (Elliptical Head)		Component geometry data depending on the type of component.
Material Specification			The specification of the material of construction, the ASME SA or SB specification for pressure vessel components or for ASTM specification for piping and tankage components. Data entry is based on the material specification, grade, year, UNS Number, class/condition/temper/size/thickness; this data is readdily available in the ASME Code.
Yield Strength	510000/650000	Kpa	The design yield strength of the material based on material specification.
Tensile Strength	335000	Kpa	The design tensile strength of the material based on material specification.
Weld Joint Efficiency	1.00	mm	Weld joint efficiency per the Code of construction.
Heat Tracing	Yes		Is the component heat traced? (Yes or No)

STEP 1 Determining the furnished thickness, t, and age for the component from the installation date.

t = 5 inch
= 12.7 mm
age = 14 years (it is assumed from the default date for the first installement in a plant on January 1st 2000 (01/01/2000) until November 26th 2014 (26/11/2014)).

STEP 2 Determining the corrosion rate for base material, $C_{r,bm}$ based on the material construction and environment, and cladding/weld overlay corrosion rate, $C_{r,cm}$.

Based on the explanation from Section 4.5.2 that the corrosion rate is **CALCULATED** using the approach of Annex 2B. Then, first of all, the corrosion screening question must be done as follows:

Table 2.B.1.1-Screening Questions for Corrosion Rate Calculations

No.	Type of Corrosion	Screening Question		Yes/No	Action
1.	Hydrochloric Acid (HCl) Corrosion	1.	Does the process contain HCl?	N	No
		2.	Is free water present in the process stream (including initial condensing condition)?	Y	
		3.	Is the pH < 7.0?	Y	
			Actual relatively pH is 5.66		
2.	High Temperature Sulfidic/Naphtenic Acid Corrosion	1.	Does the process contain oil with sulfur compounds?	N	No
		2.	Is the operating temperature > 204^{o}C (400^{o}F)?	N	
			The operating temperature is 187^{o}C.		
3.	Sulfuric Acid Corrosion	1.	Does the process contain H_2SO_4	N	No
4.	High Temperature H_2S/H_2 Corrosion	1.	Does the process contain H_2S and Hydrogen?	Y	No
		2.	Is the operating temperature > 204^{o}C (400^{o}F)?	N	
			The operating temperature is 187^{o}C.		
5.	Hydrifluoric Corrosion	1.	Does the process contain HF	N	No
6.	Sour Water Corrsion	1.	Is free water with H_2S present?	Y	Yes
7.	Amine Corrosion	1.	Is equipment exposed to acid gas treaating amines (MEA, DEA, DIPA, or MDEA)?	N	No
8.	High Temperature Oxidation Corrosion	1.	Is the temperature ≥ 482^{o}C (900^{o}F)?	N	No
			The operating temperature is 187^{o}C.		
		2.	Is the oxygen present?	N	
9.	Acid Sour Water Corrosion	1.	Is free water with H_2S present and pH < 7.0?	Y	No
			Actual relatively pH is 5.66		
		2.	Does the proocess contain < 50 ppm chlorides?	N	
10.	Cooling Water	1.	Is equipment in cooling water service?	N	No
11.	Soil Side Corrosion	1.	Is equipment in contact with soil (buried or partially buried)?	N	No
		2.	Is the material of construction carbon steel?	N	
12.	CO_2 Corrosion	1.	Is the free water with CO_2 present (including consideration for dew point condensation)?	Y	No
		2.	Is the material of construction carbon steel or < 13% Cr?	N	
13.	AST Bottom	1.	Is the equipment item an AST tank bottom?	N	No

pH = 5.56
T = 187 C
= 368 F
P = 2895.9 Kpa
H2S Concentr = 7.935979788 % mole
Material = Carbon Steel (SA 516-70)

Basically, there are 3 types of Corrosion Rate (Cr) calculation which are based on the RLA data from the last inspection, based on the calculation referred to the API 581 Annex 2B, and the last is based on worst case scenario.

1. Corrosion Rate (Cr) from the RLA data

Cr = 0.000394 inch/year
= 0.010000 mm/year

2. Corrosion Rate (Cr) based on the Annex 2B High temperature corrosion rate

The steps required to determine the corrosion rate are shown in Figure 2.B.7.1. The corrosion rate may be determined using the basic data in Table 2.B.7.1 in conjunction with the baseline corrosion rates and equations in Table 2.B.7.2 to correct for H_2S partial pressure

Basic Data	Comments
NH_4HS concentration (wt%)	Determine the NH_4HS concentration of the condensed water. It is suggested to determine this value with ionic process models. However, approximate values may be calculated from analyses of H_2S and NH_3 as follows
	If wt% $H_2S < 2$ x (wt% NH_3), wt% NH_4HS =1.5 x (wt% H_2S)
	If wt% $H_2S > 2$ x (wt% NH_3), wt% NH_4HS =3.0 x (wt% H_2S)
Strean Velocity	The vapor phase velocity should be used in a two-phase system. The liquid phase velocity should be used in a liquid full system.
H_2S partial pressure, psia [kPa]	Determine the partial pressure of H_2S by multiplying the mole% of H_2S in the gas phase by the total system pressure.

Determining NH4HS Concentration

to determine NH_4HS concentration, we must first determine if wt% H_2S is lower or higher than wt% of NH_3.

wt% H_2S = 0.02

wt% NH_3 = 0.00047639

2 X wt% NH_3 = 0.00095278

Since the value of H_2S is higher than NH_3, the wt% of NH_4HS can be determined by the formula of: wt% NH_4HS = 3.0 x (wt% H_2S)

If wt% $H_2S > 2$ x (wt% NH_3), wt% NH_4HS =3.0 x (wt% H_2S)

NH_4HS= 3.0 x (wt% H_2S)

NH_4HS = 0.06

to determine the Cr, we must first do a calculation to correct the H_2S partial pressure.

$$\text{Adjusted } CR = \max\left[\left\{\left(\frac{Baseline\ CR}{276}\right).(pH2S - 345) + Baseline\ CR\right\},0\right]$$

Adjusted CR = 0.287

STEP 3 Determine the time in service, age_{tk}, since the last known inspection, t_{rdi}.

Because of the manufactured-thickness is not provided. Then, the thickness used in this calculation is coming from the last inspection as long as as the Production Separator installed in setvice life).

t_{rdi} = 1.136 inch

= 28.8544 mm

age_{tk} = 7 year (Last inspection was held on November 2014)

STEP 4 For cladding/weld overlay pressure vessel components, calculate the age from the date starting thickness from STEP 3 required to corrode away the cladding/weld overlay material, age_{rc}, using equation below:

$$age_{rc} = \max\left[\left(\frac{t_{rdi} - tbm}{C_{r\,cm}}\right), 0.0\right] \quad \text{...} \quad \text{(equation 57)}$$

This equipment does not have cladding, so this step are skipped

STEP 5 Determine the t_{min}

Actually there are 4 methods used to determine the minimum thickness of the equipment (t_{min}). Based on the condition, the method used by the author is the first method which is for cylindrical, spherical, or head components, determine the allowable Stress, S, weld joint efficiency, E, and the minimum thickness, t_{min}.

t_{min} = 1.0202 inch

= 25.91308 mm

S = 17500 psig

= 120658300 Pa

= 120658.3 Kpa

E = 1

STEP 6 Determine the A_{rt} Parameter

For component without clading/weld overlay then use the equation below.

$$A_{rt} = \frac{Cr_{b,m} \cdot age_{tk}}{t_{rdi}}$$ ……………………………………………….. (equation 58)

= 0.0696852 (For calculated corrosion rate based on ANNEX 2B)

$$A_{rt} = \frac{Cr_{b,m} \cdot age_{tk}}{t_{rdi}}$$

= 0.002425973 (For corrosion rate based on RLA Data)

STEP 7 Calculate the Flow Stress, FS^{Thin}, using E from STEP 5 and equation below.

$$FS^{Thin} = \frac{(YS+TS)}{2} . \text{E.1,1}$$ ……………………………………………….. (equation 59)

Where;

YS = 205000 KPa

TS = 447500 KPa

E = 1

https://www.csecplates.com/astm-a283-grade-c-plate-stockists-suppliers.html

$$FS^{Thin} = \frac{(YS+TS)}{2} . \text{E.1,1}$$

= 358875

STEP 8 Calculate the strength ratio parameter, , SR_P^{Thin} the appropriate equation.

$$SR_P^{Thin} = \frac{S.E}{FS^{Thin}} . \frac{Max\,(t_{min}, t_c)}{t_{rdi}}$$ …………………………………………. (equation 60)

Where;

t_c = is the minimum structural thickness of the component base material

= 1.0202 inch

= 25.91308 mm

$$SR_P^{Thin} = \frac{S.E}{FS^{Thin}} . \frac{Max\,(t_{min}, t_c)}{t_{rdi}}$$

= 0.686008207

STEP 9 Determine the number of inspections for each of the correspondesing inspection effectiveness, $N_A^{Thin}, N_B^{Thin}, N_C^{Thin}, N_D^{Thin}$ sing Section 4.5.6 of the API RP 581 Part 2 for past inspections performed during in-service time.

N_A^{Thin} = 0

N_B^{Thin} = 0

N_C^{Thin} = 0

N_D^{Thin} = 0

STEP 10 Calculate the inspection effectiveness factors, $I_1^{Thin}, I_2^{Thin}, I_3^{Thin}$ g equation 61 below, prior probabilities, , from Table 4.5. The Conditional Probabilities (for each inspection effectiveness level), $Pr_{p1}^{Thin}, Pr_{p2}^{Thin}$ and Pr_{p3}^{Thin} le 4.6, and the number of inspection, $N_B^{Thin}, N_C^{Thin}, N_D^{Thin}$ ı effectiveness level from STEP 9.

N_A^{Thin}

$$I_1^{Thin} = Pr_{P1}^{Thin}(Co_{P1}^{ThinA})^{N_A^{Thin}}(Co_{P1}^{ThinB})^{N_B^{Thin}}(Co_{P1}^{ThinC})^{N_C^{Thin}}(Co_{P1}^{ThinD})^{N_D^{T}}$$

$$I_2^{Thin} = Pr_{P2}^{Thin}(Co_{P2}^{ThinA})^{N_A^{Thin}}(Co_{P2}^{ThinB})^{N_B^{Thin}}(Co_{P2}^{ThinC})^{N_C^{Thin}}(Co_{P2}^{ThinD})^{N_A^{T}}$$

$$I_3^{Thin} = Pr_{P3}^{Thin}(Co_{P3}^{ThinA})^{N_A^{Thin}}(Co_{P3}^{ThinB})^{N_B^{Thin}}(Co_{P3}^{ThinC})^{N_C^{Thin}}(Co_{P3}^{ThinD})^{N_A^{T}}$$

Table 4.5 - Prior Probability for Thinning Corrosion Rate

Damage State	Low Confidence Data	Medium Confidence Data	High Conf. Data
Pr_{P1}^{Thin}	0.5	0.7	0.8
Pr_{P2}^{Thin}	0.3	0.2	0.15
Pr_{P3}^{Thin}	0.2	0.1	0.05

Table 4.6 - Conditional Probability for Inspection Effectiveness

Conditional P. of Inspection	E-None or Ineffective	D-Poorly Effective	C-Fairly Effective	B-Usually Effective	A-Highly Effective
Co_{P1}^{Thin}	0.33	0.4	0.5	0.7	0.9
Co_{P2}^{Thin}	0.33	0.33	0.3	0.2	0.09
Co_{P3}^{Thin}	0.33	0.27	0.2	0.1	0.01

$$I_1^{Thin} = Pr_{P1}^{Thin}(Co_{P1}^{ThinA})^{N_A^{Thin}}(Co_{P1}^{ThinB})^{N_B^{Thin}}(Co_{P1}^{ThinC})^{N_C^{Thin}}(Co_{P1}^{ThinD})^{N_D^{T}}$$

= 0.50

$$I_2^{Thin} = Pr_{P2}^{Thin}(Co_{P2}^{ThinA})^{N_A^{Thin}}(Co_{P2}^{ThinB})^{N_B^{Thin}}(Co_{P2}^{ThinC})^{N_C^{Thin}}(Co_{P2}^{ThinD})^{N_A^{T}}$$

= 0.30

$$I_3^{Thin} = Pr_{P3}^{Thin}(Co_{P3}^{ThinA})^{N_A^{Thin}}(Co_{P3}^{ThinB})^{N_B^{Thin}}(Co_{P3}^{ThinC})^{N_C^{Thin}}(Co_{P3}^{ThinD})^{N_A^{T}}$$

= 0.20

STEP 11 Calculate the Posteroir Probability, $Po_{p1}^{Thin}, Po_{p2}^{Thin}$ and Po_{p3}^{Thin} 6 below.

$$Po_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} \quad \text{……………………………………} \quad \text{(equation 64)}$$

= 0.5

$$Po_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} \quad \text{……………………………………} \quad \text{(equation 65)}$$

= 0.3

$$Po_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} \quad \text{……………………………………} \quad \text{(equation 66)}$$

= 0.2

p Calculate the parameters, ß_1, ß_2, and ß_3 using equation 67,68,69 below and also assigning $COV_{\Delta t}$ = 0.20, COV_{sf} = 0.20, and COV_P = 0.05.

$$\text{ß}_1^{Thin} = \frac{1-D_{S1}\,.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S1}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S1}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}} \quad \text{………} \quad \text{(equation 67)}$$

$$\text{ß}_2^{Thin} = \frac{1-D_{S2}\,.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S2}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S2}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}} \quad \text{……….} \quad \text{(equation 68)}$$

$$\text{ß}_3^{Thin} = \frac{1-D_{S3}\,.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S3}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S3}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}} \quad \text{……….} \quad \text{(equation 69)}$$

Where;

$COV_{\Delta t}$ = The thinning coefficient of variance ranging from 0.1 ≤ $COV_{\Delta t}$ ≤ 0.2
= 0.2
COV_{sf} = The flow stress coefficient of variance
= 0.2
COV_P = Pressure coeffficient of variance
= 0.05
D_{s1} = Damage State 1
= 1
D_{s2} = Damage State 2
= 2
D_{s3} = Damage State 3
= 4

BASED ON CORROSION RATE FROM RLA DATA

$$\text{ß}_1^{Thin} = \frac{1-D_{S1}\,.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S1}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S1}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$
= 1.5390

$$\text{ß}_2^{Thin} = \frac{1-D_{S2}\,.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S2}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S2}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$
= 1.53065328

$$\text{ß}_3^{Thin} = \frac{1-D_{S3}\,.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S3}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S3}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$
= 1.51374389

STEP 13 For tank bottom components, determine the base damage factor for thining using Table 4.8. and based on A_{rt} parameter from STEP 6.

Because component observed in this case of analysis is including into Pressure Vessel (Production Separator), then, this step of ccalculation can be skipped.

STEP 14 For all components (excluding tank bottoms covered in STEP 13), calculate the base damage factor, D_{fB}^{Thin}.

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi(-\beta_1^{Thin})\right)+\left(Po_{P2}^{Thin}\Phi(-\beta_2^{Thin})\right)+\left(Po_{P3}^{Thin}\Phi(-\beta_3^{Thin})\right)}{1.56E-0.4} \quad \text{………} \quad \text{(equation 70)}$$

BASED ON CORROSION RATE FROM RLA DATA

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi(-\beta_1^{Thin})\right)+\left(Po_{P2}^{Thin}\Phi(-\beta_2^{Thin})\right)+\left(Po_{P3}^{Thin}\Phi(-\beta_3^{Thin})\right)}{1.56E-0.4}$$
= 0.200745959

STEP 15 Determine the DF for thinning, D_f^{Thin}, using equation equation below.

$$D_f^{Thin} = \text{Max}[(\frac{(D_{fb}^{Thin}.F_{IP}.F_{DL}.F_{WD}.F_{AM}.F_{SM})}{F_{OM}}),0.1] \quad \text{……………………} \quad \text{(equation 71)}$$

Where;

F_{IP} = DF adjustent for injection points (for piping circuit)
= 0
F_{DL} = DF adjustment for dead legs (for piping only used to intermittent service)
= 0
F_{WD} = DF adjustment for welding construction (for only AST Bottom)
= 0
F_{AM} = DF adjustment for AST maintenance per API STD 653 (for only AST)
= 0
F_{SM} = DF adjustment for settlement (for only AST Bottom)
= 0
F_{OM} = DF adjustment for online monitoring based on Table 4.9
= 1

BASED ON CORROSION RATE FROM RLA DATA

$$D_f^{Thin} = \text{Max}[(\frac{(D_{fb}^{Thin}}{F_{OM}}),0.1]$$
= 0.200745959

Calculation of SCC-Sulfide Stress Cracking Damage Factor

Step 1.

Determine the environemental severity (potential level of hydrogen flux) for cracking based on the H2S Content of water and its pH using Table 8.2

pH : 5.52
Content of water : 1000 ppm

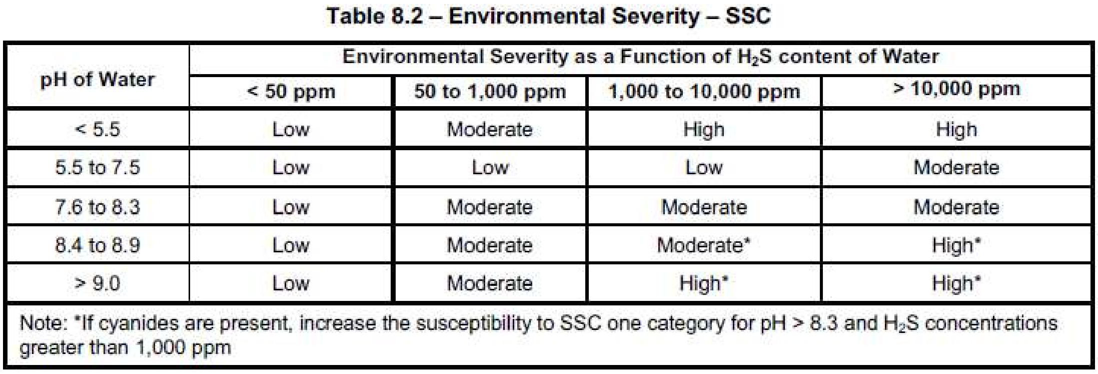


Table 8.2 – Environmental Severity – SSC

pH of Water	Environmental Severity as a Function of H_2S content of Water			
	< 50 ppm	50 to 1,000 ppm	1,000 to 10,000 ppm	> 10,000 ppm
< 5.5	Low	Moderate	High	High
5.5 to 7.5	Low	Low	Low	Moderate
7.6 to 8.3	Low	Moderate	Moderate	Moderate
8.4 to 8.9	Low	Moderate	Moderate*	High*
> 9.0	Low	Moderate	High*	High*

Note: *If cyanides are present, increase the susceptibility to SSC one category for pH > 8.3 and H_2S concentrations greater than 1,000 ppm

Environmental Severity of H2S : Moderate

Step 2

Determine the susceptibility for cracking using *figure 8.1* and *table 8.3* based on the environmental severity from step 1, the maximum brinnel hardness of weldments, and knowledge of whether the component was subject to PWHT.

Enviromental Severity of H2S : Moderate

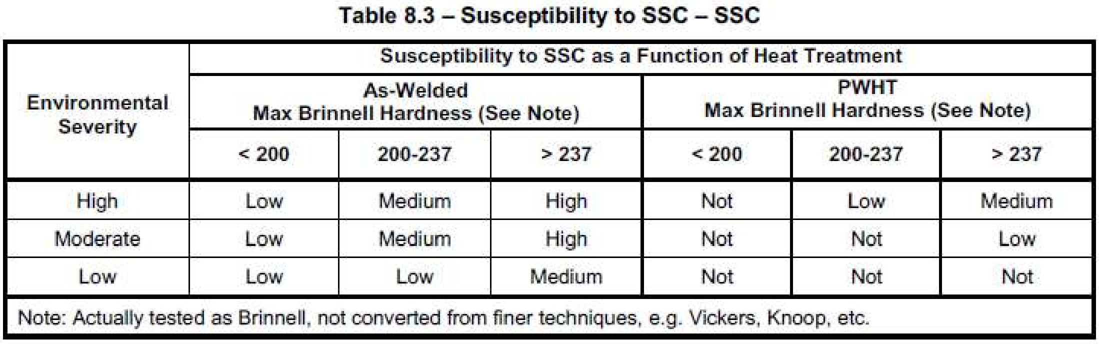


Table 8.3 – Susceptibility to SSC – SSC

Environmental Severity	Susceptibility to SSC as a Function of Heat Treatment					
	As-Welded Max Brinnell Hardness (See Note)			PWHT Max Brinnell Hardness (See Note)		
	< 200	200-237	> 237	< 200	200-237	> 237
High	Low	Medium	High	Not	Low	Medium
Moderate	Low	Medium	High	Not	Not	Low
Low	Low	Low	Medium	Not	Not	Not

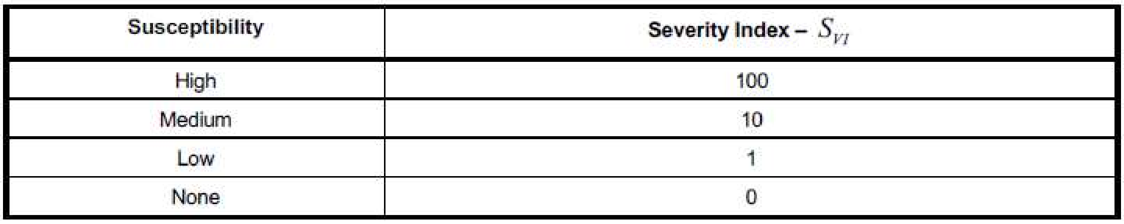
Note: Actually tested as Brinnell, not converted from finer techniques, e.g. Vickers, Knoop, etc.

Susceptibility to SCC : Low
PWTH : No

Step 3.

Based on the susceptibility in step 3, determine the severity index, S_{VI} from *Table 8.4.*

Table 8.4 – Determination of Severity Index – SSC



Susceptibility	Severity Index – S_{VI}
High	100
Medium	10
Low	1
None	0

Svi according to susceptibility to SCC : 1

Step 4.

Determine the time in-service, age , since the last Level A, B or C inspection was performed with no cracking detected or cracking was repaired. Cracking detected but not repaired should be evaluated and future inspection recommendations based upon FFS evaluation

In-service age : 14 year

age at the RBI Date

$$age_{RBI} = RBI\ Date - Last\ Inspection\ Date$$

age_{RBI} = 12/02/2019 - 26/11/2014

= 4 year

age at RBI Date: 18 year

Step 5.

Determine the number of inspections, and the corresponding inspection using Section 8.6.2 for past inspections performed during the in-service time. Combine the inspections toeffectiveness category the highest effectiveness performed using Section 3.4.3.

Inspection Performed : 2

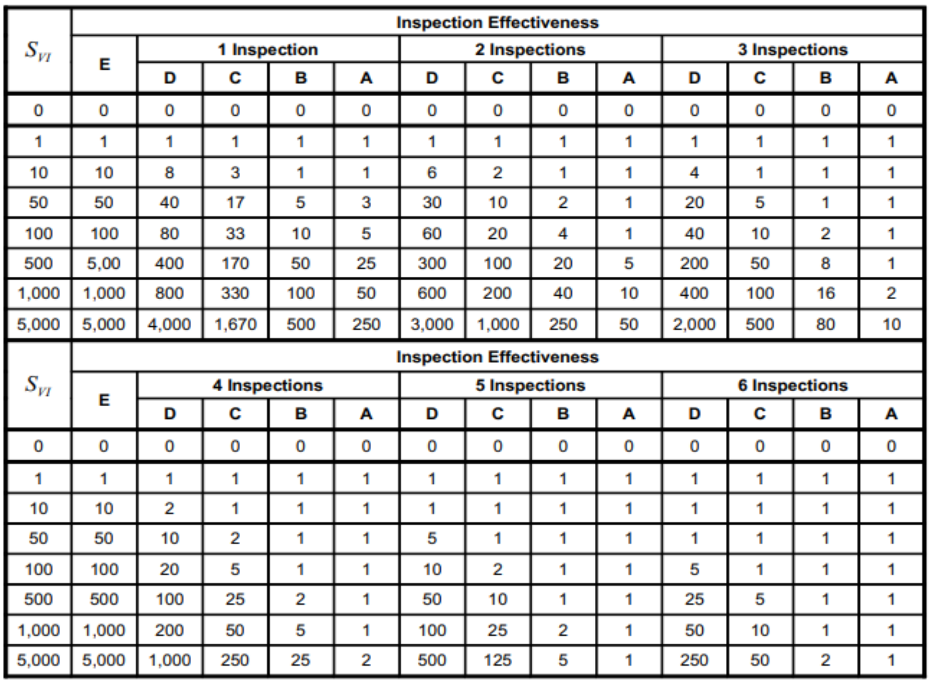
Inspection Category : 1A

Inspection Effectiveness : Highly Effective

Step 6.

Determine the base DF for sulfide stress cracking D_{fB}^{scc} using Table 6.3 based on the number of, and the highest inspection effectiveness determined in STEP 5, and the severity index S_{VI} from STEP 3.

Table 6.3 – SCC Damage Factors – All SCC Mechanisms



S_{VI}	Inspection Effectiveness												
	E	1 Inspection				2 Inspections				3 Inspections			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	8	3	1	1	6	2	1	1	4	1	1	1
50	50	40	17	5	3	30	10	2	1	20	5	1	1
100	100	80	33	10	5	60	20	4	1	40	10	2	1
500	5,00	400	170	50	25	300	100	20	5	200	50	8	1
1,000	1,000	800	330	100	50	600	200	40	10	400	100	16	2
5,000	5,000	4,000	1,670	500	250	3,000	1,000	250	50	2,000	500	80	10

S_{VI}	Inspection Effectiveness												
	E	4 Inspections				5 Inspections				6 Inspections			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	2	1	1	1	1	1	1	1	1	1	1	1
50	50	10	2	1	1	5	1	1	1	1	1	1	1
100	100	20	5	1	1	10	2	1	1	5	1	1	1
500	500	100	25	2	1	50	10	1	1	25	5	1	1
1,000	1,000	200	50	5	1	100	25	2	1	50	10	1	1
5,000	5,000	1,000	250	25	2	500	125	5	1	250	50	2	1

Inspection Effectiveness

Inspection Performed : 2

Inspection Category : 1A

Severity Index

S_{VI} according to susceptibility to SCC : 1

Base Damage factor

Base D_f : 1

Step 7.

Calculate the escalation in the DF based on the time in-service since the last inspection using the age from STEP 4 and Equation (2.27). In this equation, it is assumed that the probability for cracking will increase with time since the last inspection as a result of increased exposure to upset conditions and other non-normal conditions

by using equation 2.27 we can find out the Df.

Damage factor at RBI Date

D_f^{SSC}= $D_{fB}^{SCC}.(Max[age, 1.0])^{1.1}$

D_f^{SCC}= $1.(Max[5,1.0])^{1.1}$

D_f^{SCC}= 5.8730947

Damage factor at RBI Plan Date

D_f^{SSC}= $D_{fB}^{SCC}.(Max[age, 1.0])^{1.1}$

D_f^{SCC}= $1.(Max[11,1.0])^{1.1}$

D_f^{SCC}= 13.980798

step 1.

Determine the environmental severity (potential level of hydrogen flux) for cracking based on the content of the water and its pH using table 9.2.

pH : 5.52
Content of water : 1000 ppm

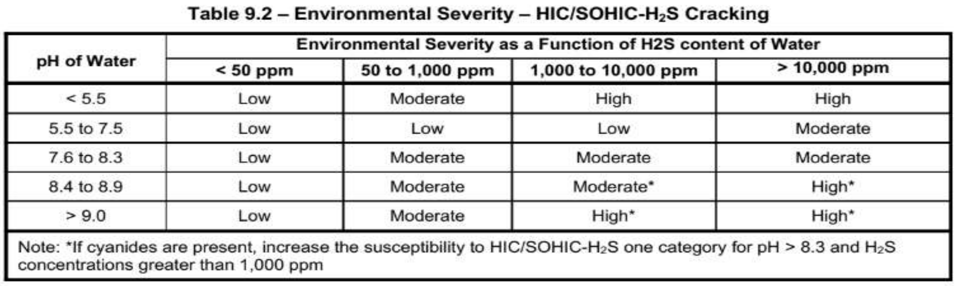


Table 9.2 – Environmental Severity – HIC/SOHIC-H_2S Cracking

pH of Water	Environmental Severity as a Function of H2S content of Water			
	< 50 ppm	50 to 1,000 ppm	1,000 to 10,000 ppm	> 10,000 ppm
< 5.5	Low	Moderate	High	High
5.5 to 7.5	Low	Low	Low	Moderate
7.6 to 8.3	Low	Moderate	Moderate	Moderate
8.4 to 8.9	Low	Moderate	Moderate*	High*
> 9.0	Low	Moderate	High*	High*

Note: *If cyanides are present, increase the susceptibility to HIC/SOHIC-H_2S one category for pH > 8.3 and H_2S concentrations greater than 1,000 ppm

Enviromental Severity : Moderate

Step 2

Determine the susceptibility for cracking using *figure 9.1* and *table 9.3* based on the environmental severity from step 1, the maximum brinnel hardness of weldments, and knowledge of whether the component was subject to PWHT.

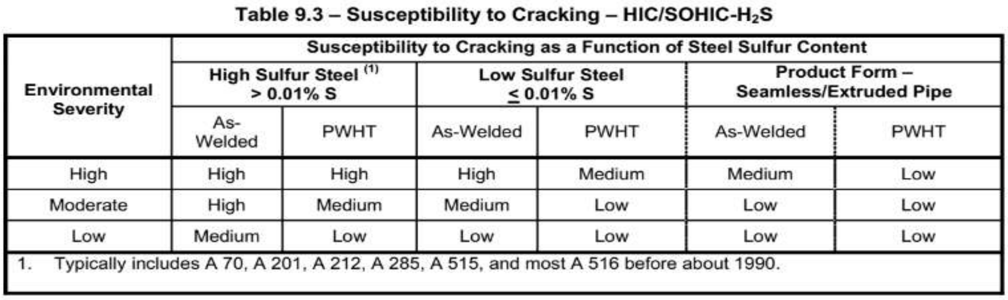


Table 9.3 – Susceptibility to Cracking – HIC/SOHIC-H_2S

Environmental Severity	Susceptibility to Cracking as a Function of Steel Sulfur Content					
	High Sulfur Steel [(1)] > 0.01% S		Low Sulfur Steel ≤ 0.01% S		Product Form – Seamless/Extruded Pipe	
	As-Welded	PWHT	As-Welded	PWHT	As-Welded	PWHT
High	High	High	High	Medium	Medium	Low
Moderate	High	Medium	Medium	Low	Low	Low
Low	Medium	Low	Low	Low	Low	Low

1. Typically includes A 70, A 201, A 212, A 285, A 515, and most A 516 before about 1990.

Steel sulfur content: 0.03 %
Environmental severity: Moderate
Post Weld Heat Treatment (PWHT): No
Susceptibility for Cracking: Medium

Step 3.

Based on the susceptibility in STEP 2, determine the severity index, SF/ , fro S_{VI} ble *9.4.*

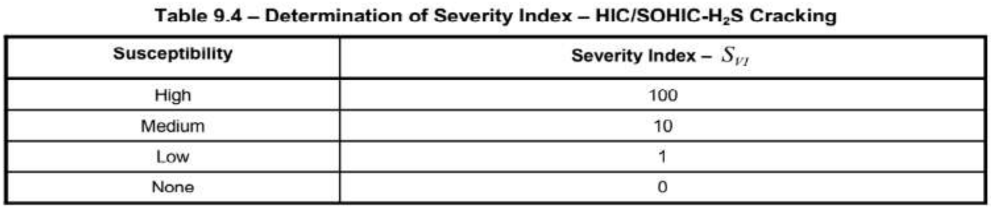


Table 9.4 – Determination of Severity Index – HIC/SOHIC-H_2S Cracking

Susceptibility	Severity Index – S_{VI}
High	100
Medium	10
Low	1
None	0

Suscpetibility from step 2 : Medium
Severity index : 10

Step 4.

Determine the time in-service, age , since the last Level A, B or C inspection was performed with no cracking detected or cracking was repaired. Cracking detected but not repaired should be evaluated and future inspection recommendations based upon FFS evaluation

Determine the time in service, age, since the last inspection.

age at the RBI Date

$age_{RBI} = RBI\ Date - Last\ Inspection\ Date$

age_{RBI} = 12/02/2019 - 26/11/2014
= 4 year

Step 5

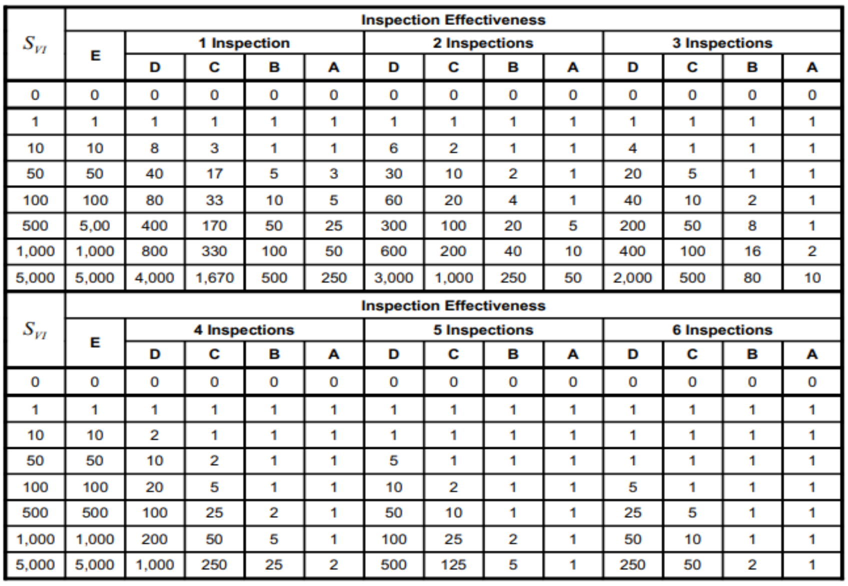
Determine the number of inspections, and the corresponding inspection using Section 9.6.2 for past inspections performed during the in-service time. Combine the inspections toeffectiveness category the highest effectiveness performed using Section 3.4.3.

Damage Mechanism : SCC
Inspection Performed : 2
Inspection Category : A
Inspection Effectiveness : Effective

Step 6.

Determine the base DF for HIC/SOHIC-H_2S using Table 6.3 based on the number of, and the highest inspection effectiveness determined in STEP 5, and the severity index from STEP 3.

Table 6.3 – SCC Damage Factors – All SCC Mechanisms



S_{VI}	Inspection Effectiveness												
	E	1 Inspection				2 Inspections				3 Inspections			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	8	3	1	1	6	2	1	1	4	1	1	1
50	50	40	17	5	3	30	10	2	1	20	5	1	1
100	100	80	33	10	5	60	20	4	1	40	10	2	1
500	5,00	400	170	50	25	300	100	20	5	200	50	8	1
1,000	1,000	800	330	100	50	600	200	40	10	400	100	16	2
5,000	5,000	4,000	1,670	500	250	3,000	1,000	250	50	2,000	500	80	10

S_{VI}	Inspection Effectiveness												
	E	4 Inspections				5 Inspections				6 Inspections			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	2	1	1	1	1	1	1	1	1	1	1	1
50	50	10	2	1	1	5	1	1	1	1	1	1	1
100	100	20	5	1	1	10	2	1	1	5	1	1	1
500	500	100	25	2	1	50	10	1	1	25	5	1	1
1,000	1,000	200	50	5	1	100	25	2	1	50	10	1	1
5,000	5,000	1,000	250	25	2	500	125	5	1	250	50	2	1

Inspection Effectiveness
Inspection Performed : 2
Inspection Category : 1A

Severity Index

S_{VI} according to susceptibility to SCC : 10

Base Damage factor

Base D_f : 10

Step 7. Determine the on-line adjustment factor, F_{OM} , from Table 9.5.

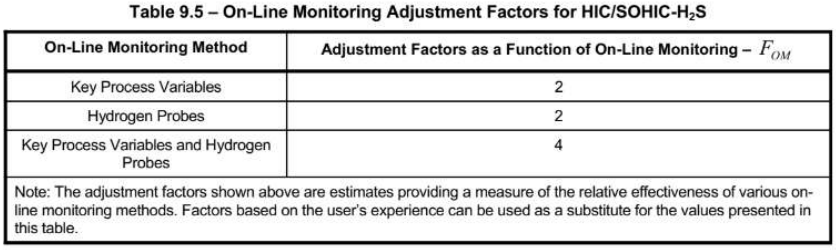


Table 9.5 – On-Line Monitoring Adjustment Factors for HIC/SOHIC-H_2S

On-Line Monitoring Method	Adjustment Factors as a Function of On-Line Monitoring – F_{OM}
Key Process Variables	2
Hydrogen Probes	2
Key Process Variables and Hydrogen Probes	4
Note: The adjustment factors shown above are estimates providing a measure of the relative effectiveness of various on-line monitoring methods. Factors based on the user's experience can be used as a substitute for the values presented in this table.	

Adjustment Factors:

Key Process Variables : 2

Step 8. Calculate the final DF accounting for escalation based on the time in-service since the last inspection using the age from STEP 4 and Equation (2.28). In this equation, it is assumed that the probability for cracking will increase with time since the last inspection as a result of increased exposure to upset conditions and other non-normal conditions. The equation also applies the adjustment factor for online monitoring

Damage Factor at RBI Date

$$D_f^{HIC\ SOHIC-H2S} = \frac{D_{fB}^{HIC\ SOHIC-H2S}.(Max[age,1.0])^{1.1}}{Fom}$$

$$D_f^{HIC\ SOHIC-H2S} = \frac{1.(Max[4,1.0])^{1.1}}{2}$$

$$D_f^{HIC\ SOHIC-H2S} = 45.94793$$

Damage Factor at RBI Plan Date

$$D_f^{HIC\ SOHIC-H2S} = \frac{D_{fB}^{HIC\ SOHIC-H2S}.(Max[age,1.0])^{1.1}}{Fom}$$

$$D_f^{HIC\ SOHIC-H2S} = \frac{1.(Max[11,1.0])^{1.1}}{2}$$

$$D_f^{HIC\ SOHIC-H2S} = 112.1158$$

Calculating Damage Factor

Damage Factor for Stress Corrosion Cracking

Calculation of damage factor for stress corrosion cracking (SCC) explained in section 3.4.2 - API RP 581 Part 2 3rd Edition. For multipe SCC damage factor mechanisms case, determined using equation (2.6).

$$D_{f-gov}^{scc} = max \begin{bmatrix} D_f^{caustic}, D_f^{amine}, D_f^{scc}, D_f^{HIC/SOHIC-H_2S}, D_f^{ACSCC}, \\ D_f^{PASCC}, D_f^{CLSCC}, D_f^{HSC\_HF}, D_f^{HIC/SOHIC-HF} \end{bmatrix}$$

D_{f-gov}^{scc} = 45.9479342

= 112.1158

Damage Factor for Thinning

D_f^{Thin} = Max[($\frac{(D_{fb}^{Thin}}{F_{OM}}$),0.1]

= 0.201588995

Total Damage Factor

If the external and thinning damage are general, then damage is likely to occur at the same location and
the total DF is given by Equation (2.3)

$$D_{f-total} = D_{f-gov}^{thin} + D_{f-gov}^{extd} + D_{f-gov}^{scc} + D_f^{htha} + D_{f-gov}^{brit} + D_f^{mfat}$$

RBI Date 46.14952 Plan Date 123.5281

Calculating Probability of Failure:

After determining the value of gff, Fms and Df we can calculate the probability of failure using the equation:

Pf (t) = gff . Fms . D f (t)

Pf (t) = 3.06E−0.5 . 0.182390 . 18.43159

Pf (t) = 0.012468978

RBI Date PoF	**RBI Plan Date PoF**
0.012468978	0.083797304

Probability of Failure

the probability of failure can be calculated using the equation of;

Pf (t) = gff . Fms . D f (t)

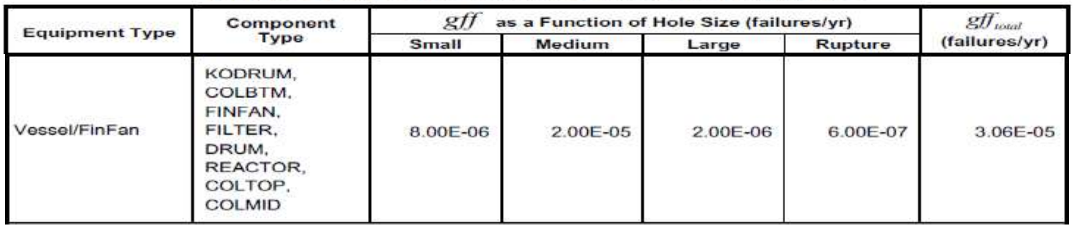
it can be known that

pf (t)	=	The PoF as a function of time
gff	=	General failure frequency
Fms	=	Management system factor
Df (t)	=	Total damage factor

Determining General failure frequency (gff)

To determine the value of gff, we can use the recommended list from table 3.1 [1-8] of API RBI 581

Table 3.1 – Suggested Component Generic Failure Frequencies

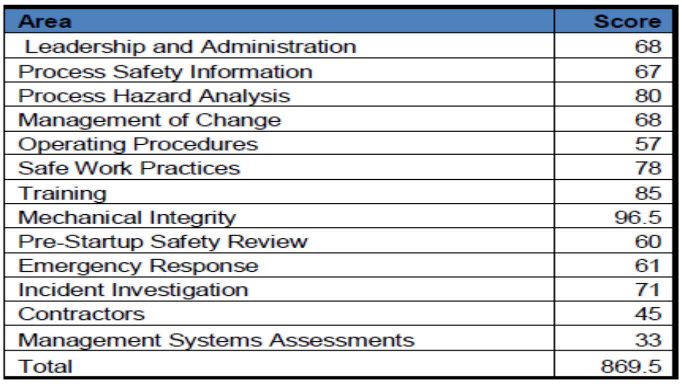


Equipment Type	Component Type	gff as a Function of Hole Size (failures/yr)				gff_{total} (failures/yr)
		Small	Medium	Large	Rupture	
Vessel/FinFan	KODRUM, COLBTM, FINFAN, FILTER, DRUM, REACTOR, COLTOP, COLMID	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05

from the table we can determine that the value of gff is: **3.06E-05**

Determining Management system factor (Fms)

To determine the value of Fms, we use a series of question and survey given by API RBI 581 to determine Fms value



Area	Score
Leadership and Administration	68
Process Safety Information	67
Process Hazard Analysis	80
Management of Change	68
Operating Procedures	57
Safe Work Practices	78
Training	85
Mechanical Integrity	96.5
Pre-Startup Safety Review	60
Emergency Response	61
Incident Investigation	71
Contractors	45
Management Systems Assessments	33
Total	869.5

Management system factor score according from the survey, the score is **869.5**

the score must first be converted into percentage using the equation of:

$$pscore = \frac{Score}{1000} \, .100 \text{ [unit is 100\%]}$$

based from equation, the $pscore$ is **86.95%**

To determine the value of Fms we can use the equation:

$$Fms = 10^{(-0.02 \, .pscore+1)}$$

$$Fms = 10^{(-0.02 \, .86.95+1)}$$

$$Fms = 0.182390$$

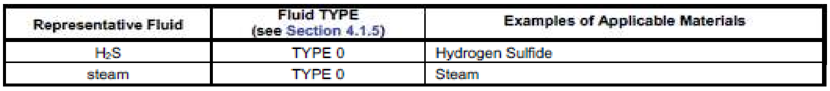
From the equation we can determine that the value of Fms is **0.182390**

Consequence of Failure

Step 1. Determine the release fluid and its properties, including the release phase.

Step 1.1. Select a representative fluid group from table 4.1.

List of representative fluid



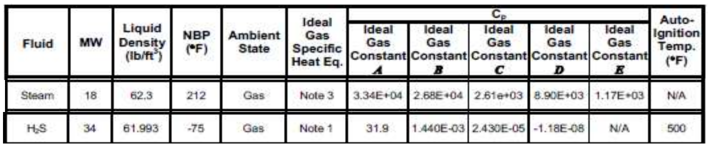
Representative Fluid	Fluid TYPE (see Section 4.1.5)	Examples of Applicable Materials
H_2S	TYPE 0	Hydrogen Sulfide
steam	TYPE 0	Steam

Choosen Representative Fluid : H_2S

Step 1.2 Determine the stored fluid phase

Stored fluid phase: Liquid

Step 1.3 Determine the stored fluid propertioes

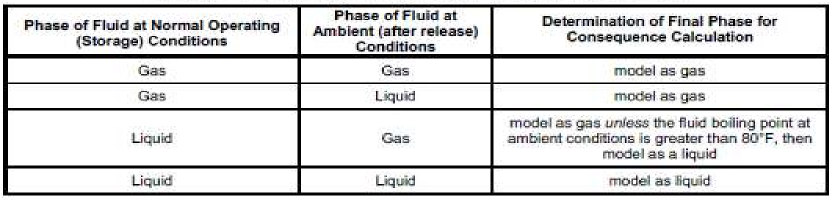


Fluid	MW	Liquid Density (lb/ft^3)	NBP (°F)	Ambient State	Ideal Gas Specific Heat Eq.	C_p Ideal Gas Constant *A*	Ideal Gas Constant *B*	Ideal Gas Constant *C*	Ideal Gas Constant *D*	Ideal Gas Constant *E*	Auto-Ignition Temp. (°F)
Steam	18	62.3	212	Gas	Note 3	3.34E+04	2.68E+04	2.61e+03	8.90E+03	1.17E+03	N/A
H_2S	34	61.993	-75	Gas	Note 1	31.9	1.440E-03	2.430E-05	-1.18E-08	N/A	500

Liquid density : 993.0326 Kg/m^3
NBP : -59.4444 C°
Auto-Ignition Tempt : 260 C°

Step 1.4 Determine the steady state phase of the liquid after release to the atmosphere using table 5.3

Table 4.3 – Level 1 Guidelines for Determining the Phase of a Fluid



Phase of Fluid at Normal Operating (Storage) Conditions	Phase of Fluid at Ambient (after release) Conditions	Determination of Final Phase for Consequence Calculation
Gas	Gas	model as gas
Gas	Liquid	model as gas
Liquid	Gas	model as gas *unless* the fluid boiling point at ambient conditions is greater than 80°F, then model as a liquid
Liquid	Liquid	model as liquid

Discharge Coefficient Liquid : 0.61
Viscosity Correction Factor : 1
Gravitional Constant : 1

The fluid is liquid in the vessel, it’s post release is gas

step 2 Select a set of release hole sizes to determine the possible range of consequences in the risk calculation.

Step. 2.1

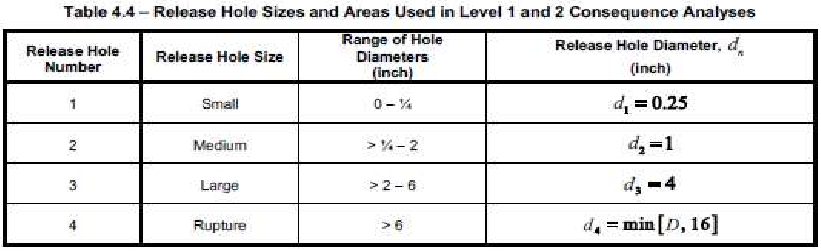
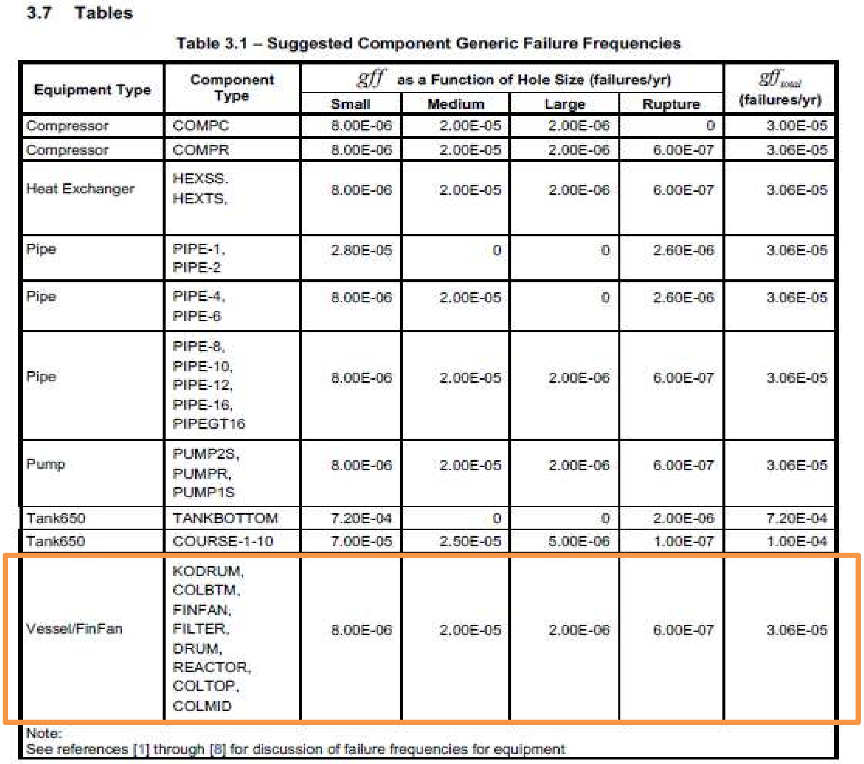


Table 4.4 – Release Hole Sizes and Areas Used in Level 1 and 2 Consequence Analyses

Release Hole Number	Release Hole Size	Range of Hole Diameters (inch)	Release Hole Diameter, d_n (inch)
1	Small	0 – ¼	$d_1 = 0.25$
2	Medium	> ¼ – 2	$d_2 = 1$
3	Large	> 2 – 6	$d_3 = 4$
4	Rupture	> 6	$d_4 = \min[D, 16]$

Step 2.2

Determine the generic failure frequency for the n release hole size from table 3.1 part 2.



3.7 Tables

Table 3.1 – Suggested Component Generic Failure Frequencies

Equipment Type	Component Type	gff as a Function of Hole Size (failures/yr)				gff_{total} (failures/yr)
		Small	Medium	Large	Rupture	
Compressor	COMPC	8.00E-06	2.00E-05	2.00E-06	0	3.00E-05
Compressor	COMPR	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Heat Exchanger	HEXSS, HEXTS,	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Pipe	PIPE-1, PIPE-2	2.80E-05	0	0	2.60E-06	3.06E-05
Pipe	PIPE-4, PIPE-6	8.00E-06	2.00E-05	0	2.60E-06	3.06E-05
Pipe	PIPE-8, PIPE-10, PIPE-12, PIPE-16, PIPEGT16	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Pump	PUMP2S, PUMPR, PUMP1S	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Tank650	TANKBOTTOM	7.20E-04	0	0	2.00E-06	7.20E-04
Tank650	COURSE-1-10	7.00E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04
Vessel/FinFan	KODRUM, COLBTM, FINFAN, FILTER, DRUM, REACTOR, COLTOP, COLMID	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05

Note:
See references [1] through [8] for discussion of failure frequencies for equipment

Step 3. Calculate the theoritical release rate

Step 3.1 Select the appropriate release rate equation using the determined stored fluid phase.

Stored fluid type : Vapour

Step 3.2 Compute the release hole size area A_n in mm^2, using equation (3.8) based on d_n

$$An = \frac{\pi d_n^2}{4} \qquad \text{e.q 3.8}$$

Release for small hole size

$$An = \frac{\pi\,(0.25)^2}{4}$$

$$An = \frac{126.6127}{4}$$

$An = 0.0491$ inch

= 3.00E-05 m^2

Release for medium hole size

$$An = \frac{\pi\,(1)^2}{4}$$

$$An = \frac{2025.802}{4}$$

$An = 0.785$ mm^2

5.00E-04 m^2

Release for Large hole size

$$An = \frac{\pi\,(4\,)^2}{4}$$

$$An = \frac{32412.84}{4}$$

$An = 12.56$ mm^2

0.008 m^2

Release for Rupture hole size

$$An = \frac{\pi\,(16\,)^2}{4}$$

$$An = \frac{72928.89}{4}$$

$An = 201$ mm^2

0.13 m^2

Step 3.3 Calculate Viscosity Correction Factor

Kv_1 = 1 Kv_4 = 1

Kv_2 = 1

Kv_3 = 1

Step 3.4

For release hole, calculate the release rate, Wn, In Kg/s for each release area, An, using the formula:

For Vapour release rate, we must first find the transition pressure (P_{trans}).

$$Ptrans = Patm\left(\frac{k+1}{2}\right)^{\frac{k}{k-1}}$$

$$k = \frac{Cp}{Cp - R}$$

$$Ptrans = 1\left(\frac{1.27+1}{2}\right)^{\frac{1.27}{1.27-1}}$$

$$k = \frac{39.1}{39.1 - 8.314}$$

$k =$ 1.270058

$$Ptrans = 1.814196$$

Since P_s is greater than $_{Ptrans}$, we can use equation (3.6) to determine vapour flow rate

$$Wn = \frac{C_d}{C_2}\,.An\,.Ps\sqrt{\left(\frac{k\,.MW\,.gc}{R\,.Ts}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

For Small hole release size

$$W_1 = \frac{C_d}{C_2}\,.An\,.Ps\sqrt{\left(\frac{k\,.MW\,.gc}{R\,.Ts}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

$$W_1 = \frac{0.90}{1}\,.31.65316\,.1060\sqrt{\left(\frac{1.27\,.34\,.1}{8.314\,.453.15}\right)\left(\frac{2}{1.27+1}\right)^{\frac{1.27+1}{1.27-1}}}$$

$$W_1 = 31214.71433\sqrt{2.33497\text{E}{-05}}$$

$W_1 =$ 0.001949247 Kg/s

For Medium hole release size

$$W_2 = \frac{C_d}{C_2}\,.An\,.Ps\sqrt{\left(\frac{k\,.MW\,.gc}{R\,.Ts}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

$$W_2 = \frac{0.90}{1000}\,.506.4506\,.1060\sqrt{\left(\frac{1.27\,.34\,.1}{8.314\,.453.15}\right)\left(\frac{2}{1.27+1}\right)^{\frac{1.27+1}{1.27-1}}}$$

$$W_2 = 499435.5\sqrt{2.33497\text{E}{-05}}$$

$W_2 =$ 0.093635081 Kg/s

For Large hole release size

$$W_3 = \frac{C_d}{C_2}\,.An\,.Ps\sqrt{\left(\frac{k\,.MW\,.gc}{R\,.Ts}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

$$W_3 = \frac{0.90}{1}\,.8103.21\,.1060\sqrt{\left(\frac{1.27\,.34\,.1}{8.314\,.453.15}\right)\left(\frac{2}{1.27+1}\right)^{\frac{1.27+1}{1.27-1}}}$$

$$W_3 = 7990968\sqrt{2.33497\text{E}{-05}}$$

$W_3 =$ 0.47857007 Kg/s

For Rupture hole release size

$$W_4 = \frac{C_d}{C_2}\,.An\,.Ps\sqrt{\left(\frac{k\,.MW\,.gc}{R\,.Ts}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

$$W_4 = \frac{0.90}{0.9674}\,.18232.22\,.1060\sqrt{\left(\frac{1.27\,.34\,.1}{8.314\,.453.15}\right)\left(\frac{2}{1.27+1}\right)^{\frac{1.27+1}{1.27-1}}}$$

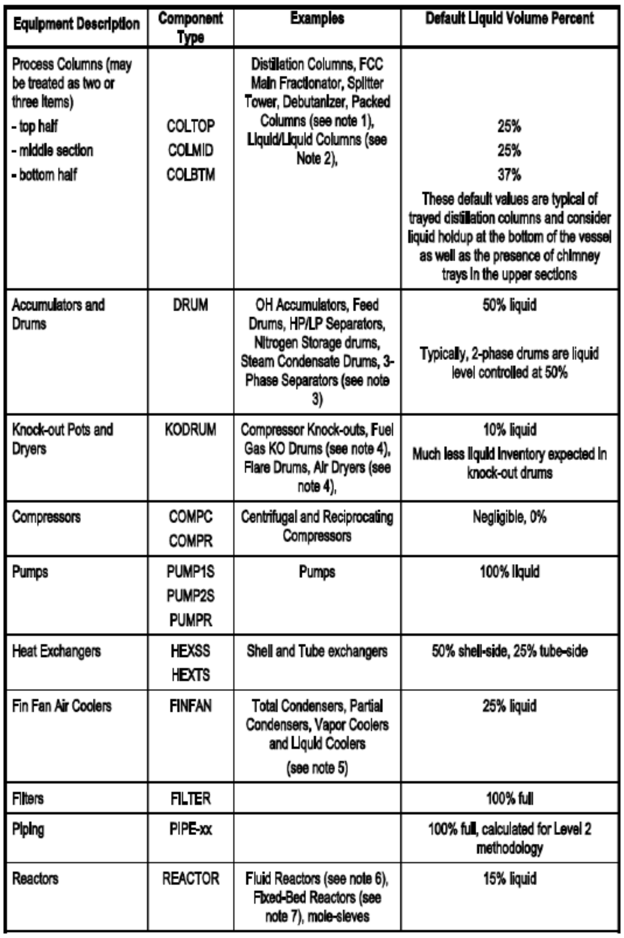
$$W_4 = 17979675.3\sqrt{2.33497\text{E}{-05}}$$

$W_4 =$ 23.9646359676799 Kg/s

Step 4. Estimate the Maximum Mass Avaible for Release (Availble Mass)

Step 4.1 Group components and equipment items into inventory groups

Table 3.A.3.2 — Assumptions Used When Calculating Liquid Inventories Within Equipment



Equipment Description	Component Type	Examples	Default Liquid Volume Percent
Process Columns (may be treated as two or three items) - top half - middle section - bottom half	 COLTOP COLMID COLBTM	Distillation Columns, FCC Main Fractionator, Splitter Tower, Debutanizer, Packed Columns (see note 1), Liquid/Liquid Columns (see Note 2),	25% 25% 37% These default values are typical of trayed distillation columns and consider liquid holdup at the bottom of the vessel as well as the presence of chimney trays in the upper sections
Accumulators and Drums	DRUM	OH Accumulators, Feed Drums, HP/LP Separators, Nitrogen Storage drums, Steam Condensate Drums, 3-Phase Separators (see note 3)	50% liquid Typically, 2-phase drums are liquid level controlled at 50%
Knock-out Pots and Dryers	KODRUM	Compressor Knock-outs, Fuel Gas KO Drums (see note 4), Flare Drums, Air Dryers (see note 4),	10% liquid Much less liquid inventory expected in knock-out drums
Compressors	COMPC COMPR	Centrifugal and Reciprocating Compressors	Negligible, 0%
Pumps	PUMP1S PUMP2S PUMPR	Pumps	100% liquid
Heat Exchangers	HEXSS HEXTS	Shell and Tube exchangers	50% shell-side, 25% tube-side
Fin Fan Air Coolers	FINFAN	Total Condensers, Partial Condensers, Vapor Coolers and Liquid Coolers (see note 5)	25% liquid
Filters	FILTER		100% full
Piping	PIPE-xx		100% full, calculated for Level 2 methodology
Reactors	REACTOR	Fluid Reactors (see note 6), Fixed-Bed Reactors (see note 7), mole-sieves	15% liquid

Step 4.2 Calculate the fluid mass, mass comp, in the component being evaluated

Volume of Cylinder

$$V_{cyl} = \pi R^2 L$$

R = ID/2 = 1.067 m

L = 10.5 m

V_{cyl} = 37.536 m^3

Liquid Volume = (50/100) x V_{cyl} = 18.77 m^3

Vapor Volume = (1-(50/100)) x $_{Vcyl}$ = 18.77 m^3

the mass in component

mass_{cc} = $(V_l \rho_l) + (V_v \rho_v)$

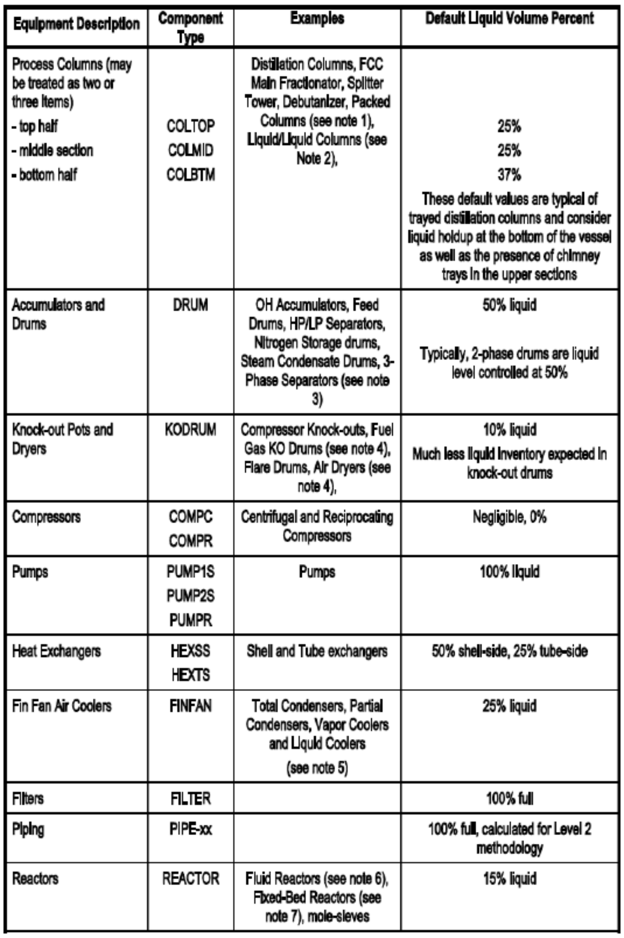
mass_{cc} = 18746 kg

Step 4.3 Calculate fluid mass in each of the other components that are included in the inventory group, mass comp

Step 4. Estimate the Maximum Mass Avaible for Release (Availble Mass)

Step 4.1 Group components and equipment items into inventory groups

Table 3.A.3.2 — Assumptions Used When Calculating Liquid Inventories Within Equipment



Equipment Description	Component Type	Examples	Default Liquid Volume Percent
Process Columns (may be treated as two or three items) - top half - middle section - bottom half	 COLTOP COLMID COLBTM	Distillation Columns, FCC Main Fractionator, Splitter Tower, Debutanizer, Packed Columns (see note 1), Liquid/Liquid Columns (see Note 2),	25% 25% 37% These default values are typical of trayed distillation columns and consider liquid holdup at the bottom of the vessel as well as the presence of chimney trays in the upper sections
Accumulators and Drums	DRUM	OH Accumulators, Feed Drums, HP/LP Separators, Nitrogen Storage drums, Steam Condensate Drums, 3-Phase Separators (see note 3)	50% liquid Typically, 2-phase drums are liquid level controlled at 50%
Knock-out Pots and Dryers	KODRUM	Compressor Knock-outs, Fuel Gas KO Drums (see note 4), Flare Drums, Air Dryers (see note 4),	10% liquid Much less liquid inventory expected in knock-out drums
Compressors	COMPC COMPR	Centrifugal and Reciprocating Compressors	Negligible, 0%
Pumps	PUMP1S PUMP2S PUMPR	Pumps	100% liquid
Heat Exchangers	HEXSS HEXTS	Shell and Tube exchangers	50% shell-side, 25% tube-side
Fin Fan Air Coolers	FINFAN	Total Condensers, Partial Condensers, Vapor Coolers and Liquid Coolers (see note 5)	25% liquid
Filters	FILTER		100% full
Piping	PIPE-xx		100% full, calculated for Level 2 methodology
Reactors	REACTOR	Fluid Reactors (see note 6), Fixed-Bed Reactors (see note 7), mole-sleves	15% liquid

Step 4.2 Calculate the fluid mass, mass comp, in the component being evaluated

Volume of Cylinder

$$V_{cyl} = \pi R^2 L$$

R = ID/2 = 1.067 m

L = 10.5 m

V_{cyl} = 37.536 m^3

Liquid Volume = (50/100) x V_{cyl} = 18.77 m^3

Vapor Volume = (1-(50/100)) x V_{cyl} = 18.77 m^3

the mass in component

$mass_{cc} = (V_l \rho_l) + (V_v \rho_v)$

$mass_{cc}$ = 18746 kg

Step 4.3 Calculate fluid mass in each of the other components that are included in the inventory group, mass comp

Step 4.4 Calculate the fluid mass on the inventory group, *mass* $_{inv}$

$$mass_{inv} = \sum_{i=1}^{N} mass\ _{comp}$$

$$mass_{inv} = \sum_{i=1}^{N} 18639.3$$

$$mass_{inv} = \sum_{i=1}^{1} 18639.3$$

$mass_{inv} =$ **18639.3 Kg**

Step 4.5 Calculate the flow rate from a 203 mm (8 inch) diameter hole, Wmax8, using equations (3.3), (3,6) or (3,7) as applicable, with $A_n = A_8$ = 32,450 mm2 (50.3 inch2).

$$W_{max\ 8} = \frac{C_d}{C_2} . A_8 . Ps \sqrt{\left(\frac{k . MW . gc}{R . Ts}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

$$W_{max\ 8} = \frac{0.90}{1} . 32450 . 1060 \sqrt{\left(\frac{1.27 . 34 . 1}{8.314 . 453.15}\right)\left(\frac{2}{1.27+1}\right)^{\frac{1.27+1}{1.27-1}}}$$

$W_{max\ 8}\ \_$ 3.716 Kg

Step 4.6 for each release hole size, calculate the added fluid mass, *mass* $_{add\ ,\ n\ ,}$, resulting from three minutes of flow from the inventory group using equation (3.10) where W_n is the leakage rate for the release hole size.

$mass\ _{\mathrm{add\ n}} = 180 . \mathrm{Min}\ [W_n , Wmax_{8]}$

for small hole release size

$mass\ _{\mathrm{add\ 1\ \_\ 180}}\ \mathrm{Min}\ [W_n , Wmax_{8]}$
$mass\ _{addl,\ 1\ =\ 180\ .} Min\ [28959.46 . 3.716]$

mass $_{add, 1}$ = 0.35086447 Kg/s

for Medium hole release size

$mass\ _{\mathrm{add\ 2\ \_\ 180}}\ \mathrm{Min}\ [W_n , Wmax_{8]}$

$mass\ _{add\ 2\ \_\ 180}\ Min\ [463351.4\ , 3841.08334]$
mass $_{add, 2}$ = 16.85 Kg/s

for Large hole release size

$mass\ _{\mathrm{add\ 3\ \_\ 180}}\ \mathrm{Min}\ [W_n , Wmax_{8]}$
mass $_{add,3}$ = 84.17

for Rupture hole release size

$mass\ _{\mathrm{add\ 4\ \_\ 180}}\ \mathrm{Min}\ [W_n , Wmax_{8]}$
mass $_{add,4}$ = 84.17

Step 4.7 For each release hole size, calculate the avaible mas for release.

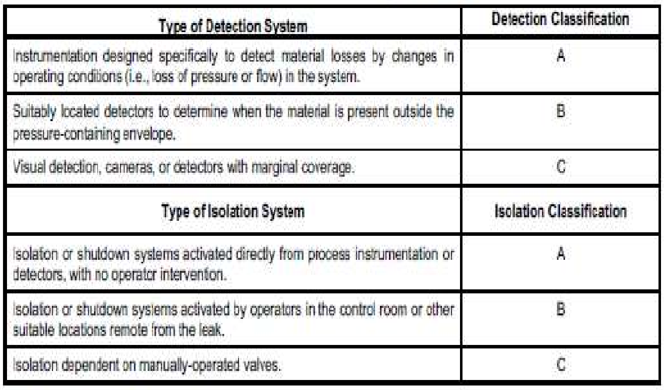
$$Mass\ _{avail} = \min[\ \{mass\ _{comp} + mass\ _{add}\}, mass\ _{Inv}]$$

$Mass\ _{avail} =$ 18746 kg

Step 6. Estimeate the impact of detection and isolation systems on release magnitude.

Step 6.1 Determine the detection and isolation systems present in the unit

Table 4.5 – Detection and Isolation System Rating Guide



Type of Detection System	Detection Classification
Instrumentation designed specifically to detect material losses by changes in operating conditions (i.e., loss of pressure or flow) in the system.	A
Suitably located detectors to determine when the material is present outside the pressure-containing envelope.	B
Visual detection, cameras, or detectors with marginal coverage.	C
Type of Isolation System	**Isolation Classification**
Isolation or shutdown systems activated directly from process instrumentation or detectors, with no operator intervention.	A
Isolation or shutdown systems activated by operators in the control room or other suitable locations remote from the leak.	B
Isolation dependent on manually-operated valves.	C

Step 6.2 Using table 4.5, select the appropriate classification (A,B,C) for the detection system.

Detection System C

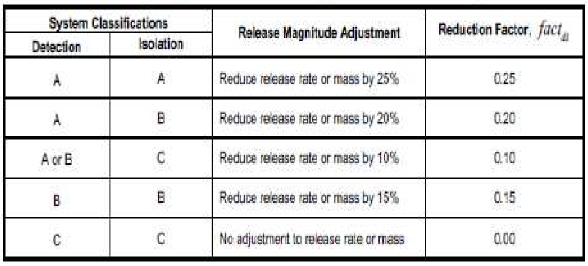
Step 6.3 Using table 4.5, select the appropriate classification (A,B,C) for the isolation system.

Isolation System C

Step 6.4

Using table 4.6 and the classification determined in step 6.2 and step 6.3, determine the release reductio factor

Table 4.6 – Adjustments to Release Based on Detection and Isolation Systems



System Classifications		Release Magnitude Adjustment	Reduction Factor, $fact_{di}$
Detection	Isolation		
A	A	Reduce release rate or mass by 25%	0.25
A	B	Reduce release rate or mass by 20%	0.20
A or B	C	Reduce release rate or mass by 10%	0.10
B	B	Reduce release rate or mass by 15%	0.15
C	C	No adjustment to release rate or mass	0.00

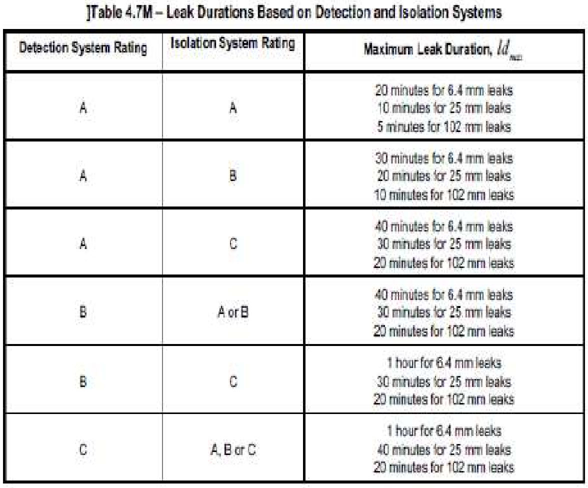
Detection System C

Isolation System C

$fact_{di}$ = 0.00

Step 6.5

Using table 4.7 and the classification determined in step 6.2 and 6.3, determine the total leak durations for each of the selected release hole sizes, $Id_{max,n}$



]Table 4.7M – Leak Durations Based on Detection and Isolation Systems

Detection System Rating	Isolation System Rating	Maximum Leak Duration, ld_{max}
A	A	20 minutes for 6.4 mm leaks 10 minutes for 25 mm leaks 5 minutes for 102 mm leaks
A	B	30 minutes for 6.4 mm leaks 20 minutes for 25 mm leaks 10 minutes for 102 mm leaks
A	C	40 minutes for 6.4 mm leaks 30 minutes for 25 mm leaks 20 minutes for 102 mm leaks
B	A or B	40 minutes for 6.4 mm leaks 30 minutes for 25 mm leaks 20 minutes for 102 mm leaks
B	C	1 hour for 6.4 mm leaks 30 minutes for 25 mm leaks 20 minutes for 102 mm leaks
C	A, B or C	1 hour for 6.4 mm leaks 40 minutes for 25 mm leaks 20 minutes for 102 mm leaks

Detection Sys	A		
Isolation Syste	B		
$Id_{max,1}$	6.4 mn	60	minutes
$Id_{max,2}$	25 mm	40	minutes
$Id_{max,3}$	102 mı	20	minutes

Step 7 Determine the release rate and mass for consequence analysis

Step 7.1

For each release hole size, calculate the adjusted release rate, $_{rate\ n}$. using equation (3.13)

$$rate_n = Wn\ (1 - factdi)$$

Small Hole size

$$rate_1 = W_1\ (1 - factdi)$$

$$rate_1 = 3746.761958\ \ (1 - factdi)$$

rate $_1$ = 0.00195 kg/s

Medium Hole size

$$rate_2 = W_2\ (1 - factdi)$$

$$rate_2 = 59948.2\ \ (1 - factdi)$$

rate $_2$ = 0.09364 kg/s

Large Hole size

$$rate_3 = W_3\ (1 - factdi)$$

$$rate_3 = 959171.184\ \ (1 - factdi)$$

rate $_3$ = 0.47857 kg/s

Large Hole size

$$rate_4 = W_4\ (1 - factdi)$$

$$rate_4 = 2158134.87\ \ (1 - factdi)$$

rate $_4$ = 23.9646 kg/s

Step 7.2

For each release hole size, calculate the leak duration, **id_{n},** of the release using equation (3.15), based on the avaible mass, ***mass*** $_{avail,n}$

$$Id_n = \min\left[\left\{\frac{mass_{availn}}{rate_n}\right\}, \{60.\,idmax_{,n}\}\right]$$

Small Hole size

$$Id_1 = \min\left[\left\{\frac{mass_{avail1}}{rate_1}\right\}, \{60.\,idmax_{,1}\}\right]$$

= 3600

Medium Hole size

$$Id_2 = \min\left[\left\{\frac{mass_{avail2}}{rate_2}\right\}, \{60.\,idmax_{,2}\}\right]$$

= 1200

Large Hole size

$$Id_3 = \min\left[\left\{\frac{mass_{avail3}}{rate_3}\right\}, \{60.\,idmax_{,3}\}\right]$$

= 600

Large Hole size

$$Id_4 = \min\left[\left\{\frac{mass_{avail4}}{rate_4}\right\}, \{60.\,idmax_{,4}\}\right]$$

= 600

Step 7.3

For each release hole size, calculate the release mass, massn, using equation (3.14) based on the release rate, raten, from step 3.2, the lead duration idn, from step 7.2 and the available mass, massavailn, from step 4.6

$$mass_n = \min[\{rate_n\,.\,idn\}, massavailn]$$

Small Hole Size

$$mass_1 = \min[\{rate_1\,.\,id_1\}, massavail_{1]}$$

$mass_1$ = 7.01729

Medium Hole Size

$$mass_2 = \min[\{rate_2\,.\,id_2\}, massavail_{2]}$$

$mass_2$ = 112.362

Large Hole Size

$$mass_3 = \min[\{rate_3\,.\,id_3\}, massavail_{3]}$$

$mass_3$ = 287.142

Rupture Hole Size

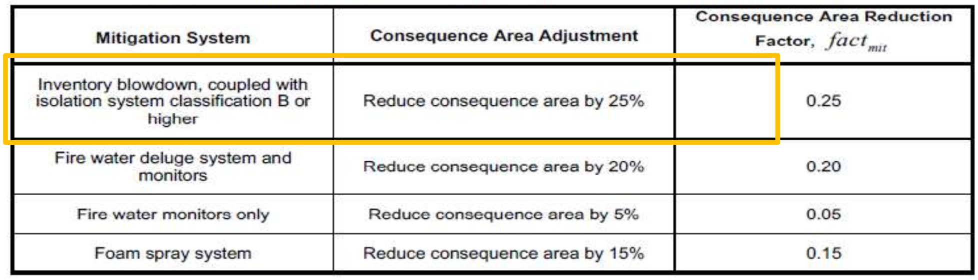
$$mass_4 = \min[\{rate_4\,.\,id_4\}, massavail_{4]}$$

$mass_4$ = 14378.8

Step 8 Determining Flammable and Explosive Consequences

Step 8.1 Select the consequence area mitigation reduction factor, $fact_{mit}$, from table 4.10

Table 4.10 – Adjustments to Flammable Consequence for Mitigation Systems



Mitigation System	Consequence Area Adjustment	Consequence Area Reduction Factor, $fact_{mit}$
Inventory blowdown, coupled with isolation system classification B or higher	Reduce consequence area by 25%	0.25
Fire water deluge system and monitors	Reduce consequence area by 20%	0.20
Fire water monitors only	Reduce consequence area by 5%	0.05
Foam spray system	Reduce consequence area by 15%	0.15

$fact_{mit}$ = 0

Step 8.2 For each release hole size, calculate the energy efficiency correction factor, $eneff_n$ using equation 3.18

$$eneff_n = 4.log_{10}[C_4.massn] - 15$$

for small hole size

$$eneff_1 = 4.log_{10}[C_4.mass_1] - 15$$

$eneff_1$ = 1.758311923 1.758

for medium hole size

$$eneff_2 = 4.log_{10}[C_4.mass_2] - 15$$

$eneff_2$ = 6.576113718

for large hole size

$$eneff_3 = 4.log_{10}[C_4.mass_2] - 15$$

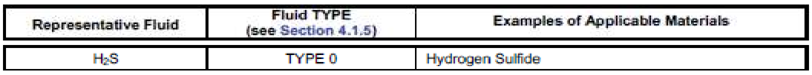
$eneff_3$ = 8.206021514

for rupture hole size

$$eneff_3 = 4.log_{10}[C_4.mass_2] - 15$$

$eneff_3$ = 15.00452272

Step 8.3 Determine the fluid type, either Type 0 or Type 1 from table 4.1



Representative Fluid	Fluid TYPE (see Section 4.1.5)	Examples of Applicable Materials
H_2S	TYPE 0	Hydrogen Sulfide

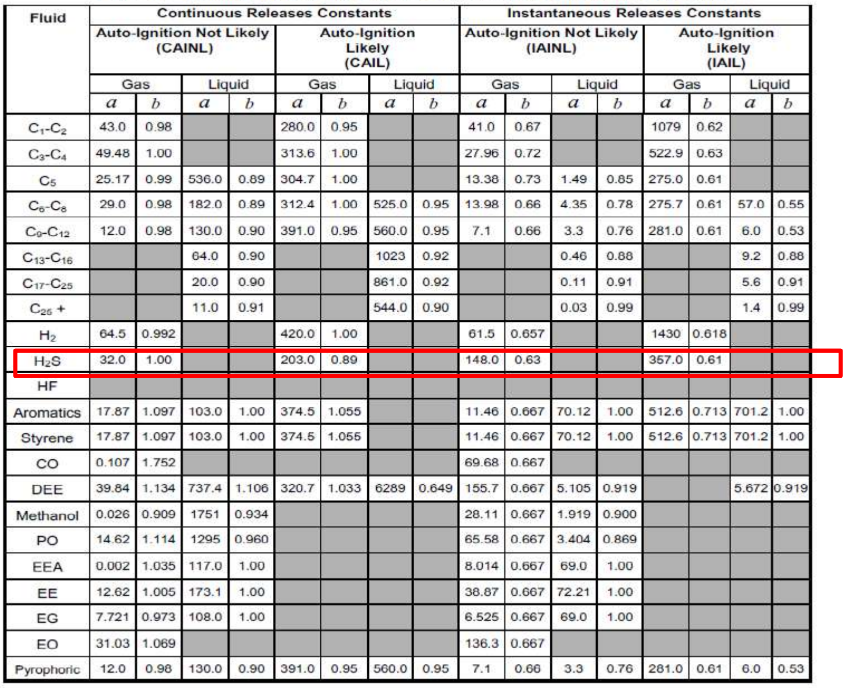
H_2S = Type 0

Step 8.4 For each release hole size, calculate the component damage consequence area.

Step 1.4 will be needed to assure selection of the correct constant

Determine the appropriate constants *a* and *b* from the table 4.8.

Table 4.8 – Component Damage Flammable Consequence Equation Constants



Fluid	Continuous Releases Constants								Instantaneous Releases Constants							
	Auto-Ignition Not Likely (CAINL)				Auto-Ignition Likely (CAIL)				Auto-Ignition Not Likely (IAINL)				Auto-Ignition Likely (IAIL)			
	Gas		Liquid		Gas		Liquid		Gas		Liquid		Gas		Liquid	
	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
C_1-C_2	43.0	0.98			280.0	0.95			41.0	0.67			1079	0.62		
C_3-C_4	49.48	1.00			313.6	1.00			27.96	0.72			522.9	0.63		
C_5	25.17	0.99	536.0	0.89	304.7	1.00			13.38	0.73	1.49	0.85	275.0	0.61		
C_6-C_8	29.0	0.98	182.0	0.89	312.4	1.00	525.0	0.95	13.98	0.66	4.35	0.78	275.7	0.61	57.0	0.55
C_9-C_{12}	12.0	0.98	130.0	0.90	391.0	0.95	560.0	0.95	7.1	0.66	3.3	0.76	281.0	0.61	6.0	0.53
C_{13}-C_{16}			64.0	0.90			1023	0.92			0.46	0.88			9.2	0.88
C_{17}-C_{25}			20.0	0.90			861.0	0.92			0.11	0.91			5.6	0.91
C_{25} +			11.0	0.91			544.0	0.90			0.03	0.99			1.4	0.99
H_2	64.5	0.992			420.0	1.00			61.5	0.657			1430	0.618		
H_2S	32.0	1.00			203.0	0.89			148.0	0.63			357.0	0.61		
HF																
Aromatics	17.87	1.097	103.0	1.00	374.5	1.055			11.46	0.667	70.12	1.00	512.6	0.713	701.2	1.00
Styrene	17.87	1.097	103.0	1.00	374.5	1.055			11.46	0.667	70.12	1.00	512.6	0.713	701.2	1.00
CO	0.107	1.752							69.68	0.667						
DEE	39.84	1.134	737.4	1.106	320.7	1.033	6289	0.649	155.7	0.667	5.105	0.919			5.672	0.919
Methanol	0.026	0.909	1751	0.934					28.11	0.667	1.919	0.900				
PO	14.62	1.114	1295	0.960					65.58	0.667	3.404	0.869				
EEA	0.002	1.035	117.0	1.00					8.014	0.667	69.0	1.00				
EE	12.62	1.005	173.1	1.00					38.87	0.667	72.21	1.00				
EG	7.721	0.973	108.0	1.00					6.525	0.667	69.0	1.00				
EO	31.03	1.069							136.3	0.667						
Pyrophoric	12.0	0.98	130.0	0.90	391.0	0.95	560.0	0.95	7.1	0.66	3.3	0.76	281.0	0.61	6.0	0.53

$a = a_{cmd}^{AINL-CONT}$ $b = b_{cmd}^{AINL-CONT}$

a = 32.0 *b* = 1.00

Determining Consequence Area for *AINL-CONT*

$$CA_{cmd,n}^{AINL-CONT} = a\,(rate)^{b} \cdot (1 - factmil)$$

for small hole size

$CA_{cmd,1}^{AINL-CONT}$ = 0.0624 m^2

for medium hole size

$CA_{cmd,2}^{AINL-CONT}$ = 2.9963 m^2

for large hole size

$CA_{cmd,3}^{AINL-CONT}$ = 15.314 m^2

for rupture hole size

$CA_{cmd,4}^{AINL-CONT}$ = 766.87 m^2

Step 8.5 For each release hole size, compute the component damage consequence areas for Autoignition likely Continous Release (*AIL-CONT*)

$a = a_{cmd}^{AIL-CONT}$ $b = b_{cmd}^{AIL-CONT}$

a = 203.0 *b* = 0.89

Determining Consequence Area for *AINL-CONT*

for small hole size

$CA_{cmd,1}^{AIL-CONT}$ = 0.7861 m^2

for medium hole size

$CA_{cmd,2}^{AIL-CONT}$ = 24.665 m^2

for large hole size

$CA_{cmd,3}^{AIL-CONT}$ = 105.35 m^2

for rupture hole size

$CA_{cmd,4}^{AIL-CONT}$ = 3430.2 m^2

Step 8.6 For each release hole size, compute the component damage consequence areas for Auto-Ignition Not Likely, Instantaneous Release (*AINL-INST*)

$$a = a_{cmd\square}^{AINL-INST}$$

$a = 148.0$ $b = 0.63$

Determining Consequence Area for ANIL-*CONT*

$$CA_{cmd,n\square}^{AINL-INST} = a\,(mass)^b \,.\, (\frac{1 - factmil}{eneff_n})$$

for small hole size

$CA_{cmd,1}^{AINL-INST} = 287.25\ m^2$

for medium hole size

$CA_{cmd,2}^{AINL-INST} = 440.74\ m^2$

for large hole size

$CA_{cmd,3}^{AINL-INST} = 637.87\ m^2$

for rupture hole size

$CA_{cmd,4}^{AINL-INST} = 4105.9\ m^2$

Step 8.7 For each release hole size, compute the component damage consequence areas for Auto-Ignition Likely, Continous Release (*AIL-CONT*)

$a = a_{cmd\square}^{AIL-CONT}$ $b = b_{cmd\square}^{AIL-CONT}$

$a = 357.0$ $b = 0.61$

Determining Consequence Area for AIL-*CONT*

$$CA_{cmd,n\square}^{AIL-INST} = a\,(mass)^b \,.\, (\frac{1 - factmil}{eneff_n})$$

for small hole size

$CA_{cmd,1}^{AIL-INST} = 666.4\ m^2$

for medium hole size

$CA_{cmd,2}^{AIL-INST} = 967.34\ m^2$

for large hole size

$CA_{cmd,3}^{AIL-INST} = 1374\ m^2$

for rupture hole size

$CA_{cmd,4}^{AIL-INST} = 8178.2\ m^2$

Step 9.1

For each release hole size selected in step 2.2, calculate the effective duration of release using equation (3.67)

$$Id_n^{tox} = \min\left(3600, \left\{\frac{mass}{W}\right\}, \{60\,.\,Idmax, n\}\right)$$

For small hole size

$$Id_1^{tox} = \min\left(3600, \left\{\frac{mass_1}{W}\right\}, \{60\,.\,Idmax_{,1}\}\right)$$

= 3600

For medium hole size

$$Id_1^{tox} = \min\left(3600, \left\{\frac{mass_1}{W}\right\}, \{60\,.\,Idmax_{,1}\}\right)$$

= 1200

For small hole size

$$Id_1^{tox} = \min\left(3600, \left\{\frac{mass_1}{W}\right\}, \{60\,.\,Idmax_{,1}\}\right)$$

= 600

Step 9.2

Determine the toxic percentage of the toxic component, *mfractox i* n the release material, if the release fluid is pure fluid, mfactox = 1.0.

H_2S = 1.55%

$mfrac^{tox}$ = 0.0155

Step 9.3

For each release hole size, calculate the release rate, ratentox, and release mass, xmassntox, to be used in toxic consequence analysis.

For H_2S

$$rate_n^{tox} = mfractox\,.\,Wn$$

for Small hole size

$$rate_1^{tox} = mfractox\,.\,W_1$$

= 3E-05 Kg/s

for Medium hole size

$$rate_2^{tox} = mfractox\,.\,W_2$$

= 0.0015 Kg/s

for Large hole size

$$rate_3^{tox} = mfractox\,.\,W_3$$

= 0.0074 Kg/s

for Rupture hole size

$$rate_3^{tox} = mfractox\,.\,W_3$$

= 0.3715 Kg/s

Step 9.4

For each release hole size calculate the toxic consequence area for each of the release hole size

HF Acid and H25 — Calculate Cit7n using Equation (3.63) for a continuous release or Equation
(3.64) for an instantaneous release. The constants used in these equations are from Table 4.11.

$$CA_{inj,n}^{tox-INST} = C_8\,.\,10(C.\log_{10}[C_{4B}.\,mass_n^{tox}]$$

for small hole size

$mass_1^{tox} = mfractox\;.\,mass_1$

= 0.1088

$CA_{inj,n}^{tox-INST} = C_8\,.\,10(C.\log_{10}[C_{4B}.\,mass_n^{tox}]$

= -0.5573

for medium hole size

$mass_2^{tox} = mfractox\;.\,mass_2$

= 1.7416

$CA_{inj,n}^{tox-INST} = C_8\,.\,10(C.\log_{10}[C_{4B}.\,mass_n^{tox}]$

= 0.5252

for large hole size

$mass_2^{tox} = mfractox\;.\,mass_2$

= 4.4507

$CA_{inj,n}^{tox-INST} = C_8\,.\,10(C.\log_{10}[C_{4B}.\,mass_n^{tox}]$

= 0.8914

for Rupture hole size

$mass_2^{tox} = mfractox\;.\,mass_2$

= 222.87

$CA_{inj,n}^{tox-INST} = C_8\,.\,10(C.\log_{10}[C_{4B}.\,mass_n^{tox}]$

= 2.4189

Step 9.5 If there are additional toxic components in the released fluid mixture, STEPs 9.2 through 9.4
should be repeated for each toxic component.

there is no other additional toxic components.

Step 9.6 Determine the final toxic consequence areas for personnel injury in accordance with
Equation (3.68)

$$CA_{inj}^{tox} = \left(\frac{\sum_{n=1}^{4} gff_n\,.\,CA_{inj,n}^{tox}}{gff_{total}}\right)$$

CA_{inj}^{tox} = 0.30324 m^2

Step 10 Calculation of Non-Flammable, Non-Toxic Consequence Area

Step 10.1 For each release hole size, calculate the non-flammable, non-toxic consequence area

$$CA_{inj,n}^{CONT} = C_9 \, . \, raten$$

$$CA_{inj,n}^{INST} = C_{10} \, (massn)^{0.6384}$$

Small hole size

$$CA_{inj,1}^{CONT} = C_9 \, . \, rate_1$$

= 2E-04

$$CA_{inj,1}^{INST} = C_{10} \, (mass_1)^{0.6384}$$

= 33.8

Medium hole size

$$CA_{inj,1}^{CONT} = C_9 \, . \, rate_1$$

= 0.012

$$CA_{inj,1}^{INST} = C_{10} \, (mass_1)^{0.6384}$$

= 361.4

Largel hole size

$$CA_{inj,1}^{CONT} = C_9 \, . \, rate_1$$

= 0.059

$$CA_{inj,1}^{INST} = C_{10} \, (mass_1)^{0.6384}$$

= 361.4

Step 10.2 For each release hole size, calculate the instantaneous/continous blending factor, for steam use equation (3.71)

$$fact_n^{IC} = \min\left[\left\{\frac{Raten}{C5}\right\}, 1.0\right]$$

Small hole size

$$fact_1^{IC} = \min\left[\left\{\frac{Rate_1}{C_5}\right\}, 1.0\right]$$

= 7.73511E-05

Medium hole size

$$fact_1^{IC} = \min\left[\left\{\frac{Rate_1}{C_5}\right\}, 1.0\right]$$

= 0.003715678

Large hole size

$$fact_1^{IC} = \min\left[\left\{\frac{Rate_1}{C_5}\right\}, 1.0\right]$$

= 0.019

Step 10.3

For each release hole size, calculate the blended non-flammable, non-toxic personnel injury consequence area for steam or acid leaks using equation (3.88) based on the consequence area from Step 10.1 and the blending factor from 10.2.

$$CA_{inj,n}^{leak} = CA_{inj,n}^{INST} \, . fact_n^{IC} + CA_{inj,n}^{CONT} \, (1 - fact_n^{IC})$$

Small hole size

$$CA_{inj,1}^{leak} = CA_{inj,1}^{INST} \, . fact_1^{IC} + CA_{inj,1}^{CONT} \, (1 - fact_1^{IC})$$

= 0.003

Medium hole size

$$CA_{inj,2}^{leak} = CA_{inj,2}^{INST} \, . fact_2^{IC} + CA_{inj,2}^{CONT} \, (1 - fact_2^{IC})$$

= 1.354

Large hole size

$$CA_{inj,1}^{leak} = CA_{inj,1}^{INST} \, . fact_1^{IC} + CA_{inj,1}^{CONT} \, (1 - fact_1^{IC})$$

= 354.5

Step 10.4

Determine the final non-flammable, non-toxic consequence areas for personnel injury using Equation (3.80) based on consequence areas calculated for each release hole size in STEP 10.3.

Note that there is no need to calculate a final non-flammable, non-toxic consequence area for componDetermdamage area for the Level 1 non-flammable releases (steam or acid/caustic).

$$CA_{inj}^{nfnt} = \left(\frac{\sum_{n=1}^{4} gff_n \, . CA_{inj,n}^{nfnt}}{gff_{total}}\right)$$

$CA_{inj}^{nfnt} =$ 24.05822469 m^2

Step 11.1 Calculate the final component damage consequence area, Cacmd

Note that since the component damage consequence areas for toxic releases, $CAcmd^{tox}$, and non-flammable, non-toxic releases, $CAcmd^{nfnt}$, are both equal to zero. Then, the final component damage consequence area is equal to the consequence area calculated for flammable releases, $CAcmd^{flam}$.

……………………………………… (equation 47)

$CA_{cmd} = CA_{cmd}^{flam}$ = 652.1247212 m^2

Step 11.2 Calculate the final personnel injury consequence area,

CA_{inj} = max $\left[CA_{inj}^{flam}, CA_{inj}^{tox}, CA_{inj}^{nfnt}\right]$

………………….. (equation 48)

CA_{inj} = max $\left[CA_{inj}^{flam}, CA_{inj}^{tox}, CA_{inj}^{nfnt}\right]$

= 223 m^2

Step 11.3 Calculate the final consequence area, CA, using equation below:

CA=max$\left[CA_{cmd}, CA_{inj}\right]$

= 652.1 m^2

Risk Analysis

Determining RBI Date

Age at RBI date

$$age = RBI\ Date - Last\ Inspection\ Date$$

= 12-Feb-2019 - 22-Nov-2014

= 5 year

Age at RBI plan date

$$age = Plan\ date - Last\ Inspection\ Date$$

= 01-Jan-23 - 22-Nov-14

= 9 year

$Risk_{RBIDate}$ Age at RBI date

$$Risk_{RBIDate} = PoF\ .\max(CAinj, CAequip)$$

= 20.459347 m_2

$Risk_{RBIDate}$ Age at RBI plan date

$$Risk_{PlanDate} = PoF\ .\max(CAinj, CAequip)$$

= 54.646294 m_2

R(t) Age at RBI date

$$Risk_{RBIDate} = PoF\ \ .\ CoF$$

= 8.1313291 m_2

R(t) Age at RBI plan date

$$Risk_{PlanDate} = PoF\ \ .\ CoF$$

= 54.646294 m_2

Probability Range

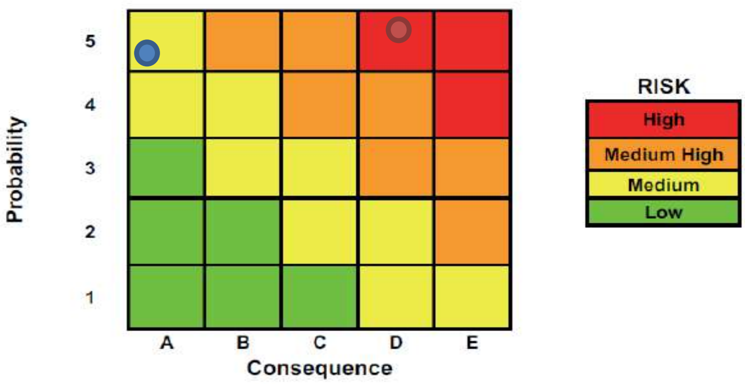
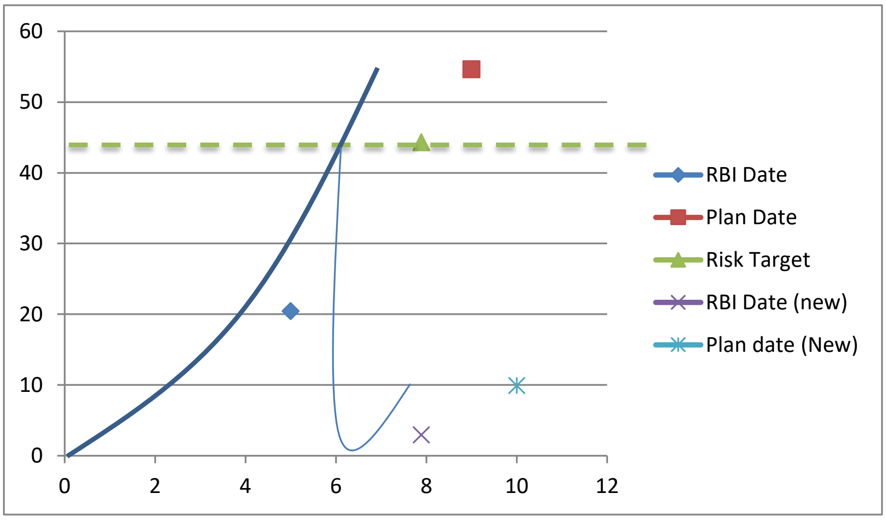


Figure 4.3 – Balanced Risk Matrix Example

Inspection Planning

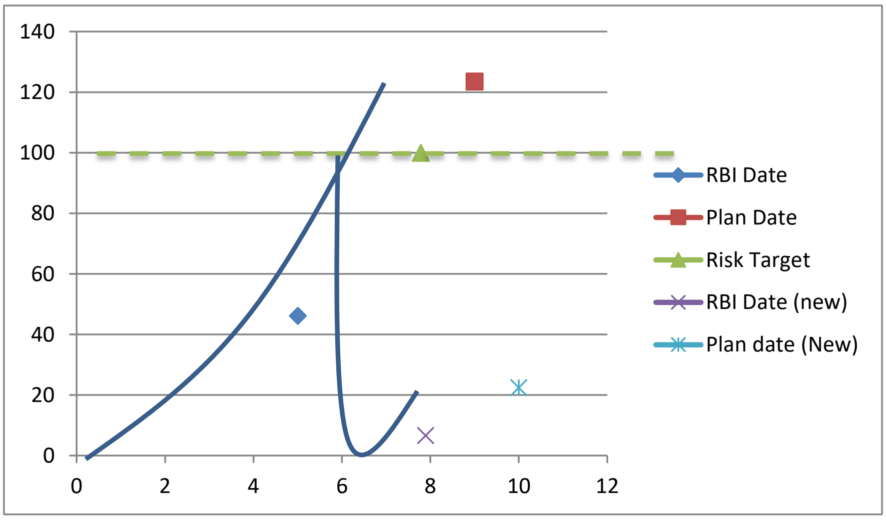
Step 1 Estimate Target Date

Item	Date	Time since RBI Assessment	Risk Area (m^2/yr)
RBI Date	02/12/2019	5	20.45934724
Risk Target	12/05/2019	7.89	44.33273807
Plan Date	02/12/2023	9	54.6462938



Target date = 7.89 year after RBI Assessment
= 03/02/2002

Item	Date	Time since RBI Assessment	Damage Factor
RBI Date	02/12/2019	5	46.1495232
Risk Target	03/02/2022	7.25	100
Plan Date	02/12/2023	9	123.528109



Target date = 7.25 Year after RBI Assessment
= 03/02/2022

Lampiran 5

Calculation for VS-80-002.

“Halaman ini sengaja dikosongkan”

Calculation of Thinning Damage Factor

Basic Data	Value	Unit	Comments
Start Date	01/01/2000		The date the component was placed in service.
Thickness	28.85	mm	The thickness used for DF calculation that is either the furnished thickness or the measured thickness.
Corrosion Allowance	3.00	mm	The corrosion allowance is the specified design or actual corrosion allowance upon being placed in the current servicce.
Design Tempearture	50-200	^oC	The design temperature, shell side and tube side for heat exchanger.
Design Pressure	1450	Kpa	The design pressure, shell side and tubbe side for heat exchanger.
Operating Tempearture	187	^oC	The highest expected operating temperature expected during operation including normal and unusual operating conditions, shell side and tube side for heat exchanger.
Operating Pressure	1060	Kpa	The highest expected operating pressure expected during operation including normal and unusual operating conditions, shell side and tube side for heat exchanger.
Design Code	ASME Section VIII Division I Ed. 2015		The designing of the component containing the component.
Equipment Type	Separator (Pressure Vessel)		The type of equipment.
Component Type	Filter		The type of component.
Geometry Data	ELL (Elliptical Head)		Component geometry data depending on the type of component.
Material Specification			The specification of the material of construction, the ASME SA or SB specification for pressure vessel components or for ASTM specification for piping and tankage components. Data entry is based on the material specification, grade, year, UNS Number, class/condition/temper/size/thickness; this data is readdily available in the ASME Code.
Yield Strength	510000/650000	Kpa	The design yield strength of the material based on material specification.
Tensile Strength	335000	Kpa	The design tensile strength of the material based on material specification.
Weld Joint Efficiency	1.00	mm	Weld joint efficiency per the Code of construction.
Heat Tracing	Yes		Is the component heat traced? (Yes or No)

STEP 1 Determining the furnished thickness, t, and age for the component from the installation date.

t = 5 inch
= 12.7 mm
age = 14 years (it is assumed from the default date for the first installement in a plant on January 1st 2000 (01/01/2000) until November 26th 2014 (26/11/2014)).

STEP 2 Determining the corrosion rate for base material, $C_{r,bm}$ based on the material construction and environment, and cladding/weld overlay corrosion rate, $C_{r,cm}$.

Based on the explanation from Section 4.5.2 that the corrosion rate is **CALCULATED** using the approach of Annex 2B. Then, first of all, the corrosion screening question must be done as follows:

Table 2.B.1.1-Screening Questions for Corrosion Rate Calculations

No.	**Type of Corrosion**	**Screening Question**		**Yes/No**	**Action**
1.	Hydrochloric Acid (HCl) Corrosion	1.	Does the process contain HCl?	N	No
		2.	Is free water present in the process stream (including initial condensing condition)?	Y	
		3.	Is the pH < 7.0?	Y	
			Actual relatively pH is 5.66		
2.	High Temperature Sulfidic/Naphtenic Acid Corrosion	1.	Does the process contain oil with sulfur compounds?	N	No
		2.	Is the operating temperature > 204^{o}C (400^{o}F)?	N	
			The operating temperature is 187^{o}C.		
3.	Sulfuric Acid Corrosion	1.	Does the process contain H_2SO_4	N	No
4.	High Temperature H_2S/H_2 Corrosion	1.	Does the process contain H_2S and Hydrogen?	Y	No
		2.	Is the operating temperature > 204^{o}C (400^{o}F)?	N	
			The operating temperature is 187^{o}C.		
5.	Hydrifluoric Corrosion	1.	Does the process contain HF	N	No
6.	Sour Water Corrsion	1.	Is free water with H_2S present?	Y	Yes
7.	Amine Corrosion	1.	Is equipment exposed to acid gas treaating amines (MEA, DEA, DIPA, or MDEA)?	N	No
8.	High Temperature Oxidation Corrosion	1.	Is the temperature ≥ 482^{o}C (900^{o}F)?	N	No
			The operating temperature is 187^{o}C.		
		2.	Is the oxygen present?	N	
9.	Acid Sour Water Corrosion	1.	Is free water with H_2S present and pH < 7.0?	Y	No
			Actual relatively pH is 5.66		
		2.	Does the proocess contain < 50 ppm chlorides?	N	
10.	Cooling Water	1.	Is equipment in cooling water service?	N	No
11.	Soil Side Corrosion	1.	Is equipment in contact with soil (buried or partially buried)?	N	No
		2.	Is the material of construction carbon steel?	N	
12.	CO_2 Corrosion	1.	Is the free water with CO_2 present (including consideration for dew point condensation)?	Y	No
		2.	Is the material of construction carbon steel or < 13% Cr?	N	
13.	AST Bottom	1.	Is the equipment item an AST tank bottom?	N	No

pH = 5.56
T = 187 C
= 368 F
P = 2895.9 Kpa
H2S Concentr = 7.935979788 % mole
Material = Carbon Steel (SA 516-70)

Basically, there are 3 types of Corrosion Rate (Cr) calculation which are based on the RLA data from the last inspection, based on the calculation referred to the API 581 Annex 2B, and the last is based on worst case scenario.

1. Corrosion Rate (Cr) from the RLA data
   Cr = 0.000394 inch/year
   = 0.010000 mm/year

2. Corrosion Rate (Cr) based on the Annex 2B High temperature corrosion rate
   The steps required to determine the corrosion rate are shown in Figure 2.B.7.1. The corrosion rate may be determined using the basic data in Table 2.B.7.1 in conjunction with the baseline corrosion rates and equations in Table 2.B.7.2 to correct for H_2S partial pressure

Basic Data	Comments
NH_4HS concentration (wt%)	Determine the NH_4HS concentration of the condensed water. It is suggested to determine this value with ionic process models. However, approximate values may be calculated from analyses of H_2S and NH_3 as follows
	If wt% $H_2S < 2$ x (wt% NH_3), wt% NH_4HS =1.5 x (wt% H_2S)
	If wt% $H_2S > 2$ x (wt% NH_3), wt% NH_4HS =3.0 x (wt% H_2S)
Strean Velocity	The vapor phase velocity should be used in a two-phase system. The liquid phase velocity should be used in a liquid full system.
H_2S partial pressure, psia [kPa]	Determine the partial pressure of H_2S by multiplying the mole% of H_2S in the gas phase by the total system pressure.

Determining NH4HS Concentration

to determine NH_4HS concentration, we must first determine if wt% H_2S is lower or higher than wt% of NH_3.

wt% H_2S = 0.02

wt% NH_3 = 0.00047639

2 X wt% NH_3 = 0.00095278

Since the value of H_2S is higher than NH_3, the wt% of NH_4HS can be determined by the formula of: wt% NH_4HS = 3.0 x (wt% H_2S)

If wt% $H_2S > 2$ x (wt% NH_3), wt% NH_4HS =3.0 x (wt% H_2S)

NH_4HS= 3.0 x (wt% H_2S)

NH_4HS = 0.06

to determine the Cr, we must first do a calculation to correct the H_2S partial pressure.

$$\text{Adjusted } CR = \max\left[\left\{\left(\frac{Baseline\ CR}{276}\right).(pH2S - 345) + Baseline\ CR\right\}, 0\right]$$

Adjusted CR = 0.287

STEP 3 Determine the time in service, age_{tk}, since the last known inspection, t_{rdi}.

Because of the manufactured-thickness is not provided. Then, the thickness used in this calculation is coming from the last inspection as long as as the Production Separator installed in setvice life).

t_{rdi} = 1.136 inch

= 28.8544 mm

age_{tk} = 7 year (Last inspection was held on November 2014)

STEP 4 For cladding/weld overlay pressure vessel components, calculate the age from the date starting thickness from STEP 3 required to corrode away the cladding/weld overlay material, age_{rc}, using equation below:

$$age_{rc} = \max\left[\left(\frac{t_{rdi} - tbm}{C_{r\,cm}}\right), 0.0\right] \quad \text{...} \quad \text{(equation 57)}$$

This equipment does not have cladding, so this step are skipped

STEP 5 Determine the t_{min}

Actually there are 4 methods used to determine the minimum thickness of the equipment (t_{min}). Based on the condition, the method used by the author is the first method which is for cylindrical, spherical, or head components, determine the allowable Stress, S, weld joint efficiency, E, and the minimum thickness, t_{min}.

t_{min} = 1.0202 inch

= 25.91308 mm

S = 17500 psig

= 120658300 Pa

= 120658.3 Kpa

E = 1

STEP 6 Determine the A_{rt} Parameter

For component without clading/weld overlay then use the equation below.

$$A_{rt} = \frac{Cr_{b,m} \cdot age_{tk}}{t_{rdi}}$$ ……………………………………………….. (equation 58)

= 0.0696852 (For calculated corrosion rate based on ANNEX 2B)

$$A_{rt} = \frac{Cr_{b,m} \cdot age_{tk}}{t_{rdi}}$$

= 0.002425973 (For corrosion rate based on RLA Data)

STEP 7 Calculate the Flow Stress, FS^{Thin}, using E from STEP 5 and equation below.

$$FS^{Thin} = \frac{(YS+TS)}{2} . E.1,1$$ ……………………………………………….. (equation 59)

Where;

YS = 205000 KPa https://www.csecplates.com/astm-a283-grade-c-plate-stockists-suppliers.html

TS = 447500 KPa

E = 1

$$FS^{Thin} = \frac{(YS+TS)}{2} . E.1,1$$

= 358875

STEP 8 Calculate the strength ratio parameter, , SR_P^{Thin} the appropriate equation.

$$SR_P^{Thin} = \frac{S.E}{FS^{Thin}} . \frac{Max\,(t_{min}, t_c)}{t_{rdi}}$$ …………………………………………. (equation 60)

Where;

t_c = is the minimum structural thickness of the component base material

= 1.0202 inch

= 25.91308 mm

$$SR_P^{Thin} = \frac{S.E}{FS^{Thin}} . \frac{Max\,(t_{min}, t_c)}{t_{rdi}}$$

= 0.686008207

STEP 9 Determine the number of inspections for each of the correspondesing inspection effectiveness, $N_A^{Thin}, N_B^{Thin}, N_C^{Thin}, N_D^{Thin}$ sing Section 4.5.6 of the API RP 581 Part 2 for past inspections performed during in-service time.

N_A^{Thin} = 0

N_B^{Thin} = 0

N_C^{Thin} = 0

N_D^{Thin} = 0

STEP 10 Calculate the inspection effectiveness factors, $I_1^{Thin}, I_2^{Thin}, I_3^{Thin}$ g equation 61 below, prior probabilities, , from Table 4.5. The Conditional Probabilities (for each inspection effectiveness level), $Pr_{p1}^{Thin}, Pr_{p2}^{Thin}$ and Pr_{p3}^{Thin} le 4.6, and the number of inspection, $N_B^{Thin}, N_C^{Thin}, N_D^{Thin}$ ı effectiveness level from STEP 9.

N_A^{Thin}

$$I_1^{Thin} = Pr_{P1}^{Thin}(Co_{P1}^{ThinA})^{N_A^{Thin}}(Co_{P1}^{ThinB})^{N_B^{Thin}}(Co_{P1}^{ThinC})^{N_C^{Thin}}(Co_{P1}^{ThinD})^{N_D^{T}}$$

$$I_2^{Thin} = Pr_{P2}^{Thin}(Co_{P2}^{ThinA})^{N_A^{Thin}}(Co_{P2}^{ThinB})^{N_B^{Thin}}(Co_{P2}^{ThinC})^{N_C^{Thin}}(Co_{P2}^{ThinD})^{N_A^{T}}$$

$$I_3^{Thin} = Pr_{P3}^{Thin}(Co_{P3}^{ThinA})^{N_A^{Thin}}(Co_{P3}^{ThinB})^{N_B^{Thin}}(Co_{P3}^{ThinC})^{N_C^{Thin}}(Co_{P3}^{ThinD})^{N_A^{T}}$$

Table 4.5 - Prior Probability for Thinning Corrosion Rate

Damage State	Low Confidence Data	Medium Confidence Data	High Conf. Data
Pr_{P1}^{Thin}	0.5	0.7	0.8
Pr_{P2}^{Thin}	0.3	0.2	0.15
Pr_{P3}^{Thin}	0.2	0.1	0.05

Table 4.6 - Conditional Probability for Inspection Effectiveness

Conditional P. of Inspection	E-None or Ineffective	D-Poorly Effective	C-Fairly Effective	B-Usually Effective	A-Highly Effective
Co_{P1}^{Thin}	0.33	0.4	0.5	0.7	0.9
Co_{P2}^{Thin}	0.33	0.33	0.3	0.2	0.09
Co_{P3}^{Thin}	0.33	0.27	0.2	0.1	0.01

$$I_1^{Thin} = Pr_{P1}^{Thin}(Co_{P1}^{ThinA})^{N_A^{Thin}}(Co_{P1}^{ThinB})^{N_B^{Thin}}(Co_{P1}^{ThinC})^{N_C^{Thin}}(Co_{P1}^{ThinD})^{N_D^{T}}$$

= 0.50

$$I_2^{Thin} = Pr_{P2}^{Thin}(Co_{P2}^{ThinA})^{N_A^{Thin}}(Co_{P2}^{ThinB})^{N_B^{Thin}}(Co_{P2}^{ThinC})^{N_C^{Thin}}(Co_{P2}^{ThinD})^{N_A^{T}}$$

= 0.30

$$I_3^{Thin} = Pr_{P3}^{Thin}(Co_{P3}^{ThinA})^{N_A^{Thin}}(Co_{P3}^{ThinB})^{N_B^{Thin}}(Co_{P3}^{ThinC})^{N_C^{Thin}}(Co_{P3}^{ThinD})^{N_A^{T}}$$

= 0.20

STEP 11 Calculate the Posteroir Probability, $Po_{p1}^{Thin}, Po_{p2}^{Thin}$ and Po_{p3}^{Thin} 36 below.

$$Po_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} \quad \text{……………………………………} \quad \text{(equation 64)}$$

= 0.5

$$Po_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} \quad \text{……………………………………} \quad \text{(equation 65)}$$

= 0.3

$$Po_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} \quad \text{……………………………………} \quad \text{(equation 66)}$$

= 0.2

p Calculate the parameters, ß$_1$, ß$_2$, and ß$_3$ using equation 67,68,69 below and also assigning $COV_{\Delta t}$ = 0.20, COV_{sf} = 0.20, and COV_P = 0.05.

$$ß_1^{Thin} = \frac{1-D_{S1}\,.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S1}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S1}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$ ……… (equation 67)

$$ß_2^{Thin} = \frac{1-D_{S2}\,.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S2}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S2}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$ ………. (equation 68)

$$ß_3^{Thin} = \frac{1-D_{S3}\,.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S3}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S3}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$ ………. (equation 69)

Where;

$COV_{\Delta t}$ = The thinning coefficient of variance ranging from 0.1 ≤ $COV_{\Delta t}$ ≤ 0.2
= 0.2
COV_{sf} = The flow stress coefficient of variance
= 0.2
COV_P = Pressure coeffficient of variance
= 0.05
D_{s1} = Damage State 1
= 1
D_{s2} = Damage State 2
= 2
D_{s3} = Damage State 3
= 4

<u>BASED ON CORROSION RATE FROM RLA DATA</u>

$$ß_1^{Thin} = \frac{1-D_{S1}\,.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S1}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S1}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

= 1.5390

$$ß_2^{Thin} = \frac{1-D_{S2}\,.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S2}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S2}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

= 1.53065328

$$ß_3^{Thin} = \frac{1-D_{S3}\,.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S3}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S3}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

= 1.51374389

STEP 13 For tank bottom components, determine the base damage factor for thining using Table 4.8. and based on A_{rt} parameter from STEP 6.

Because component observed in this case of analysis is including into Pressure Vessel (Production Separator), then, this step of ccalculation can be skipped.

STEP 14 For all components (excluding tank bottoms covered in STEP 13), calculate the base damage factor, D_{fB}^{Thin} .

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi(-\beta_1^{Thin})\right)+\left(Po_{P2}^{Thin}\Phi(-\beta_2^{Thin})\right)+\left(Po_{P3}^{Thin}\Phi(-\beta_3^{Thin})\right)}{1.56E-0.4}$$ ……… (equation 70)

<u>BASED ON CORROSION RATE FROM RLA DATA</u>

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi(-\beta_1^{Thin})\right)+\left(Po_{P2}^{Thin}\Phi(-\beta_2^{Thin})\right)+\left(Po_{P3}^{Thin}\Phi(-\beta_3^{Thin})\right)}{1.56E-0.4}$$

= 0.200745959

STEP 15 Determine the DF for thinning, , using equation equatiD_f^{Thin}elow.

$$D_f^{Thin} = \mathrm{Max}[(\frac{(D_{fb}^{Thin}.\,F_{IP}\,.\,F_{DL}\,.F_{WD}.F_{AM}\,.F_{SM})}{F_{OM}}),0.1]$$ …………………… (equation 71)

Where;

F_{IP} = DF adjustent for injection points (for piping circuit)
= 0
F_{DL} = DF adjustment for dead legs (for piping only used to intermittent service)
= 0
F_{WD} = DF adjustment for welding construction (for only AST Bottom)
= 0
F_{AM} = DF adjustment for AST maintenance per API STD 653 (for only AST)
= 0
F_{SM} = DF adjustment for settlement (for only AST Bottom)
= 0
F_{OM} = DF adjustment for online monitoring based on Table 4.9
= 1

<u>BASED ON CORROSION RATE FROM RLA DATA</u>

$$D_f^{Thin} = \mathrm{Max}[(\frac{(D_{fb}^{Thin}.}{F_{OM}}),0.1]$$

= 0.200745959

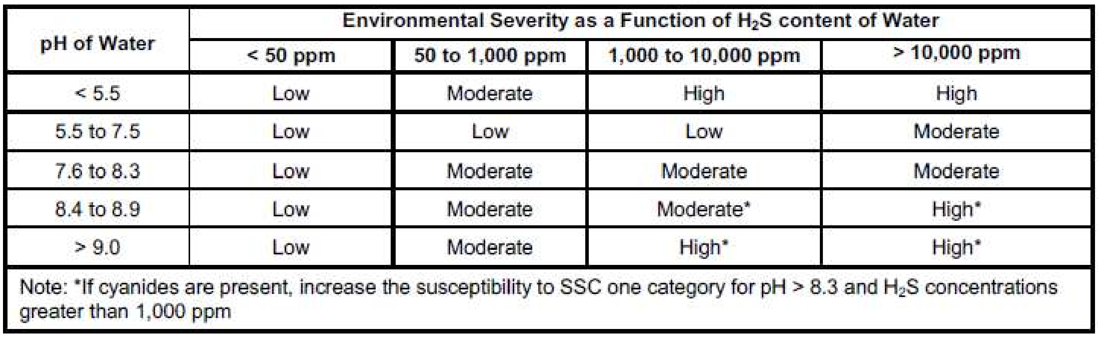
Calculation of SCC-Sulfide Stress Cracking Damage Factor

Step 1.

Determine the environemental severity (potential level of hydrogen flux) for cracking based on the H2S Content of water and its pH using Table 8.2

pH : 5.52
Content of water : 1000 ppm

Table 8.2 – Environmental Severity – SSC



pH of Water	Environmental Severity as a Function of H_2S content of Water			
	< 50 ppm	50 to 1,000 ppm	1,000 to 10,000 ppm	> 10,000 ppm
< 5.5	Low	Moderate	High	High
5.5 to 7.5	Low	Low	Low	Moderate
7.6 to 8.3	Low	Moderate	Moderate	Moderate
8.4 to 8.9	Low	Moderate	Moderate*	High*
> 9.0	Low	Moderate	High*	High*

Note: *If cyanides are present, increase the susceptibility to SSC one category for pH > 8.3 and H_2S concentrations greater than 1,000 ppm

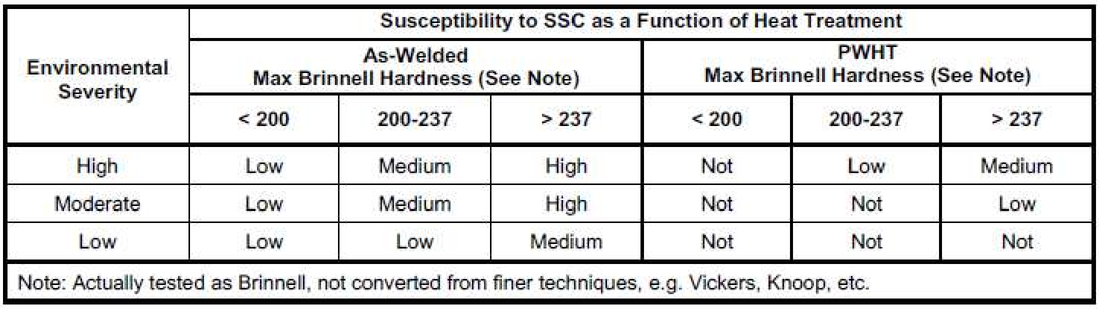
Environmental Severity of H2S : Moderate

Step 2

Determine the susceptibility for cracking using *figure 8.1* and *table 8.3* based on the environmental severity from step 1, the maximum brinnel hardness of weldments, and knowledge of whether the component was subject to PWHT.

Enviromental Severity of H2S : Moderate

Table 8.3 – Susceptibility to SSC – SSC



Environmental Severity	Susceptibility to SSC as a Function of Heat Treatment					
	As-Welded Max Brinnell Hardness (See Note)			PWHT Max Brinnell Hardness (See Note)		
	< 200	200-237	> 237	< 200	200-237	> 237
High	Low	Medium	High	Not	Low	Medium
Moderate	Low	Medium	High	Not	Not	Low
Low	Low	Low	Medium	Not	Not	Not

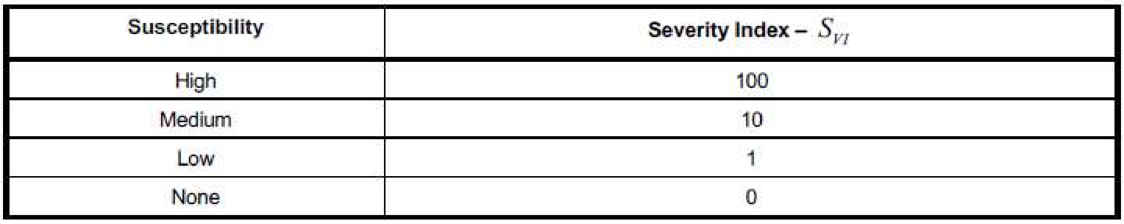
Note: Actually tested as Brinnell, not converted from finer techniques, e.g. Vickers, Knoop, etc.

Susceptibility to SCC : Low
PWTH : No

Step 3.

Based on the susceptibility in step 3, determine the severity index, S_{VI} from *Table 8.4.*

Table 8.4 – Determination of Severity Index – SSC



Susceptibility	Severity Index – S_{VI}
High	100
Medium	10
Low	1
None	0

Svi according to susceptibility to SCC : 1

Step 4.

Determine the time in-service, age , since the last Level A, B or C inspection was performed with no cracking detected or cracking was repaired. Cracking detected but not repaired should be evaluated and future inspection recommendations based upon FFS evaluation

In-service age : 14 year

age at the RBI Date

age_{RBI} = $RBI\ Date - Last\ Inspection\ Date$

age_{RBI} = 12/02/2019 - 26/11/2014

= 4 year

age at RBI Date: 18 year

Step 5.

Determine the number of inspections, and the corresponding inspection using Section 8.6.2 for past inspections performed during the in-service time. Combine the inspections toeffectiveness category the highest effectiveness performed using Section 3.4.3.

Inspection Performed : 2

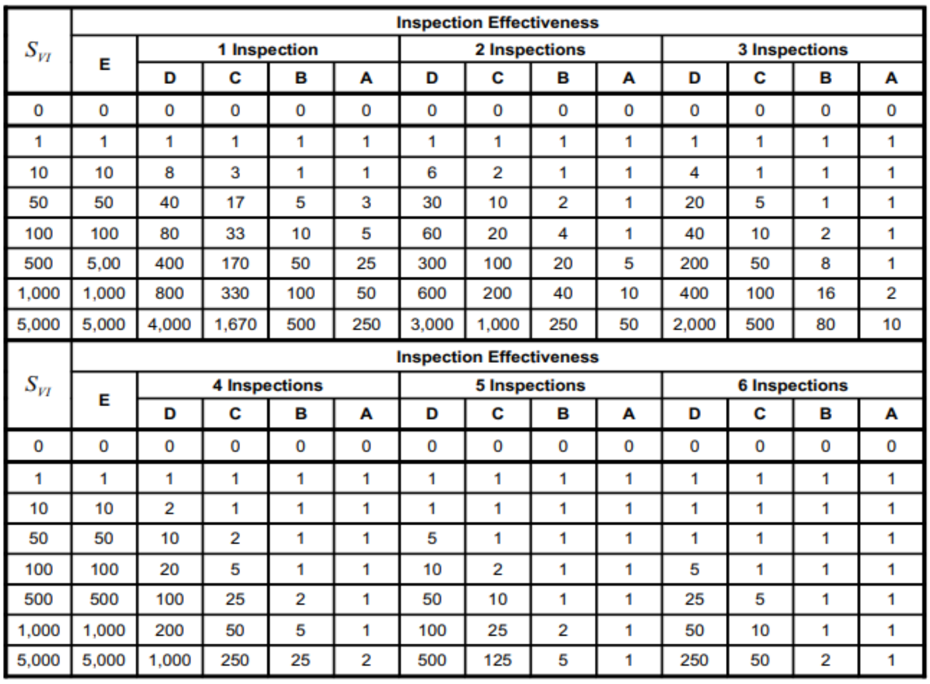
Inspection Category : 1A

Inspection Effectiveness : Highly Effective

Step 6.

Determine the base DF for sulfide stress cracking D_{fB}^{ssc} using Table 6.3 based on the number of, and the highest inspection effectiveness determined in STEP 5, and the severity index S_{VI} from STEP 3.

Table 6.3 – SCC Damage Factors – All SCC Mechanisms



S_{VI}	Inspection Effectiveness												
	E	1 Inspection				2 Inspections				3 Inspections			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	8	3	1	1	6	2	1	1	4	1	1	1
50	50	40	17	5	3	30	10	2	1	20	5	1	1
100	100	80	33	10	5	60	20	4	1	40	10	2	1
500	5,00	400	170	50	25	300	100	20	5	200	50	8	1
1,000	1,000	800	330	100	50	600	200	40	10	400	100	16	2
5,000	5,000	4,000	1,670	500	250	3,000	1,000	250	50	2,000	500	80	10

S_{VI}	Inspection Effectiveness												
	E	4 Inspections				5 Inspections				6 Inspections			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	2	1	1	1	1	1	1	1	1	1	1	1
50	50	10	2	1	1	5	1	1	1	1	1	1	1
100	100	20	5	1	1	10	2	1	1	5	1	1	1
500	500	100	25	2	1	50	10	1	1	25	5	1	1
1,000	1,000	200	50	5	1	100	25	2	1	50	10	1	1
5,000	5,000	1,000	250	25	2	500	125	5	1	250	50	2	1

Inspection Effectiveness

Inspection Performed : 2
Inspection Category : 1A

Severity Index

S_{VI} according to susceptibility to SCC : 1

Base Damage factor

Base D_f : 1

Step 7.

Calculate the escalation in the DF based on the time in-service since the last inspection using the age from STEP 4 and Equation (2.27). In this equation, it is assumed that the probability for cracking will increase with time since the last inspection as a result of increased exposure to upset conditions and other non-normal conditions

by using equation 2.27 we can find out the Df.

Damage factor at RBI Date

$D_f^{SSC} = D_{fB}^{SCC}.(Max[age, 1.0])^{1.1}$

$D_f^{SCC} = 1.(Max[5,1.0])^{1.1}$

$D_f^{SCC} = 5.8730947$

Damage factor at RBI Plan Date

$D_f^{SSC} = D_{fB}^{SCC}.(Max[age, 1.0])^{1.1}$

$D_f^{SCC} = 1.(Max[11,1.0])^{1.1}$

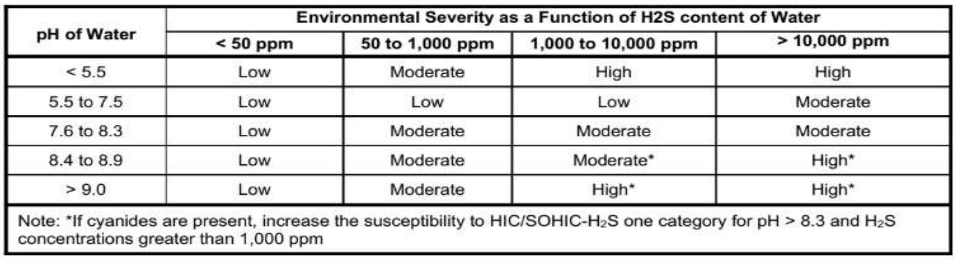
$D_f^{SCC} = 13.980798$

step 1.

Determine the environmental severity (potential level of hydrogen flux) for cracking based on the content of the water and its pH using table 9.2.

pH : 5.52
Content of water : 1000 ppm

Table 9.2 – Environmental Severity – HIC/SOHIC-H_2S Cracking



pH of Water	Environmental Severity as a Function of H2S content of Water			
	< 50 ppm	50 to 1,000 ppm	1,000 to 10,000 ppm	> 10,000 ppm
< 5.5	Low	Moderate	High	High
5.5 to 7.5	Low	Low	Low	Moderate
7.6 to 8.3	Low	Moderate	Moderate	Moderate
8.4 to 8.9	Low	Moderate	Moderate*	High*
> 9.0	Low	Moderate	High*	High*

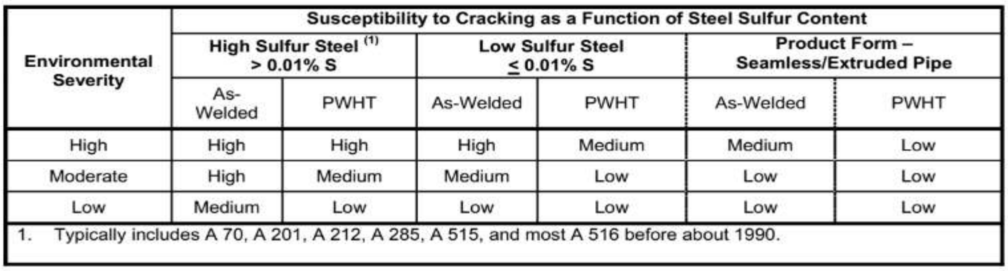
Note: *If cyanides are present, increase the susceptibility to HIC/SOHIC-H_2S one category for pH > 8.3 and H_2S concentrations greater than 1,000 ppm

Enviromental Severity : Moderate

Step 2

Determine the susceptibility for cracking using *figure 9.1* and *table 9.3* based on the environmental severity from step 1, the maximum brinnel hardness of weldments, and knowledge of whether the component was subject to PWHT.

Table 9.3 – Susceptibility to Cracking – HIC/SOHIC-H_2S



Environmental Severity	Susceptibility to Cracking as a Function of Steel Sulfur Content					
	High Sulfur Steel [(1)] > 0.01% S		Low Sulfur Steel ≤ 0.01% S		Product Form – Seamless/Extruded Pipe	
	As-Welded	PWHT	As-Welded	PWHT	As-Welded	PWHT
High	High	High	High	Medium	Medium	Low
Moderate	High	Medium	Medium	Low	Low	Low
Low	Medium	Low	Low	Low	Low	Low

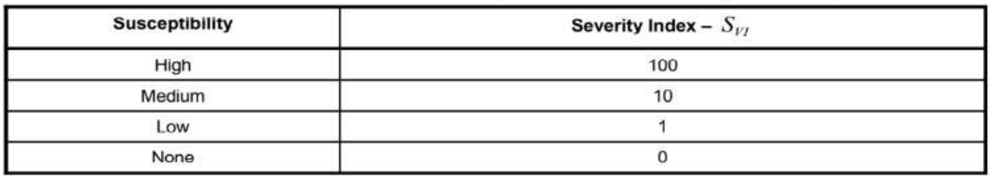
1. Typically includes A 70, A 201, A 212, A 285, A 515, and most A 516 before about 1990.

Steel sulfur content: 0.03 %
Environmental severity: Moderate
Post Weld Heat Treatment (PWHT): No
Susceptibility for Cracking: Medium

Step 3.

Based on the susceptibility in STEP 2, determine the severity index, SF/ , fro S_{VI} ble *9.4.*

Table 9.4 – Determination of Severity Index – HIC/SOHIC-H_2S Cracking



Susceptibility	Severity Index – S_{VI}
High	100
Medium	10
Low	1
None	0

Suscpetibility from step 2 : Medium
Severity index : 10

Step 4.

Determine the time in-service, age , since the last Level A, B or C inspection was performed with no cracking detected or cracking was repaired. Cracking detected but not repaired should be evaluated and future inspection recommendations based upon FFS evaluation

Determine the time in service, age, since the last inspection.

age at the RBI Date

age_{RBI} = $RBI\ Date - Last\ Inspection\ Date$

age_{RBI} = 12/02/2019 - 26/11/2014

= 4 year

Step 5

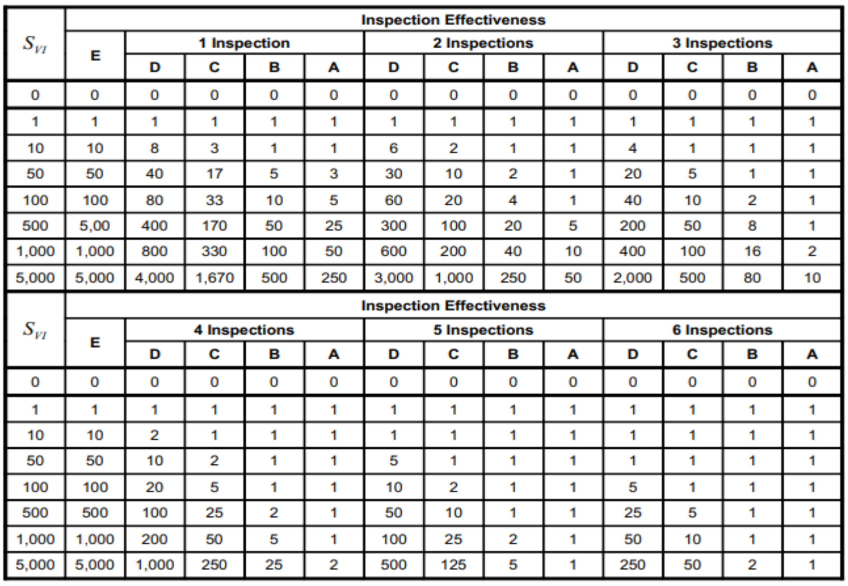
Determine the number of inspections, and the corresponding inspection using Section 9.6.2 for past inspections performed during the in-service time. Combine the inspections toeffectiveness category the highest effectiveness performed using Section 3.4.3.

Damage Mechanism	:	SCC
Inspection Performed	:	2
Inspection Category	:	A
Inspection Effectiveness	:	Effective

Step 6.

Determine the base DF for HIC/SOHIC-H_2S using Table 6.3 based on the number of, and the highest inspection effectiveness determined in STEP 5, and the severity index from STEP 3.

Table 6.3 – SCC Damage Factors – All SCC Mechanisms



S_{VI}	Inspection Effectiveness												
	E	1 Inspection				2 Inspections				3 Inspections			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	8	3	1	1	6	2	1	1	4	1	1	1
50	50	40	17	5	3	30	10	2	1	20	5	1	1
100	100	80	33	10	5	60	20	4	1	40	10	2	1
500	5,00	400	170	50	25	300	100	20	5	200	50	8	1
1,000	1,000	800	330	100	50	600	200	40	10	400	100	16	2
5,000	5,000	4,000	1,670	500	250	3,000	1,000	250	50	2,000	500	80	10

S_{VI}	Inspection Effectiveness												
	E	4 Inspections				5 Inspections				6 Inspections			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	2	1	1	1	1	1	1	1	1	1	1	1
50	50	10	2	1	1	5	1	1	1	1	1	1	1
100	100	20	5	1	1	10	2	1	1	5	1	1	1
500	500	100	25	2	1	50	10	1	1	25	5	1	1
1,000	1,000	200	50	5	1	100	25	2	1	50	10	1	1
5,000	5,000	1,000	250	25	2	500	125	5	1	250	50	2	1

Inspection Effectiveness

Inspection Performed	:	2
Inspection Category	:	1A

Severity Index

S_{VI} according to susceptibility to SCC : 10

Base Damage factor

Base D_f : 10

Step 7. Determine the on-line adjustment factor, F_{OM} , from Table 9.5.

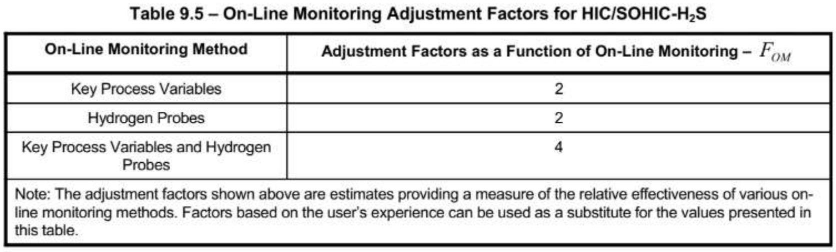


Table 9.5 – On-Line Monitoring Adjustment Factors for HIC/SOHIC-H_2S

On-Line Monitoring Method	Adjustment Factors as a Function of On-Line Monitoring – F_{OM}
Key Process Variables	2
Hydrogen Probes	2
Key Process Variables and Hydrogen Probes	4
Note: The adjustment factors shown above are estimates providing a measure of the relative effectiveness of various on-line monitoring methods. Factors based on the user's experience can be used as a substitute for the values presented in this table.	

Adjustment Factors:

Key Process Variables : 2

Step 8. Calculate the final DF accounting for escalation based on the time in-service since the last inspection using the age from STEP 4 and Equation (2.28). In this equation, it is assumed that the probability for cracking will increase with time since the last inspection as a result of increased exposure to upset conditions and other non-normal conditions. The equation also applies the adjustment factor for online monitoring

Damage Factor at RBI Date

$$D_f^{HIC\ SOHIC-H2S} = \frac{D_{fB}^{HIC\ SOHIC-H2S} .(Max[age,1.0])^{1.1}}{Fom}$$

$$D_f^{HIC\ SOHIC-H2S} = \frac{1.(Max[4,1.0])^{1.1}}{2}$$

$$D_f^{HIC\ SOHIC-H2S} = 45.94793$$

Damage Factor at RBI Plan Date

$$D_f^{HIC\ SOHIC-H2S} = \frac{D_{fB}^{HIC\ SOHIC-H2S} .(Max[age,1.0])^{1.1}}{Fom}$$

$$D_f^{HIC\ SOHIC-H2S} = \frac{1.(Max[11,1.0])^{1.1}}{2}$$

$$D_f^{HIC\ SOHIC-H2S} = 112.1158$$

Calculating Damage Factor

Damage Factor for Stress Corrosion Cracking

Calculation of damage factor for stress corrosion cracking (SCC) explained in section 3.4.2 - API RP 581 Part 2 3rd Edition. For multipe SCC damage factor mechanisms case, determined using equation (2.6).

$$D_{f-gov}^{scc} = max\begin{bmatrix} D_f^{caustic}, D_f^{amine}, D_f^{scc}, D_f^{HIC/SOHIC-H_2S}, D_f^{ACSCC}, \\ D_f^{PASCC}, D_f^{CLSCC}, D_f^{HSC\_HF}, D_f^{HIC/SOHIC-HF} \end{bmatrix}$$

D_{f-gov}^{scc} = 45.9479342

= 112.1158

Damage Factor for Thinning

D_f^{Thin} = Max[($\frac{(D_{fb}^{Thin}}{F_{OM}}$),0.1]

= 0.201588995

Total Damage Factor

If the external and thinning damage are general, then damage is likely to occur at the same location and
the total DF is given by Equation (2.3)

$$D_{f-total} = D_{f-gov}^{thin} + D_{f-gov}^{extd} + D_{f-gov}^{scc} + D_f^{htha} + D_{f-gov}^{brit} + D_f^{mfat}$$

RBI Date 46.14952 Plan Date 123.5281

Calculating Probability of Failure:

After determining the value of gff, Fms and Df we can calculate the probability of failure using the equation:

Pf (t) = gff . Fms . D f (t)

Pf (t) = 3.06E−0.5 . 0.182390 . 18.43159

Pf (t) = 0.012468978

RBI Date PoF	**RBI Plan Date PoF**
0.012468978	0.083797304

Probability of Failure

the probability of failure can be calculated using the equation of;

Pf (t) = gff . Fms . D f (t)

it can be known that

pf (t) = The PoF as a function of time
gff = General failure frequency
Fms = Management system factor
Df (t) = Total damage factor

Determining General failure frequency (gff)

To determine the value of gff, we can use the recommended list from table 3.1 [1-8] of API RBI 581

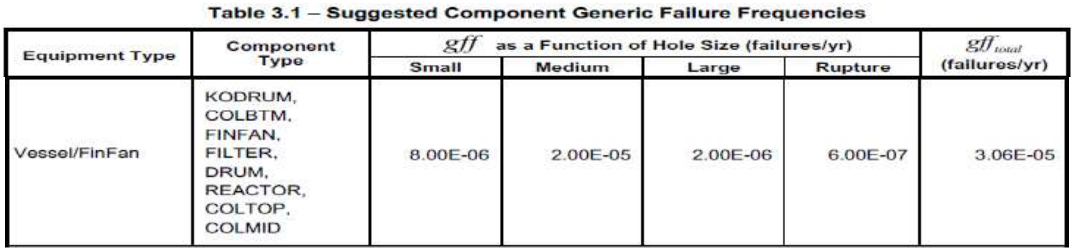


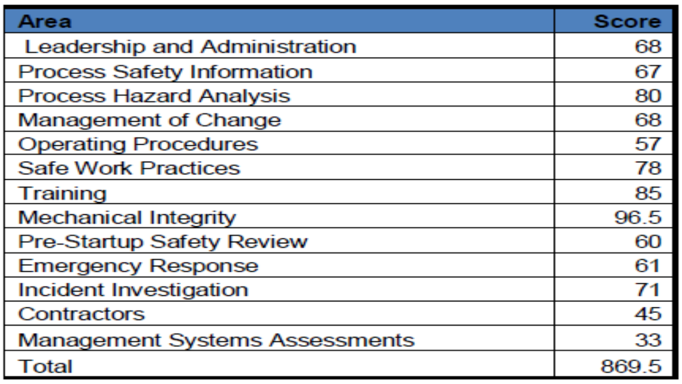
Table 3.1 – Suggested Component Generic Failure Frequencies

Equipment Type	Component Type	gff as a Function of Hole Size (failures/yr)				gff_{total} (failures/yr)
		Small	Medium	Large	Rupture	
Vessel/FinFan	KODRUM, COLBTM, FINFAN, FILTER, DRUM, REACTOR, COLTOP, COLMID	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05

from the table we can determine that the value of gff is: **3.06E-05**

Determining Management system factor (Fms)

To determine the value of Fms, we use a series of question and survey given by API RBI 581 to determine Fms value



Area	Score
Leadership and Administration	68
Process Safety Information	67
Process Hazard Analysis	80
Management of Change	68
Operating Procedures	57
Safe Work Practices	78
Training	85
Mechanical Integrity	96.5
Pre-Startup Safety Review	60
Emergency Response	61
Incident Investigation	71
Contractors	45
Management Systems Assessments	33
Total	869.5

Management system factor score according from the survey, the score is **869.5**

the score must first be converted into percentage using the equation of:

$$pscore = \frac{Score}{1000} \,.100 \text{ [unit is 100\%]}$$

based from equation, the *pscore* is **86.95%**

To determine the value of Fms we can use the equation:

$$Fms = \ 10^{(-0.02\,.pscore+1)}$$

$$Fms = \ 10^{(-0.02\,.86.95+1)}$$

$$Fms = \ 0.182390$$

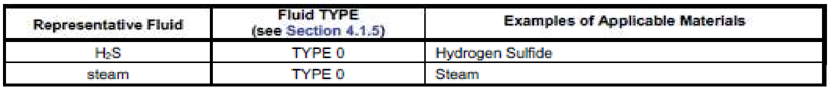
From the equation we can determine that the value of Fms is **0.182390**

Consequence of Failure

Step 1. Determine the release fluid and its properties, including the release phase.

Step 1.1. Select a representative fluid group from table 4.1.

List of representative fluid



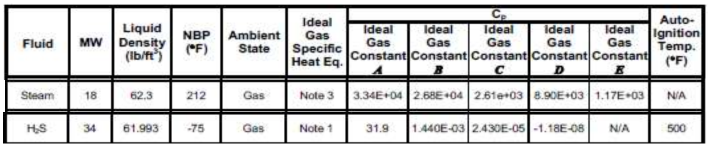
Representative Fluid	Fluid TYPE (see Section 4.1.5)	Examples of Applicable Materials
H_2S	TYPE 0	Hydrogen Sulfide
steam	TYPE 0	Steam

Choosen Representative Fluid : H_2S

Step 1.2 Determine the stored fluid phase

Stored fluid phase: Liquid

Step 1.3 Determine the stored fluid propertioes

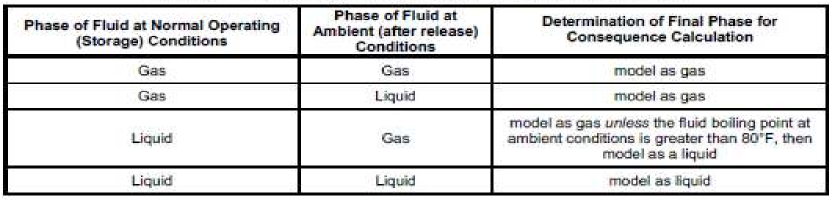


Fluid	MW	Liquid Density (lb/ft^3)	NBP (°F)	Ambient State	Ideal Gas Specific Heat Eq.	C_p Ideal Gas Constant *A*	Ideal Gas Constant *B*	Ideal Gas Constant *C*	Ideal Gas Constant *D*	Ideal Gas Constant *E*	Auto-Ignition Temp. (°F)
Steam	18	62.3	212	Gas	Note 3	3.34E+04	2.68E+04	2.61e+03	8.90E+03	1.17E+03	N/A
H_2S	34	61.993	-75	Gas	Note 1	31.9	1.440E-03	2.430E-05	-1.18E-08	N/A	500

Liquid density : 993.0326 Kg/m^3
NBP : -59.4444 C°
Auto-Ignition Tempt : 260 C°

Step 1.4 Determine the steady state phase of the liquid after release to the atmosphere using table 5.3

Table 4.3 – Level 1 Guidelines for Determining the Phase of a Fluid



Phase of Fluid at Normal Operating (Storage) Conditions	Phase of Fluid at Ambient (after release) Conditions	Determination of Final Phase for Consequence Calculation
Gas	Gas	model as gas
Gas	Liquid	model as gas
Liquid	Gas	model as gas *unless* the fluid boiling point at ambient conditions is greater than 80°F, then model as a liquid
Liquid	Liquid	model as liquid

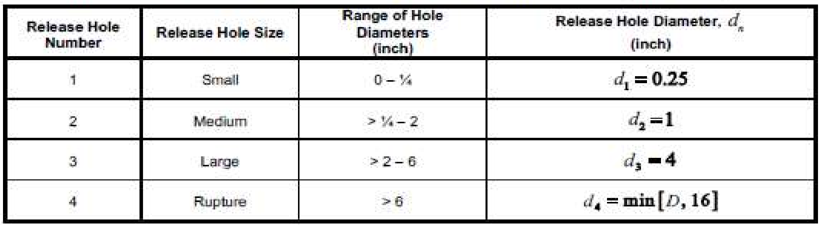
Discharge Coefficient Liquid : 0.61
Viscosity Correction Factor : 1
Gravitional Constant : 1

The fluid is liquid in the vessel, it’s post release is gas

step 2 Select a set of release hole sizes to determine the possible range of consequences in the risk calculation.

Step. 2.1

Table 4.4 – Release Hole Sizes and Areas Used in Level 1 and 2 Consequence Analyses



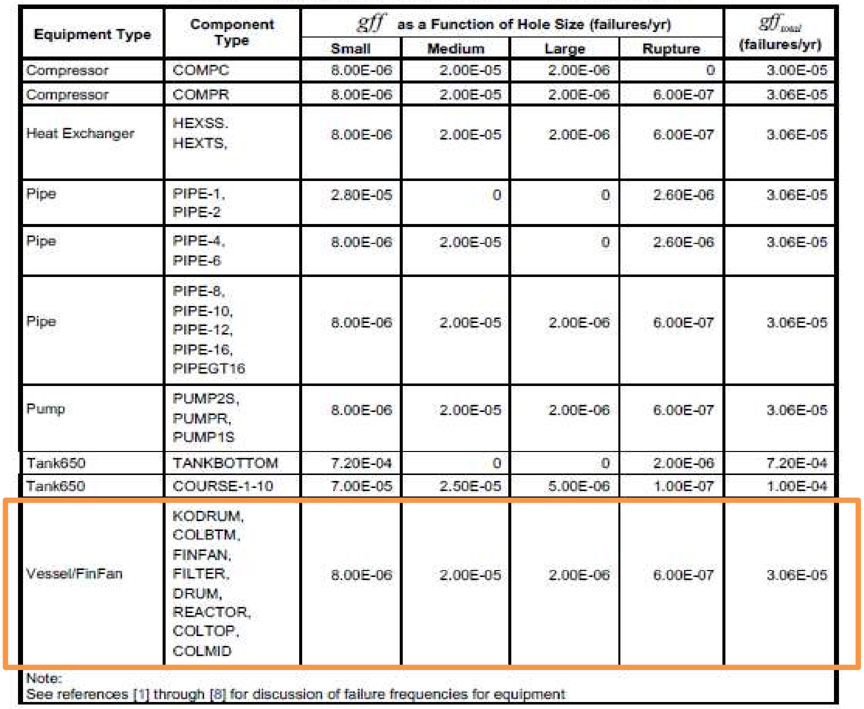
Release Hole Number	Release Hole Size	Range of Hole Diameters (inch)	Release Hole Diameter, d_n (inch)
1	Small	0 – ¼	$d_1 = 0.25$
2	Medium	> ¼ – 2	$d_2 = 1$
3	Large	> 2 – 6	$d_3 = 4$
4	Rupture	> 6	$d_4 = \min[D, 16]$

Step 2.2

Determine the generic failure frequency for the n release hole size from table 3.1 part 2.

3.7 Tables

Table 3.1 – Suggested Component Generic Failure Frequencies



Equipment Type	Component Type	gff as a Function of Hole Size (failures/yr)				gff_{total} (failures/yr)
		Small	Medium	Large	Rupture	
Compressor	COMPC	8.00E-06	2.00E-05	2.00E-06	0	3.00E-05
Compressor	COMPR	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Heat Exchanger	HEXSS. HEXTS,	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Pipe	PIPE-1, PIPE-2	2.80E-05	0	0	2.60E-06	3.06E-05
Pipe	PIPE-4, PIPE-6	8.00E-06	2.00E-05	0	2.60E-06	3.06E-05
Pipe	PIPE-8, PIPE-10, PIPE-12, PIPE-16, PIPEGT16	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Pump	PUMP2S, PUMPR, PUMP1S	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Tank650	TANKBOTTOM	7.20E-04	0	0	2.00E-06	7.20E-04
Tank650	COURSE-1-10	7.00E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04
Vessel/FinFan	KODRUM, COLBTM, FINFAN, FILTER, DRUM, REACTOR, COLTOP, COLMID	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05

Note:
See references [1] through [8] for discussion of failure frequencies for equipment

Step 3. Calculate the theoritical release rate

Step 3.1

Select the appropriate release rate equation using the determined stored fluid phase.

Stored fluid type : Vapour

Step 3.2

Compute the release hole size area A_n in mm^2, using equation (3.8) based on d_n

$$An = \frac{\pi d_n^2}{4} \qquad \text{e.q 3.8}$$

Release for small hole size

$$An = \frac{\pi\ (0.25)^2}{4}$$

$$An = \frac{126.6127}{4}$$

$An = 0.0491$ inch

$= 3.00E\text{-}05\ m^2$

Release for medium hole size

$$An = \frac{\pi\ (1)^2}{4}$$

$$An = \frac{2025.802}{4}$$

$An = 0.785\ mm^2$

$5.00E\text{-}04\ m^2$

Release for Large hole size

$$An = \frac{\pi\ (4\ )^2}{4}$$

$$An = \frac{32412.84}{4}$$

$An = 12.56\ mm^2$

$0.008\ m^2$

Release for Rupture hole size

$$An = \frac{\pi\ (16\ )^2}{4}$$

$$An = \frac{72928.89}{4}$$

$An = 201\ mm^2$

$0.13\ m^2$

Step 3.3

Calculate Viscosity Correction Factor

$Kv_1 = 1$ $Kv_4 = 1$

$Kv_2 = 1$

$Kv_3 = 1$

Step 3.4

For release hole, calculate the release rate, Wn, In Kg/s for each release area, An, using the formula:

For Vapour release rate, we must first find the transition pressure (P_{trans}).

$$Ptrans = Patm\left(\frac{k+1}{2}\right)^{\frac{\kappa}{k-1}}$$

$$Ptrans = 1\left(\frac{1.27+1}{2}\right)^{\frac{1.27}{1.27-1}}$$

$$Ptrans = 1.814196$$

$$k = \frac{Cp}{Cp-R}$$

$$k = \frac{39.1}{39.1-8.314}$$

$k =$ 1.270058

Since P_s is greater than $_{Ptrans}$, we can use equation (3.6) to determine vapour flow rate

$$Wn = \frac{C_d}{C_2}\,.An\,.Ps\sqrt{\left(\frac{k\,.MW\,.gc}{R\,.Ts}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

For Small hole release size

$$W_1 = \frac{C_d}{C_2}\,.An\,.Ps\sqrt{\left(\frac{k\,.MW\,.gc}{R\,.Ts}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

$$W_1 = \frac{0.90}{1}\,.31.65316\,.1060\sqrt{\left(\frac{1.27\,.34\,.1}{8.314\,.453.15}\right)\left(\frac{2}{1.27+1}\right)^{\frac{1.27+1}{1.27-1}}}$$

$$W_1 = 31214.71433\sqrt{2.33497E{-}05}$$

$W_1 =$ 0.001949247 Kg/s

For Medium hole release size

$$W_2 = \frac{C_d}{C_2}\,.An\,.Ps\sqrt{\left(\frac{k\,.MW\,.gc}{R\,.Ts}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

$$W_2 = \frac{0.90}{1000}\,.506.4506\,.1060\sqrt{\left(\frac{1.27\,.34\,.1}{8.314\,.453.15}\right)\left(\frac{2}{1.27+1}\right)^{\frac{1.27+1}{1.27-1}}}$$

$$W_2 = 499435.5\sqrt{2.33497E{-}05}$$

$W_2 =$ 0.093635081 Kg/s

For Large hole release size

$$W_3 = \frac{C_d}{C_2}\,.An\,.Ps\sqrt{\left(\frac{k\,.MW\,.gc}{R\,.Ts}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

$$W_3 = \frac{0.90}{1}\,.8103.21\,.1060\sqrt{\left(\frac{1.27\,.34\,.1}{8.314\,.453.15}\right)\left(\frac{2}{1.27+1}\right)^{\frac{1.27+1}{1.27-1}}}$$

$$W_3 = 7990968\sqrt{2.33497E{-}05}$$

$W_3 =$ 0.47857007 Kg/s

For Rupture hole release size

$$W_4 = \frac{C_d}{C_2}\,.An\,.Ps\sqrt{\left(\frac{k\,.MW\,.gc}{R\,.Ts}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

$$W_4 = \frac{0.90}{0.9674}\,.18232.22\,.1060\sqrt{\left(\frac{1.27\,.34\,.1}{8.314\,.453.15}\right)\left(\frac{2}{1.27+1}\right)^{\frac{1.27+1}{1.27-1}}}$$

$$W_4 = 17979675.3\sqrt{2.33497E{-}05}$$

$W_4 =$ 23.9646359676799 Kg/s

Step 4. Estimate the Maximum Mass Avaible for Release (Availble Mass)

Step 4.1 Group components and equipment items into inventory groups

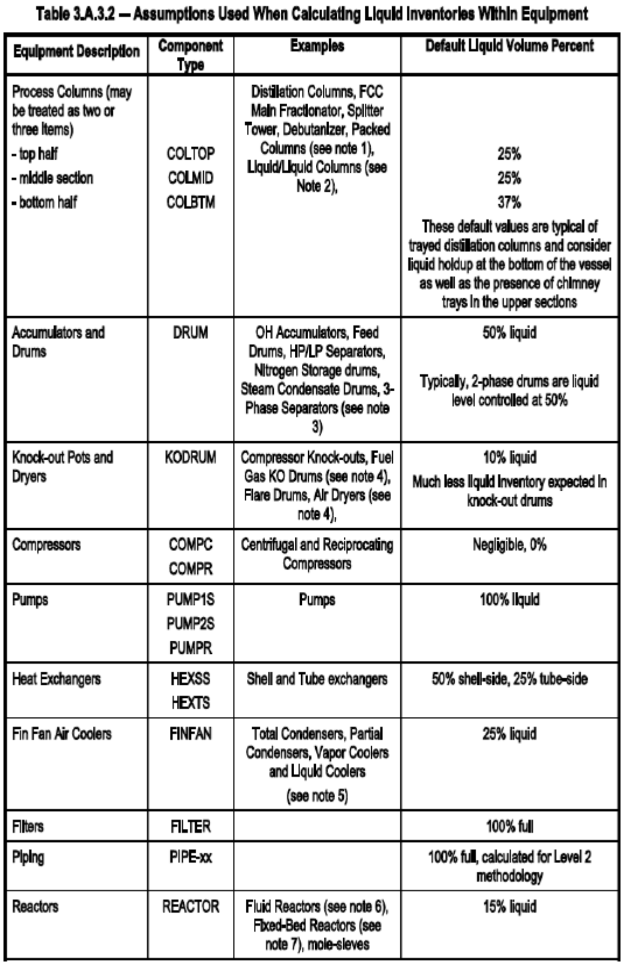


Table 3.A.3.2 — Assumptions Used When Calculating Liquid Inventories Within Equipment

Equipment Description	Component Type	Examples	Default Liquid Volume Percent
Process Columns (may be treated as two or three items) - top half - middle section - bottom half	 COLTOP COLMID COLBTM	Distillation Columns, FCC Main Fractionator, Splitter Tower, Debutanizer, Packed Columns (see note 1), Liquid/Liquid Columns (see Note 2),	 25% 25% 37% These default values are typical of trayed distillation columns and consider liquid holdup at the bottom of the vessel as well as the presence of chimney trays in the upper sections
Accumulators and Drums	DRUM	OH Accumulators, Feed Drums, HP/LP Separators, Nitrogen Storage drums, Steam Condensate Drums, 3-Phase Separators (see note 3)	50% liquid Typically, 2-phase drums are liquid level controlled at 50%
Knock-out Pots and Dryers	KODRUM	Compressor Knock-outs, Fuel Gas KO Drums (see note 4), Flare Drums, Air Dryers (see note 4),	10% liquid Much less liquid inventory expected in knock-out drums
Compressors	COMPC COMPR	Centrifugal and Reciprocating Compressors	Negligible, 0%
Pumps	PUMP1S PUMP2S PUMPR	Pumps	100% liquid
Heat Exchangers	HEXSS HEXTS	Shell and Tube exchangers	50% shell-side, 25% tube-side
Fin Fan Air Coolers	FINFAN	Total Condensers, Partial Condensers, Vapor Coolers and Liquid Coolers (see note 5)	25% liquid
Filters	FILTER		100% full
Piping	PIPE-xx		100% full, calculated for Level 2 methodology
Reactors	REACTOR	Fluid Reactors (see note 6), Fixed-Bed Reactors (see note 7), mole-sieves	15% liquid

Step 4.2 Calculate the fluid mass, mass comp, in the component being evaluated

Volume of Cylinder

$$V_{cyl} = \pi R^2 L$$

R = ID/2 = 1.067 m

L = 10.5 m

V_{cyl} = 37.536 m^3

Liquid Volume = $(50/100) \times V_{cyl}$ = 18.77 m^3

Vapor Volume = $(1-(50/100)) \times V_{cyl}$ = 18.77 m^3

the mass in component

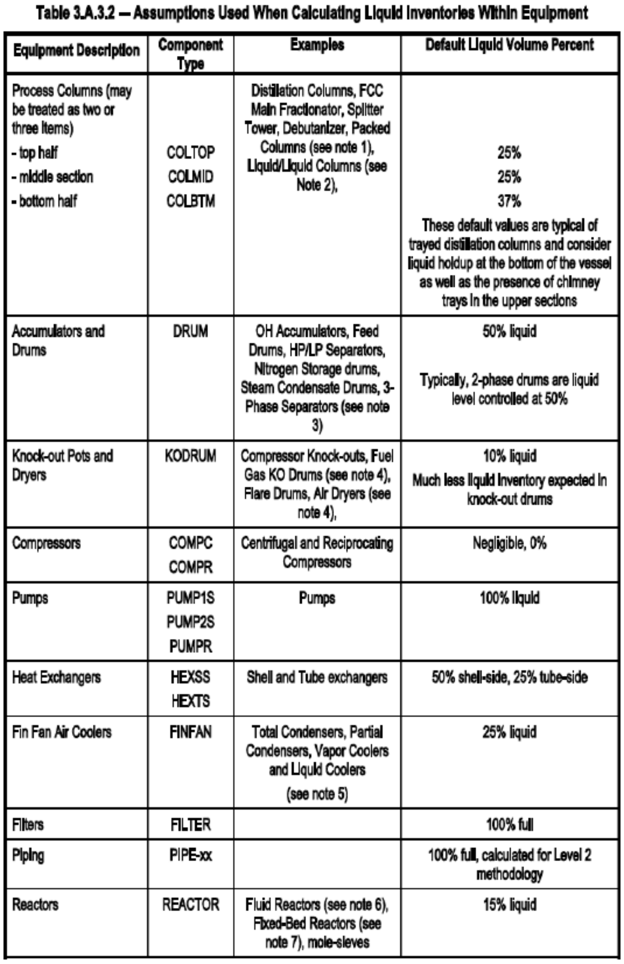
mass_{cc} = $(V_l \rho_l) + (V_v \rho_v)$

mass_{cc} = 18746 kg

Step 4.3 Calculate fluid mass in each of the other components that are included in the inventory group, mass comp

Step 4. Estimate the Maximum Mass Avaible for Release (Availble Mass)

Step 4.1 Group components and equipment items into inventory groups



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Process Columns (may be treated as two or three items) - top half - middle section - bottom half	COLTOP COLMID COLBTM	Distillation Columns, FCC Main Fractionator, Splitter Tower, Debutanizer, Packed Columns (see note 1), Liquid/Liquid Columns (see Note 2),	25% 25% 37% These default values are typical of trayed distillation columns and consider liquid holdup at the bottom of the vessel as well as the presence of chimney trays in the upper sections
Accumulators and Drums	DRUM	OH Accumulators, Feed Drums, HP/LP Separators, Nitrogen Storage drums, Steam Condensate Drums, 3-Phase Separators (see note 3)	50% liquid Typically, 2-phase drums are liquid level controlled at 50%
Knock-out Pots and Dryers	KODRUM	Compressor Knock-outs, Fuel Gas KO Drums (see note 4), Flare Drums, Air Dryers (see note 4),	10% liquid Much less liquid inventory expected in knock-out drums
Compressors	COMPC COMPR	Centrifugal and Reciprocating Compressors	Negligible, 0%
Pumps	PUMP1S PUMP2S PUMPR	Pumps	100% liquid
Heat Exchangers	HEXSS HEXTS	Shell and Tube exchangers	50% shell-side, 25% tube-side
Fin Fan Air Coolers	FINFAN	Total Condensers, Partial Condensers, Vapor Coolers and Liquid Coolers (see note 5)	25% liquid
Filters	FILTER		100% full
Piping	PIPE-xx		100% full, calculated for Level 2 methodology
Reactors	REACTOR	Fluid Reactors (see note 6), Fixed-Bed Reactors (see note 7), mole-sieves	15% liquid

Step 4.2 Calculate the fluid mass, mass comp, in the component being evaluated

Volume of Cylinder

$$V_{cyl} = \pi R^2 L$$

R = ID/2 = 1.067 m

L = 10.5 m

V_{cyl} = 37.536 m^3

Liquid Volume = (50/100) x V_{cyl} = 18.77 m^3

Vapor Volume = (1-(50/100)) x V_{cyl} = 18.77 m^3

the mass in component

mass $_{cc}$ = $(V_l \rho_l) + (V_v \rho_v)$

mass $_{cc}$ = 18746 kg

Step 4.3 Calculate fluid mass in each of the other components that are included in the inventory group, mass comp

Step 4.4 Calculate the fluid mass on the inventory group, *mass* $_{inv}$

$$mass_{inv} = \sum_{i=1}^{N} mass_{\ comp}$$

$$mass_{inv} = \sum_{i=1}^{N} 18639.3$$

$$mass_{inv} = \sum_{i=1}^{1} 18639.3$$

$mass_{inv} =$ **18639.3 Kg**

Step 4.5 Calculate the flow rate from a 203 mm (8 inch) diameter hole, Wmax8, using equations (3.3), (3,6) or (3,7) as applicable, with A_n = A_8 = 32,450 mm2 (50.3 inch2).

$$W_{max\ 8} = \frac{C_d}{C_2} \, . A_8 \, . Ps \sqrt{\left(\frac{k\, .MW\, .gc}{R\, .Ts}\right) \left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

$$W_{max\ 8} = \frac{0.90}{1} \, .32450\, .1060 \sqrt{\left(\frac{1.27\, .34\, .1}{8.314\, .453.15}\right) \left(\frac{2}{1.27+1}\right)^{\frac{1.27+1}{1.27-1}}}$$

$W_{max\ 8}$ _ 3.716 Kg

Step 4.6 for each release hole size, calculate the added fluid mass, *mass* $_{add\ ,\ n\ ,}$, resulting from three minutes of flow from the inventory group using equation (3.10) where W_n is the leakage rate for the release hole size.

$mass_{\text{ add n}} = 180\, .\text{Min}\ [W_n\, , Wmax_{8,}$

for small hole release size

$mass_{\text{ add 1 \_ 180}}\ \text{Min}\ [W_n\, , Wmax_{8,}$
$mass_{\ addl,\ 1\ =\ 180\ .}\ Min\ [28959.46\ .3.716]$

mass $_{add,\ 1}$ = 0.35086447 Kg/s

for Medium hole release size

$mass_{\text{ add 2 \_ 180}}\ \text{Min}\ [W_n\, , Wmax_{8,}$

$mass_{\ add\ 2\ \_\ 180}\ Min\ [463351.4\ \ , 3841.08334]$
mass $_{add,\ 2}$ = 16.85 Kg/s

for Large hole release size

$mass_{\text{ add 3 \_ 180}}\ \text{Min}\ [W_n\, , Wmax_{8,}$
mass $_{add,3}$ = 84.17

for Rupture hole release size

$mass_{\text{ add 4 \_ 180}}\ \text{Min}\ [W_n\, , Wmax_{8,}$
mass $_{add,4}$ = 84.17

Step 4.7 For each release hole size, calculate the avaible mas for release.

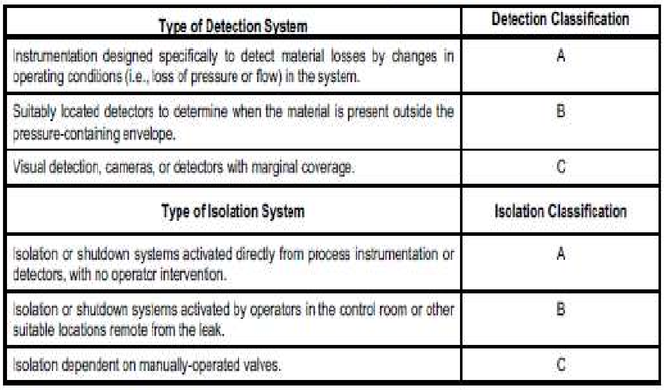
$$Mass_{\ avail} = \min[\ \{mass_{\ comp} + mass_{\ add}\}, mass_{\ Inv}]$$

$Mass_{\ avail} =$ 18746 kg

Step 6. Estimeate the impact of detection and isolation systems on release magnitude.

Step 6.1 Determine the detection and isolation systems present in the unit

Table 4.5 – Detection and Isolation System Rating Guide



Type of Detection System	Detection Classification
Instrumentation designed specifically to detect material losses by changes in operating conditions (i.e., loss of pressure or flow) in the system.	A
Suitably located detectors to determine when the material is present outside the pressure-containing envelope.	B
Visual detection, cameras, or detectors with marginal coverage.	C
Type of Isolation System	**Isolation Classification**
Isolation or shutdown systems activated directly from process instrumentation or detectors, with no operator intervention.	A
Isolation or shutdown systems activated by operators in the control room or other suitable locations remote from the leak.	B
Isolation dependent on manually-operated valves.	C

Step 6.2 Using table 4.5, select the appropriate classification (A,B,C) for the detection system.

Detection System C

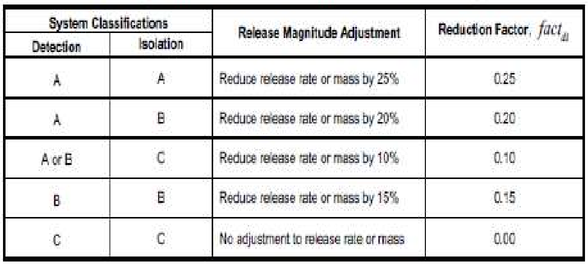
Step 6.3 Using table 4.5, select the appropriate classification (A,B,C) for the isolation system.

Isolation System C

Step 6.4

Using table 4.6 and the classification determined in step 6.2 and step 6.3, determine the release reductio factor

Table 4.6 – Adjustments to Release Based on Detection and Isolation Systems



System Classifications		Release Magnitude Adjustment	Reduction Factor, $fact_{di}$
Detection	Isolation		
A	A	Reduce release rate or mass by 25%	0.25
A	B	Reduce release rate or mass by 20%	0.20
A or B	C	Reduce release rate or mass by 10%	0.10
B	B	Reduce release rate or mass by 15%	0.15
C	C	No adjustment to release rate or mass	0.00

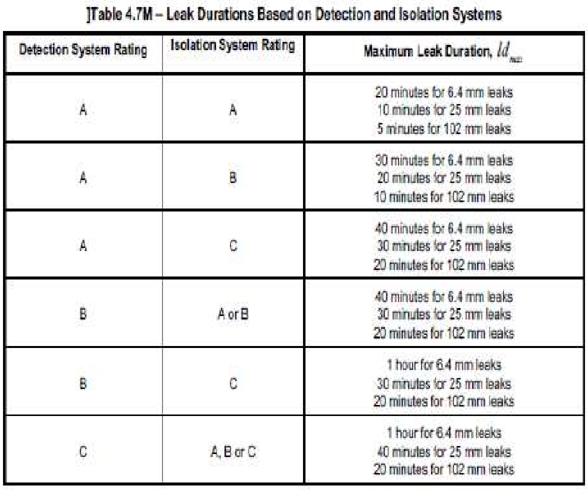
Detection System C

Isolation System C

$fact_{di}$ = 0.00

Step 6.5

Using table 4.7 and the classification determined in step 6.2 and 6.3, determine the total leak durations for each of the selected release hole sizes, $\boldsymbol{Id}_{\boldsymbol{max,n}}$



]Table 4.7M – Leak Durations Based on Detection and Isolation Systems

Detection System Rating	Isolation System Rating	Maximum Leak Duration, ld_{max}
A	A	20 minutes for 6.4 mm leaks 10 minutes for 25 mm leaks 5 minutes for 102 mm leaks
A	B	30 minutes for 6.4 mm leaks 20 minutes for 25 mm leaks 10 minutes for 102 mm leaks
A	C	40 minutes for 6.4 mm leaks 30 minutes for 25 mm leaks 20 minutes for 102 mm leaks
B	A or B	40 minutes for 6.4 mm leaks 30 minutes for 25 mm leaks 20 minutes for 102 mm leaks
B	C	1 hour for 6.4 mm leaks 30 minutes for 25 mm leaks 20 minutes for 102 mm leaks
C	A, B or C	1 hour for 6.4 mm leaks 40 minutes for 25 mm leaks 20 minutes for 102 mm leaks

Detection Sys	A		
Isolation Syste	B		
$Id_{max,1}$	6.4 mn	60	minutes
$Id_{max,2}$	25 mm	40	minutes
$Id_{max,3}$	102 mi	20	minutes

Step 7 Determine the release rate and mass for consequence analysis

Step 7.1

For each release hole size, calculate the adjusted release rate, $_{rate\ n}$. using equation (3.13)

$$rate_n = Wn\ (1 - factdi)$$

Small Hole size

$$rate_1 = W_1\ (1 - factdi)$$

$$rate_1 = 3746.761958\ \ (1 - factdi)$$

rate $_1$ = 0.00195 kg/s

Medium Hole size

$$rate_2 = W_2\ (1 - factdi)$$

$$rate_2 = 59948.2\ \ (1 - factdi)$$

rate $_2$ = 0.09364 kg/s

Large Hole size

$$rate_3 = W_3\ (1 - factdi)$$

$$rate_3 = 959171.184\ \ \ (1 - factdi)$$

rate $_3$ = 0.47857 kg/s

Large Hole size

$$rate_4 = W_4\ (1 - factdi)$$

$$rate_4 = 2158134.87\ \ \ (1 - factdi)$$

rate $_4$ = 23.9646 kg/s

Step 7.2

For each release hole size, calculate the leak duration, **id$_n$,** of the release using equation (3.15), based on the avaible mass, ***mass*** $_{avail,n}$

$$Id_n = \min\left[\left\{\frac{mass_{availn}}{rate_n}\right\}, \{60.\, idmax_{,n}\}\right]$$

Small Hole size

$$Id_1 = \min\left[\left\{\frac{mass_{avail1}}{rate_1}\right\}, \{60.\, idmax_{,1}\}\right]$$

= 3600

Medium Hole size

$$Id_2 = \min\left[\left\{\frac{mass_{avail2}}{rate_2}\right\}, \{60.\, idmax_{,2}\}\right]$$

= 1200

Large Hole size

$$Id_3 = \min\left[\left\{\frac{mass_{avail3}}{rate_3}\right\}, \{60.\, idmax_{,3}\}\right]$$

= 600

Large Hole size

$$Id_4 = \min\left[\left\{\frac{mass_{avail4}}{rate_4}\right\}, \{60.\, idmax_{,4}\}\right]$$

= 600

Step 7.3

For each release hole size, calculate the release mass, massn, using equation (3.14) based on the release rate, raten, from step 3.2, the lead duration idn, from step 7.2 and the available mass, massavailn, from step 4.6

$$mass_n = \min[\{rate_n\, .\, idn\}, massavailn]$$

Small Hole Size

$$mass_1 = \min[\{rate_1\, .\, id_1\}, massavail_{1_]}$$

mass $_1$ = 7.01729

Medium Hole Size

$$mass_2 = \min[\{rate_2\, .\, id_2\}, massavail_{2_]}$$

mass $_2$ = 112.362

Large Hole Size

$$mass_3 = \min[\{rate_3\, .\, id_3\}, massavail_{3_]}$$

mass $_3$ = 287.142

Rupture Hole Size

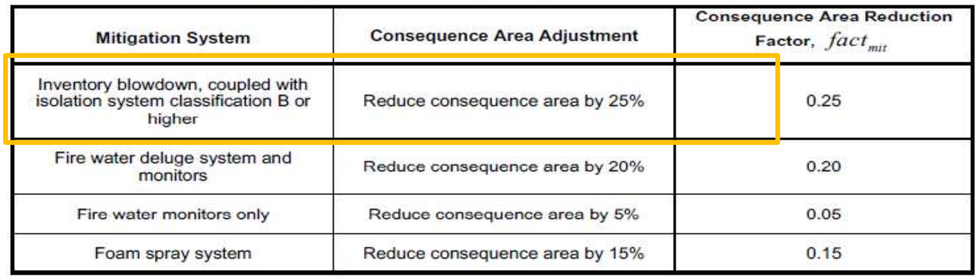
$$mass_4 = \min[\{rate_4\, .\, id_4\}, massavail_{4_]}$$

mass $_4$ = 14378.8

Step 8 Determining Flammable and Explosive Consequences

Step 8.1 Select the consequence area mitigation reduction factor, ***fact*** $_{mit}$**,** from table 4.10

Table 4.10 – Adjustments to Flammable Consequence for Mitigation Systems



Mitigation System	Consequence Area Adjustment	Consequence Area Reduction Factor, $fact_{mit}$
Inventory blowdown, coupled with isolation system classification B or higher	Reduce consequence area by 25%	0.25
Fire water deluge system and monitors	Reduce consequence area by 20%	0.20
Fire water monitors only	Reduce consequence area by 5%	0.05
Foam spray system	Reduce consequence area by 15%	0.15

$fact_{mit}$ = 0

Step 8.2 For each release hole size, calculate the energy efficiency correction factor, *eneff* $_n$ using equation 3.18

$$eneff_n = 4.log_{10}[C_4.massn] - 15$$

for small hole size

$$eneff_1 = 4.log_{10}[C_4.mass_1] - 15$$

eneff $_1$ = 1.758311923 1.758

for medium hole size

$$eneff_2 = 4.log_{10}[C_4.mass_2] - 15$$

eneff $_2$ = 6.576113718

for large hole size

$$eneff_3 = 4.log_{10}[C_4.mass_2] - 15$$

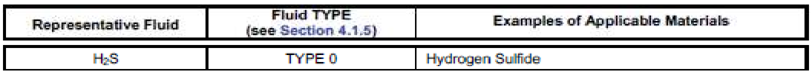
eneff $_3$ = 8.206021514

for rupture hole size

$$eneff_3 = 4.log_{10}[C_4.mass_2] - 15$$

eneff $_3$ = 15.00452272

Step 8.3 Determine the fluid type, either Type 0 or Type 1 from table 4.1



Representative Fluid	Fluid TYPE (see Section 4.1.5)	Examples of Applicable Materials
H_2S	TYPE 0	Hydrogen Sulfide

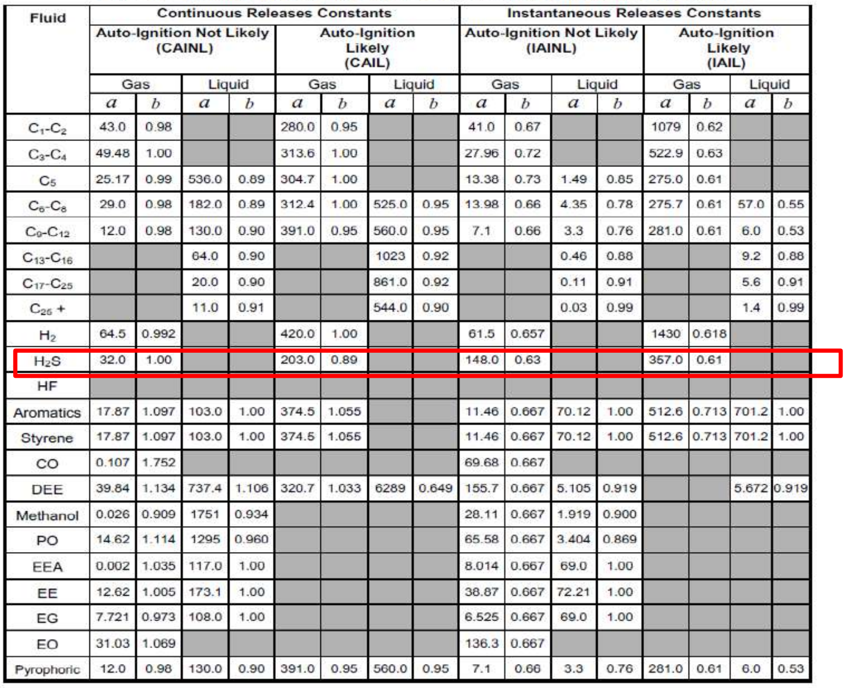
H_2S = Type 0

Step 8.4 For each release hole size, calculate the component damage consequence area.

Step 1.4 will be needed to assure selection of the correct constant

Determine the appropriate constants *a* and *b* from the table 4.8.

Table 4.8 – Component Damage Flammable Consequence Equation Constants



Fluid	Continuous Releases Constants								Instantaneous Releases Constants							
	Auto-Ignition Not Likely (CAINL)				Auto-Ignition Likely (CAIL)				Auto-Ignition Not Likely (IAINL)				Auto-Ignition Likely (IAIL)			
	Gas		Liquid		Gas		Liquid		Gas		Liquid		Gas		Liquid	
	a	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*
C_1-C_2	43.0	0.98			280.0	0.95			41.0	0.67			1079	0.62		
C_3-C_4	49.48	1.00			313.6	1.00			27.96	0.72			522.9	0.63		
C_5	25.17	0.99	536.0	0.89	304.7	1.00			13.38	0.73	1.49	0.85	275.0	0.61		
C_6-C_8	29.0	0.98	182.0	0.89	312.4	1.00	525.0	0.95	13.98	0.66	4.35	0.78	275.7	0.61	57.0	0.55
C_9-C_{12}	12.0	0.98	130.0	0.90	391.0	0.95	560.0	0.95	7.1	0.66	3.3	0.76	281.0	0.61	6.0	0.53
C_{13}-C_{16}			64.0	0.90			1023	0.92			0.46	0.88			9.2	0.88
C_{17}-C_{25}			20.0	0.90			861.0	0.92			0.11	0.91			5.6	0.91
C_{25} +			11.0	0.91			544.0	0.90			0.03	0.99			1.4	0.99
H_2	64.5	0.992			420.0	1.00			61.5	0.657			1430	0.618		
H_2S	32.0	1.00			203.0	0.89			148.0	0.63			357.0	0.61		
HF																
Aromatics	17.87	1.097	103.0	1.00	374.5	1.055			11.46	0.667	70.12	1.00	512.6	0.713	701.2	1.00
Styrene	17.87	1.097	103.0	1.00	374.5	1.055			11.46	0.667	70.12	1.00	512.6	0.713	701.2	1.00
CO	0.107	1.752							69.68	0.667						
DEE	39.84	1.134	737.4	1.106	320.7	1.033	6289	0.649	155.7	0.667	5.105	0.919			5.672	0.919
Methanol	0.026	0.909	1751	0.934					28.11	0.667	1.919	0.900				
PO	14.62	1.114	1295	0.960					65.58	0.667	3.404	0.869				
EEA	0.002	1.035	117.0	1.00					8.014	0.667	69.0	1.00				
EE	12.62	1.005	173.1	1.00					38.87	0.667	72.21	1.00				
EG	7.721	0.973	108.0	1.00					6.525	0.667	69.0	1.00				
EO	31.03	1.069							136.3	0.667						
Pyrophoric	12.0	0.98	130.0	0.90	391.0	0.95	560.0	0.95	7.1	0.66	3.3	0.76	281.0	0.61	6.0	0.53

$a = a_{cmd}^{AINL-CONT}$ $b = b_{cmd}^{AINL-CONT}$

a = 32.0 *b* = 1.00

Determining Consequence Area for *AINL-CONT*

$$CA_{cmd,n}^{AINL-CONT} = a\,(rate)^{b} \,.\, (1 - factmil)$$

for small hole size

$CA_{cmd,1}^{AINL-CONT}$ = 0.0624 m^2

for medium hole size

$CA_{cmd,2}^{AINL-CONT}$ = 2.9963 m^2

for large hole size

$CA_{cmd,3}^{AINL-CONT}$ = 15.314 m^2

for rupture hole size

$CA_{cmd,4}^{AINL-CONT}$ = 766.87 m^2

Step 8.5 For each release hole size, compute the component damage consequence areas for Autoignition likely Continous Release (*AIL-CONT*)

$a = a_{cmd}^{AIL-CONT}$ $b = b_{cmd}^{AIL-CONT}$

a = 203.0 *b* = 0.89

Determining Consequence Area for *AINL-CONT*

for small hole size

$CA_{cmd,1}^{AIL-CONT}$ = 0.7861 m^2

for medium hole size

$CA_{cmd,2}^{AIL-CONT}$ = 24.665 m^2

for large hole size

$CA_{cmd,3}^{AIL-CONT}$ = 105.35 m^2

for rupture hole size

$CA_{cmd,4}^{AIL-CONT}$ = 3430.2 m^2

Step 8.6 For each release hole size, compute the component damage consequence areas for Auto-Ignition Not Likely, Instantaneous Release (*AINL-INST*)

$$a = a_{cmd\square}^{AINL-INST}$$

$a =$ 148.0 $b =$ 0.63

Determining Consequence Area for ANIL-*CONT*

$$CA_{cmd,n\square}^{AINL-INST} = a\,(mass)^b \,.\, (\frac{1 - factmil}{eneff_n})$$

for small hole size

$CA_{cmd,1}^{AINL-INST}$ = 287.25 m^2

for medium hole size

$CA_{cmd,2}^{AINL-INST}$ = 440.74 m^2

for large hole size

$CA_{cmd,3}^{AINL-INST}$ = 637.87 m^2

for rupture hole size

$CA_{cmd,4}^{AINL-INST}$ = 4105.9 m^2

Step 8.7 For each release hole size, compute the component damage consequence areas for Auto-Ignition Likely, Continous Release (*AIL-CONT*)

$$a = a_{cmd\square}^{AIL-CONT} \qquad b = b_{cmd\square}^{AIL-CONT}$$

$a =$ 357.0 $b =$ 0.61

Determining Consequence Area for AIL-*CONT*

$$CA_{cmd,n\square}^{AIL-INST} = a\,(mass)^b \,.\, (\frac{1 - factmil}{eneff_n})$$

for small hole size

$CA_{cmd,1}^{AIL-INST}$ = 666.4 m^2

for medium hole size

$CA_{cmd,2}^{AIL-INST}$ = 967.34 m^2

for large hole size

$CA_{cmd,3}^{AIL-INST}$ = 1374 m^2

for rupture hole size

$CA_{cmd,4}^{AIL-INST}$ = 8178.2 m^2

Step 9.1

For each release hole size selected in step 2.2, calculate the effective duration of release using equation (3.67)

$$Id_n^{tox} = \min\left(3600, \left\{\frac{mass}{W}\right\}, \{60\,.\,Idmax, n\}\right)$$

For small hole size

$$Id_1^{tox} = \min\left(3600, \left\{\frac{mass_1}{W}\right\}, \{60\,.\,Idmax_{,\,1}\}\right)$$

= 3600

For medium hole size

$$Id_1^{tox} = \min\left(3600, \left\{\frac{mass_1}{W}\right\}, \{60\,.\,Idmax_{,\,1}\}\right)$$

= 1200

For small hole size

$$Id_1^{tox} = \min\left(3600, \left\{\frac{mass_1}{W}\right\}, \{60\,.\,Idmax_{,\,1}\}\right)$$

= 600

Step 9.2

Determine the toxic percentage of the toxic component, *mfractox i* n the release material, if the release fluid is pure fluid, mfactox = 1.0.

H_2S = 1.55%

$mfrac^{tox}$ = 0.0155

Step 9.3

For each release hole size, calculate the release rate, ratentox, and release mass, xmassntox, to be used in toxic consequence analysis.

For H_2S

$$rate_n^{tox} = mfractox\,.\,Wn$$

for Small hole size

$$rate_1^{tox} = mfractox\,.\,W_1$$

= 3E-05 Kg/s

for Medium hole size

$$rate_2^{tox} = mfractox\,.\,W_2$$

= 0.0015 Kg/s

for Large hole size

$$rate_3^{tox} = mfractox\,.\,W_3$$

= 0.0074 Kg/s

for Rupture hole size

$$rate_3^{tox} = mfractox\,.\,W_3$$

= 0.3715 Kg/s

Step 9.4

For each release hole size calculate the toxic consequence area for each of the release hole size

HF Acid and H25 — Calculate Cit7n using Equation (3.63) for a continuous release or Equation (3.64) for an instantaneous release. The constants used in these equations are from Table 4.11.

$$CA_{inj,n}^{tox-INST} = C_8 \,.\, 10(C.\log_{10}[C_{4B}.\, mass_n^{tox}]$$

for small hole size

$$mass_1^{tox} = mfractox \,.\, mass_1$$

= 0.1088

$$CA_{inj,n}^{tox-INST} = C_8 \,.\, 10(C.\log_{10}[C_{4B}.\, mass_n^{tox}]$$

= -0.5573

for medium hole size

$$mass_2^{tox} = mfractox \,.\, mass_2$$

= 1.7416

$$CA_{inj,n}^{tox-INST} = C_8 \,.\, 10(C.\log_{10}[C_{4B}.\, mass_n^{tox}]$$

= 0.5252

for large hole size

$$mass_2^{tox} = mfractox \,.\, mass_2$$

= 4.4507

$$CA_{inj,n}^{tox-INST} = C_8 \,.\, 10(C.\log_{10}[C_{4B}.\, mass_n^{tox}]$$

= 0.8914

for Rupture hole size

$$mass_2^{tox} = mfractox \,.\, mass_2$$

= 222.87

$$CA_{inj,n}^{tox-INST} = C_8 \,.\, 10(C.\log_{10}[C_{4B}.\, mass_n^{tox}]$$

= 2.4189

Step 9.5 If there are additional toxic components in the released fluid mixture, STEPs 9.2 through 9.4 should be repeated for each toxic component.

there is no other additional toxic components.

Step 9.6 Determine the final toxic consequence areas for personnel injury in accordance with Equation (3.68)

$$CA_{inj}^{tox} = \left(\frac{\sum_{n=1}^{4} gff_n \,.\, CA_{inj,n}^{tox}}{gff_{total}} \right)$$

CA_{inj}^{tox} = 0.30324 m^2

Step 10 Calculation of Non-Flammable, Non-Toxic Consequence Area

Step 10.1 For each release hole size, calculate the non-flammable, non-toxic consequence area

$$CA_{inj,n}^{CONT} = C_9 \, . \, raten$$

$$CA_{inj,n}^{INST} = C_{10} \, (massn)^{0.6384}$$

Small hole size

$$CA_{inj,1}^{CONT} = C_9 \, . \, rate_1$$

= 2E-04

$$CA_{inj,1}^{INST} = C_{10} \, (mass_1)^{0.6384}$$

= 33.8

Medium hole size

$$CA_{inj,1}^{CONT} = C_9 \, . \, rate_1$$

= 0.012

$$CA_{inj,1}^{INST} = C_{10} \, (mass_1)^{0.6384}$$

= 361.4

Largel hole size

$$CA_{inj,1}^{CONT} = C_9 \, . \, rate_1$$

= 0.059

$$CA_{inj,1}^{INST} = C_{10} \, (mass_1)^{0.6384}$$

= 361.4

Step 10.2 For each release hole size, calculate the instantaneous/continous blending factor, for steam use equation (3.71)

$$fact_n^{IC} = \min\left[\left\{\frac{Raten}{C5}\right\}, 1.0\right]$$

Small hole size

$$fact_1^{IC} = \min\left[\left\{\frac{Rate_1}{C_5}\right\}, 1.0\right]$$

= 7.73511E-05

Medium hole size

$$fact_1^{IC} = \min\left[\left\{\frac{Rate_1}{C_5}\right\}, 1.0\right]$$

= 0.003715678

Large hole size

$$fact_1^{IC} = \min\left[\left\{\frac{Rate_1}{C_5}\right\}, 1.0\right]$$

= 0.019

Step 10.3

For each release hole size, calculate the blended non-flammable, non-toxic personnel injury consequence area for steam or acid leaks using equation (3.88) based on the consequence area from Step 10.1 and the blending factor from 10.2.

$$CA_{inj,n}^{leak} = CA_{inj,n}^{INST} . fact_n^{IC} + CA_{inj,n}^{CONT}\ (1 - fact_n^{IC})$$

Small hole size

$$CA_{inj,1}^{leak} = CA_{inj,1}^{INST} . fact_1^{IC} + CA_{inj,1}^{CONT}\ (1 - fact_1^{IC})$$

= 0.003

Medium hole size

$$CA_{inj,2}^{leak} = CA_{inj,2}^{INST} . fact_2^{IC} + CA_{inj,2}^{CONT}\ (1 - fact_2^{IC})$$

= 1.354

Large hole size

$$CA_{inj,1}^{leak} = CA_{inj,1}^{INST} . fact_1^{IC} + CA_{inj,1}^{CONT}\ (1 - fact_1^{IC})$$

= 354.5

Step 10.4

Determine the final non-flammable, non-toxic consequence areas for personnel injury using Equation (3.80) based on consequence areas calculated for each release hole size in STEP 10.3.

Note that there is no need to calculate a final non-flammable, non-toxic consequence area for componDetermdamage area for the Level 1 non-flammable releases (steam or acid/caustic).

$$CA_{inj}^{nfnt} = \left(\frac{\sum_{n=1}^{4} gff_n . CA_{inj,n}^{nfnt}}{gff_{total}}\right)$$

$CA_{inj}^{nfnt} =$ 24.05822469 m^2

Step 11.1 Calculate the final component damage consequence area, Cacmd

Note that since the component damage consequence areas for toxic releases, $CAcmd^{tox}$, and non-flammable, non-toxic releases, $CAcmd^{nfnt}$, are both equal to zero. Then, the final component damage consequence area is equal to the consequence area calculated for flammable releases, $CAcmd^{flam}$.

………………………………………… (equation 47)

$CA_{cmd} = CA_{cmd}^{flam}$ = 652.1247212 m^2

Step 11.2 Calculate the final personnel injury consequence area,

$CA_{inj} = \max\left[CA_{inj}^{flam}, CA_{inj}^{tox}, CA_{inj}^{nfnt}\right]$

………………….. (equation 48)

$CA_{inj} = \max\left[CA_{inj}^{flam}, CA_{inj}^{tox}, CA_{inj}^{nfnt}\right]$

= 223 m^2

Step 11.3 Calculate the final consequence area, CA, using equation below:

$CA = \max\left[CA_{cmd}, CA_{inj}\right]$

= 652.1 m^2

Risk Analysis

Determining RBI Date

Age at RBI date

$$age = RBI\ Date - Last\ Inspection\ Date$$

= 12-Feb-2019 - 22-Nov-2014

= 5 year

Age at RBI plan date

$$age = Plan\ date - Last\ Inspection\ Date$$

= 01-Jan-23 - 22-Nov-14

= 9 year

$Risk_{RBIDate}$ Age at RBI date

$$Risk_{RBIDate} = PoF\ .\max(CAinj, CAequip)$$

= 20.459347 m_2

$Risk_{RBIDate}$ Age at RBI plan date

$$Risk_{PlanDate} = PoF\ .\max(CAinj, CAequip)$$

= 54.646294 m_2

R(t) Age at RBI date

$$Risk_{RBIDate} = PoF\ \ .\ CoF$$

= 8.1313291 m_2

R(t) Age at RBI plan date

$$Risk_{PlanDate} = PoF\ \ .\ CoF$$

= 54.646294 m_2

Probability Range

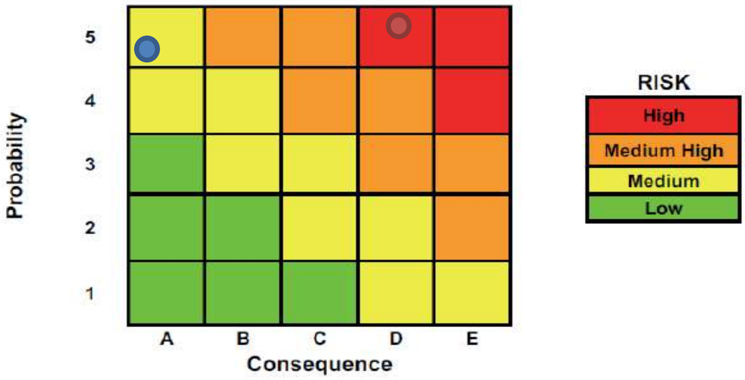
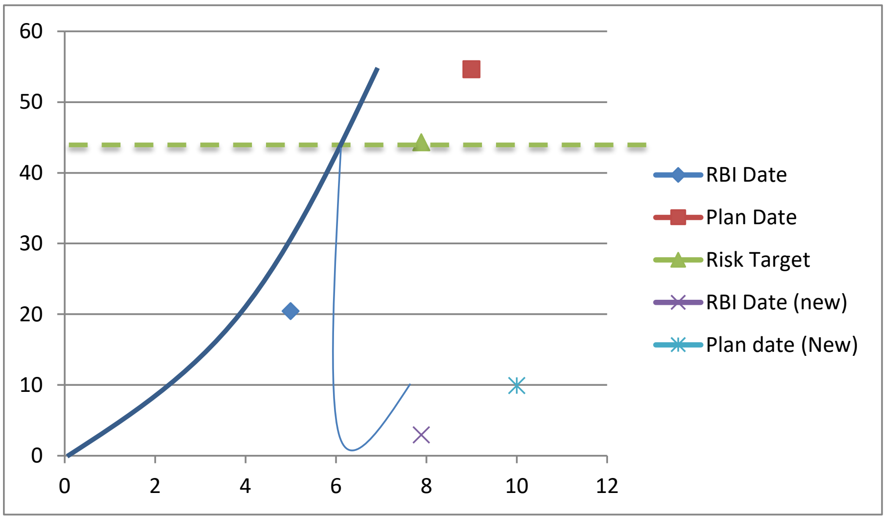


Figure 4.3 – Balanced Risk Matrix Example

Inspection Planning

Step 1 Estimate Target Date

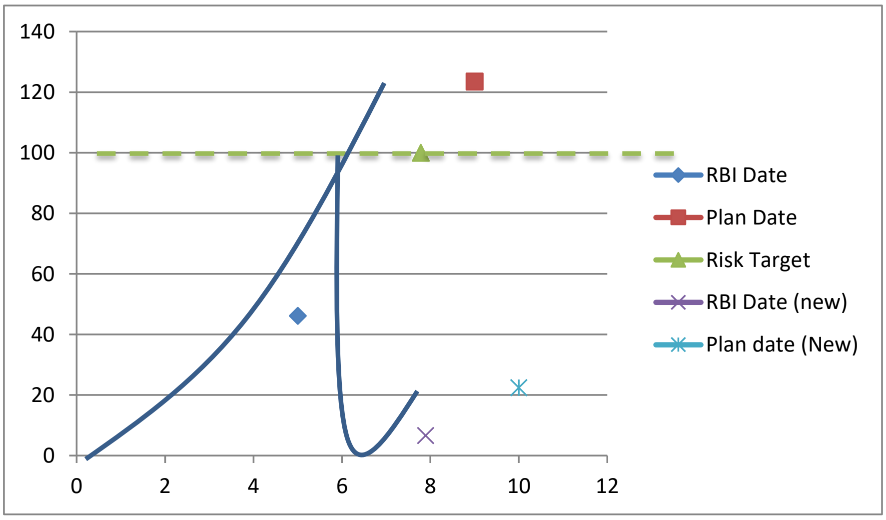
Item	Date	Time since RBI Assessment	Risk Area (m^2/yr)
RBI Date	02/12/2019	5	20.45934724
Risk Target	12/05/2019	7.89	44.33273807
Plan Date	02/12/2023	9	54.6462938



Target date = 7.89 year after RBI Assessment

= 03/02/2002

Item	Date	Time since RBI Assessment	Damage Factor
RBI Date	02/12/2019	5	46.1495232
Risk Target	03/02/2022	7.25	100
Plan Date	02/12/2023	9	123.528109



Target date = 7.25 Year after RBI Assessment

= 03/02/2022

Lampiran 6

Calculation for VS-80-003

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Calculation of Thinning Damage Factor

Basic Data	Value	Unit	Comments
Start Date	01/01/2000		The date the component was placed in service.
Thickness	28.85	mm	The thickness used for DF calculation that is either the furnished thickness or the measured thickness.
Corrosion Allowance	3.00	mm	The corrosion allowance is the specified design or actual corrosion allowance upon being placed in the current servicce.
Design Tempearture	50-200	°C	The design temperature, shell side and tube side for heat exchanger.
Design Pressure	1450	Kpa	The design pressure, shell side and tubbe side for heat exchanger.
Operating Tempearture	187	°C	The highest expected operating temperature expected during operation including normal and unusual operating conditions, shell side and tube side for heat exchanger.
Operating Pressure	1060	Kpa	The highest expected operating pressure expected during operation including normal and unusual operating conditions, shell side and tube side for heat exchanger.
Design Code	ASME Section VIII Division I Ed. 2015		The designing of the component containing the component.
Equipment Type	Separator (Pressure Vessel)		The type of equipment.
Component Type	Filter		The type of component.
Geometry Data	ELL (Elliptical Head)		Component geometry data depending on the type of component.
Material Specification			The specification of the material of construction, the ASME SA or SB specification for pressure vessel components or for ASTM specification for piping and tankage components. Data entry is based on the material specification, grade, year, UNS Number, class/condition/temper/size/thickness; this data is readdily available in the ASME Code.
Yield Strength	510000/650000	Kpa	The design yield strength of the material based on material specification.
Tensile Strength	335000	Kpa	The design tensile strength of the material based on material specification.
Weld Joint Efficiency	1.00	mm	Weld joint efficiency per the Code of construction.
Heat Tracing	Yes		Is the component heat traced? (Yes or No)

STEP 1 Determining the furnished thickness, t, and age for the component from the installation date.

t = 5 inch

= 12.7 mm

age = 14 years (it is assumed from the default date for the first installement in a plant on January 1st 2000 (01/01/2000) until November 26th 2014 (26/11/2014)).

STEP 2 Determining the corrosion rate for base material, $C_{r,bm}$ based on the material construction and environment, and cladding/weld overlay corrosion rate, $C_{r,cm}$.

Based on the explanation from Section 4.5.2 that the corrosion rate is **CALCULATED** using the approach of Annex 2B. Then, first of all, the corrosion screening question must be done as follows:

Table 2.B.1.1-Screening Questions for Corrosion Rate Calculations

No.	Type of Corrosion	Screening Question		Yes/No	Action
1.	Hydrochloric Acid (HCl) Corrosion	1.	Does the process contain HCl?	N	No
		2.	Is free water present in the process stream (including initial condensing condition)?	Y	
		3.	Is the pH < 7.0?	Y	
			Actual relatively pH is 5.66		
2.	High Temperature Sulfidic/Naphtenic Acid Corrosion	1.	Does the process contain oil with sulfur compounds?	N	No
		2.	Is the operating temperature > 204°C (400°F)?	N	
			The operating temperature is 187°C.		
3.	Sulfuric Acid Corrosion	1.	Does the process contain H_2SO_4	N	No
4.	High Temperature H_2S/H_2 Corrosion	1.	Does the process contain H_2S and Hydrogen?	Y	No
		2.	Is the operating temperature > 204°C (400°F)?	N	
			The operating temperature is 187°C.		
5.	Hydrifluoric Corrosion	1.	Does the process contain HF	N	No
6.	Sour Water Corrsion	1.	Is free water with H_2S present?	Y	Yes
7.	Amine Corrosion	1.	Is equipment exposed to acid gas treaating amines (MEA, DEA, DIPA, or MDEA)?	N	No
8.	High Temperature Oxidation Corrosion	1.	Is the temperature ≥ 482°C (900°F)?	N	No
			The operating temperature is 187°C.		
		2.	Is the oxygen present?	N	
9.	Acid Sour Water Corrosion	1.	Is free water with H_2S present and pH < 7.0?	Y	No
			Actual relatively pH is 5.66		
		2.	Does the proocess contain < 50 ppm chlorides?	N	
10.	Cooling Water	1.	Is equipment in cooling water service?	N	No
11.	Soil Side Corrosion	1.	Is equipment in contact with soil (buried or partially buried)?	N	No
		2.	Is the material of construction carbon steel?	N	
12.	CO_2 Corrosion	1.	Is the free water with CO_2 present (including consideration for dew point condensation)?	Y	No
		2.	Is the material of construction carbon steel or < 13% Cr?	N	
13.	AST Bottom	1.	Is the equipment item an AST tank bottom?	N	No

pH = 5.56
T = 187 C
= 368 F
P = 2895.9 Kpa
H2S Concentr = 7.935979788 % mole
Material = Carbon Steel (SA 516-70)

Basically, there are 3 types of Corrosion Rate (Cr) calculation which are based on the RLA data from the last inspection, based on the calculation referred to the API 581 Annex 2B, and the last is based on worst case scenario.

1. Corrosion Rate (Cr) from the RLA data

Cr = 0.000394 inch/year
= 0.010000 mm/year

2. Corrosion Rate (Cr) based on the Annex 2B High temperature corrosion rate

The steps required to determine the corrosion rate are shown in Figure 2.B.7.1. The corrosion rate may be determined using the basic data in Table 2.B.7.1 in conjunction with the baseline corrosion rates and equations in Table 2.B.7.2 to correct for H_2S partial pressure

Basic Data	Comments
NH_4HS concentration (wt%)	Determine the NH_4HS concentration of the condensed water. It is suggested to determine this value with ionic process models. However, approximate values may be calculated from analyses of H_2S and NH_3 as follows
	If wt% H_2S < 2 x (wt% NH_3), wt% NH_4HS =1.5 x (wt% H_2S)
	If wt% H_2S > 2 x (wt% NH_3), wt% NH_4HS =3.0 x (wt% H_2S)
Strean Velocity	The vapor phase velocity should be used in a two-phase system. The liquid phase velocity should be used in a liquid full system.
H_2S partial pressure, psia [kPa]	Determine the partial pressure of H_2S by multiplying the mole% of H_2S in the gas phase by the total system pressure.

Determining NH4HS Concentration

to determine NH_4HS concentration, we must first determine if wt% H_2S is lower or higher than wt% of NH_3.

wt% H_2S = 0.02
wt% NH_3 = 0.00047639
2 X wt% NH_3 = 0.00095278

Since the value of H_2S is higher than NH_3, the wt% of NH_4HS can be determined by the formula of: wt% NH_4HS = 3.0 x (wt% H_2S)

If wt% H_2S > 2 x (wt% NH_3), wt% NH_4HS =3.0 x (wt% H_2S)
NH_4HS= 3.0 x (wt% H_2S)
NH_4HS = 0.06

to determine the Cr, we must first do a calculation to correct the H_2S partial pressure.

$$\text{Adjusted } CR = \max\left[\left\{\left(\frac{Baseline\ CR}{276}\right) . (pH2S\ - 345) + Baseline\ CR\right\}, 0\right]$$

Adjusted CR = 0.287

STEP 3 Determine the time in service, age_{tk}, since the last known inspection, t_{rdi}.

Because of the manufactured-thickness is not provided. Then, the thickness used in this calculation is coming from the last inspection as long as as the Production Separator installed in setvice life).

t_{rdi} = 1.136 inch
= 28.8544 mm
age_{tk} = 7 year (Last inspection was held on November 2014)

STEP 4 For cladding/weld overlay pressure vessel components, calculate the age from the date starting thickness from STEP 3 required to corrode away the cladding/weld overlay material, age_{rc}, using equation below:

$$age_{rc} = \max\left[\left(\frac{t_{rdi} - tbm}{C_{r\,cm}}\right), 0.0\right] \quad \text{...} \quad \text{(equation 57)}$$

This equipment does not have cladding, so this step are skipped

STEP 5 Determine the t_{min}

Actually there are 4 methods used to determine the minimum thickness of the equipment (t_{min}). Based on the condition, the method used by the author is the first method which is for cylindrical, spherical, or head components, determine the allowable Stress, S, weld joint efficiency, E, and the minimum thickness, t_{min}.

t_{min} = 1.0202 inch
= 25.91308 mm
S = 17500 psig
= 120658300 Pa
= 120658.3 Kpa
E = 1

STEP 6 Determine the A_{rt} Parameter

For component without clading/weld overlay then use the equation below.

$$A_{rt} = \frac{Cr_{b,m} \cdot age_{tk}}{t_{rdi}}$$ ……………………………………………….. (equation 58)

= 0.0696852 (For calculated corrosion rate based on ANNEX 2B)

$$A_{rt} = \frac{Cr_{b,m} \cdot age_{tk}}{t_{rdi}}$$

= 0.002425973 (For corrosion rate based on RLA Data)

STEP 7 Calculate the Flow Stress, FS^{Thin}, using E from STEP 5 and equation below.

$$FS^{Thin} = \frac{(YS+TS)}{2} . E.1,1$$ ……………………………………………….. (equation 59)

Where;

YS = 205000 KPa https://www.csecplates.com/astm-a283-grade-c-plate-stockists-suppliers.html

TS = 447500 KPa

E = 1

$$FS^{Thin} = \frac{(YS+TS)}{2} . E.1,1$$

= 358875

STEP 8 Calculate the strength ratio parameter, , SR_P^{Thin} the appropriate equation.

$$SR_P^{Thin} = \frac{S.E}{FS^{Thin}} \cdot \frac{Max\,(t_{min}, t_c)}{t_{rdi}}$$ …………………………………………. (equation 60)

Where;

t_c = is the minimum structural thickness of the component base material

= 1.0202 inch

= 25.91308 mm

$$SR_P^{Thin} = \frac{S.E}{FS^{Thin}} \cdot \frac{Max\,(t_{min}, t_c)}{t_{rdi}}$$

= 0.686008207

STEP 9 Determine the number of inspections for each of the correspondesing inspection effectiveness, $N_A^{Thin}, N_B^{Thin}, N_C^{Thin}, N_D^{Thin}$sing Section 4.5.6 of the API RP 581 Part 2 for past inspections performed during in-service time.

N_A^{Thin} = 0

N_B^{Thin} = 0

N_C^{Thin} = 0

N_D^{Thin} = 0

STEP 10 Calculate the inspection effectiveness factors, $I_1^{Thin}, I_2^{Thin}, I_3^{Thin}$ g equation 61 below, prior probabilities, , from Table 4.5. The Conditional Probabilities (for each inspection effectiveness level), $Pr_{p1}^{Thin}, Pr_{p2}^{Thin}$ and Pr_{p3}^{Thin} le 4.6, and the number of inspection, $N_B^{Thin}, N_C^{Thin}, N_D^{Thin}$ ı effectiveness level from STEP 9.

N_A^{Thin}

$$I_1^{Thin} = Pr_{P1}^{Thin}(Co_{P1}^{ThinA})^{N_A^{Thin}}(Co_{P1}^{ThinB})^{N_B^{Thin}}(Co_{P1}^{ThinC})^{N_C^{Thin}}(Co_{P1}^{ThinD})^{N_D^{T}}$$

$$I_2^{Thin} = Pr_{P2}^{Thin}(Co_{P2}^{ThinA})^{N_A^{Thin}}(Co_{P2}^{ThinB})^{N_B^{Thin}}(Co_{P2}^{ThinC})^{N_C^{Thin}}(Co_{P2}^{ThinD})^{N_A^{T}}$$

$$I_3^{Thin} = Pr_{P3}^{Thin}(Co_{P3}^{ThinA})^{N_A^{Thin}}(Co_{P3}^{ThinB})^{N_B^{Thin}}(Co_{P3}^{ThinC})^{N_C^{Thin}}(Co_{P3}^{ThinD})^{N_A^{T}}$$

Table 4.5 - Prior Probability for Thinning Corrosion Rate

Damage State	Low Confidence Data	Medium Confidence Data	High Conf. Data
Pr_{P1}^{Thin}	0.5	0.7	0.8
Pr_{P2}^{Thin}	0.3	0.2	0.15
Pr_{P3}^{Thin}	0.2	0.1	0.05

Table 4.6 - Conditional Probability for Inspection Effectiveness

Conditional P. of Inspection	E-None or Ineffective	D-Poorly Effective	C-Fairly Effective	B-Usually Effective	A-Highly Effective
Co_{P1}^{Thin}	0.33	0.4	0.5	0.7	0.9
Co_{P2}^{Thin}	0.33	0.33	0.3	0.2	0.09
Co_{P3}^{Thin}	0.33	0.27	0.2	0.1	0.01

$$I_1^{Thin} = Pr_{P1}^{Thin}(Co_{P1}^{ThinA})^{N_A^{Thin}}(Co_{P1}^{ThinB})^{N_B^{Thin}}(Co_{P1}^{ThinC})^{N_C^{Thin}}(Co_{P1}^{ThinD})^{N_D^{T}}$$

= 0.50

$$I_2^{Thin} = Pr_{P2}^{Thin}(Co_{P2}^{ThinA})^{N_A^{Thin}}(Co_{P2}^{ThinB})^{N_B^{Thin}}(Co_{P2}^{ThinC})^{N_C^{Thin}}(Co_{P2}^{ThinD})^{N_A^{T}}$$

= 0.30

$$I_3^{Thin} = Pr_{P3}^{Thin}(Co_{P3}^{ThinA})^{N_A^{Thin}}(Co_{P3}^{ThinB})^{N_B^{Thin}}(Co_{P3}^{ThinC})^{N_C^{Thin}}(Co_{P3}^{ThinD})^{N_A^{T}}$$

= 0.20

STEP 11 Calculate the Posteroir Probability, $Po_{p1}^{Thin}, Po_{p2}^{Thin}$ and Po_{p3}^{Thin} 56 below.

$$Po_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} \qquad \text{……………………………………} \qquad \text{(equation 64)}$$

= 0.5

$$Po_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} \qquad \text{……………………………………} \qquad \text{(equation 65)}$$

= 0.3

$$Po_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} \qquad \text{……………………………………} \qquad \text{(equation 66)}$$

= 0.2

p Calculate the parameters, $ß_1$, $ß_2$, and $ß_3$ using equation 67,68,69 below and also assigning $COV_{\Delta t} = 0.20$, $COV_{sf} = 0.20$, and $COV_P = 0.05$.

$$ß_1^{Thin} = \frac{1-D_{S1}\,.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S1}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S1}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}} \quad \text{.........} \quad \text{(equation 67)}$$

$$ß_2^{Thin} = \frac{1-D_{S2}\,.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S2}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S2}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}} \quad \text{..........} \quad \text{(equation 68)}$$

$$ß_3^{Thin} = \frac{1-D_{S3}\,.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S3}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S3}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}} \quad \text{..........} \quad \text{(equation 69)}$$

Where;

$COV_{\Delta t}$ = The thinning coefficient of variance ranging from $0.1 \leq COV_{\Delta t} \leq 0.2$
= 0.2
COV_{sf} = The flow stress coefficient of variance
= 0.2
COV_P = Pressure coeffficient of variance
= 0.05
D_{s1} = Damage State 1
= 1
D_{s2} = Damage State 2
= 2
D_{s3} = Damage State 3
= 4

BASED ON CORROSION RATE FROM RLA DATA

$$ß_1^{Thin} = \frac{1-D_{S1}\,.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S1}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S1}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

= 1.5390

$$ß_2^{Thin} = \frac{1-D_{S2}\,.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S2}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S2}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

= 1.53065328

$$ß_3^{Thin} = \frac{1-D_{S3}\,.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S3}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S3}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

= 1.51374389

STEP 13 For tank bottom components, determine the base damage factor for thining using Table 4.8. and based on A_{rt} parameter from STEP 6.

Because component observed in this case of analysis is including into Pressure Vessel (Production Separator), then, this step of ccalculation can be skipped.

STEP 14 For all components (excluding tank bottoms covered in STEP 13), calculate the base damage factor, D_{fB}^{Thin}.

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi(-\beta_1^{Thin})\right)+\left(Po_{P2}^{Thin}\Phi(-\beta_2^{Thin})\right)+\left(Po_{P3}^{Thin}\Phi(-\beta_3^{Thin})\right)}{1.56E\ -0.4} \quad \text{.........} \quad \text{(equation 70)}$$

BASED ON CORROSION RATE FROM RLA DATA

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi(-\beta_1^{Thin})\right)+\left(Po_{P2}^{Thin}\Phi(-\beta_2^{Thin})\right)+\left(Po_{P3}^{Thin}\Phi(-\beta_3^{Thin})\right)}{1.56E\ -0.4}$$

= 0.200745959

STEP 15 Determine the DF for thinning, , using equation equatiD_f^{Thin}elow.

$$D_f^{Thin} = \text{Max}[(\frac{(D_{fb}^{Thin}.\,F_{IP}\,.\,F_{DL}\,.F_{WD}.F_{AM}\,.F_{SM})}{F_{OM}}),0.1] \quad \text{........................} \quad \text{(equation 71)}$$

Where;

F_{IP} = DF adjustent for injection points (for piping circuit)
= 0
F_{DL} = DF adjustment for dead legs (for piping only used to intermittent service)
= 0
F_{WD} = DF adjustment for welding construction (for only AST Bottom)
= 0
F_{AM} = DF adjustment for AST maintenance per API STD 653 (for only AST)
= 0
F_{SM} = DF adjustment for settlement (for only AST Bottom)
= 0
F_{OM} = DF adjustment for online monitoring based on Table 4.9
= 1

BASED ON CORROSION RATE FROM RLA DATA

$$D_f^{Thin} = \text{Max}[(\frac{(D_{fb}^{Thin}}{F_{OM}}),0.1]$$

= 0.200745959

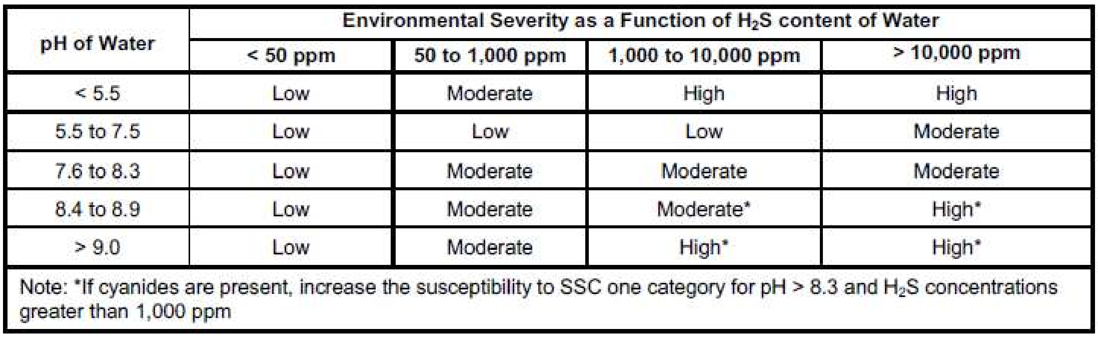
Calculation of SCC-Sulfide Stress Cracking Damage Factor

Step 1.

Determine the environemental severity (potential level of hydrogen flux) for cracking based on the H2S Content of water and its pH using Table 8.2

pH : 5.52
Content of water : 1000 ppm

Table 8.2 – Environmental Severity – SSC



pH of Water	Environmental Severity as a Function of H_2S content of Water			
	< 50 ppm	50 to 1,000 ppm	1,000 to 10,000 ppm	> 10,000 ppm
< 5.5	Low	Moderate	High	High
5.5 to 7.5	Low	Low	Low	Moderate
7.6 to 8.3	Low	Moderate	Moderate	Moderate
8.4 to 8.9	Low	Moderate	Moderate*	High*
> 9.0	Low	Moderate	High*	High*

Note: *If cyanides are present, increase the susceptibility to SSC one category for pH > 8.3 and H_2S concentrations greater than 1,000 ppm

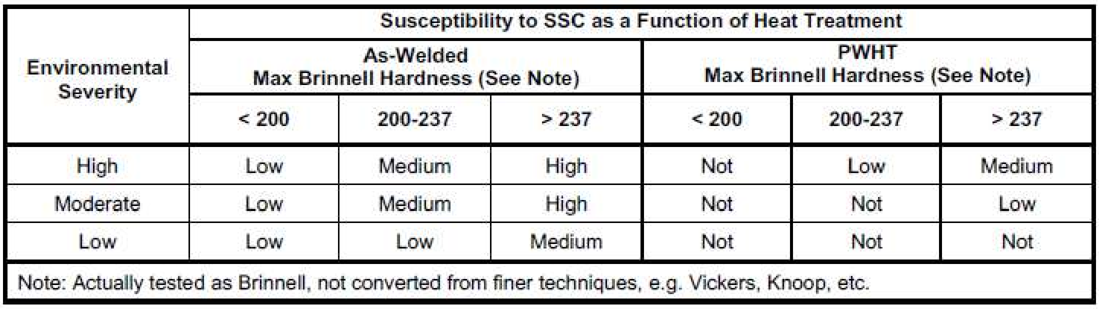
Environmental Severity of H2S : Moderate

Step 2

Determine the susceptibility for cracking using *figure 8.1* and *table 8.3* based on the environmental severity from step 1, the maximum brinnel hardness of weldments, and knowledge of whether the component was subject to PWHT.

Enviromental Severity of H2S : Moderate

Table 8.3 – Susceptibility to SSC – SSC



Environmental Severity	Susceptibility to SSC as a Function of Heat Treatment					
	As-Welded Max Brinnell Hardness (See Note)			PWHT Max Brinnell Hardness (See Note)		
	< 200	200-237	> 237	< 200	200-237	> 237
High	Low	Medium	High	Not	Low	Medium
Moderate	Low	Medium	High	Not	Not	Low
Low	Low	Low	Medium	Not	Not	Not

Note: Actually tested as Brinnell, not converted from finer techniques, e.g. Vickers, Knoop, etc.

Susceptibility to SCC : Low
PWTH : No

Step 3.

Based on the susceptibility in step 3, determine the severity index, S_{VI} from *Table 8.4.*

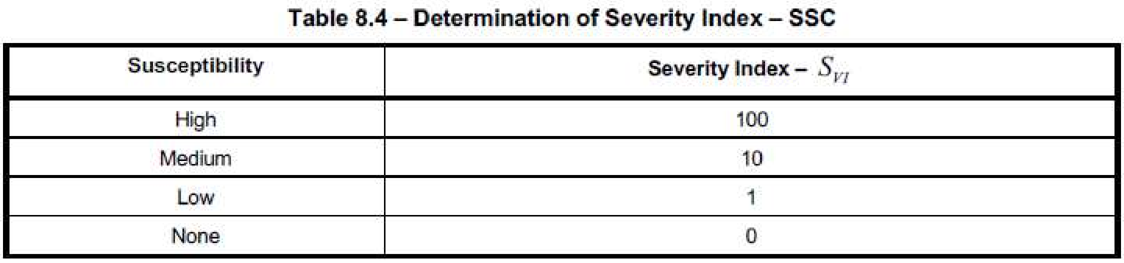


Table 8.4 – Determination of Severity Index – SSC

Susceptibility	Severity Index – S_{VI}
High	100
Medium	10
Low	1
None	0

Svi according to susceptibility to SCC : 1

Step 4.

Determine the time in-service, age , since the last Level A, B or C inspection was performed with no cracking detected or cracking was repaired. Cracking detected but not repaired should be evaluated and future inspection recommendations based upon FFS evaluation

In-service age : 14 year

age at the RBI Date

$$age_{RBI} = RBI\ Date - Last\ Inspection\ Date$$

age_{RBI} = 12/02/2019 - 26/11/2014

= 4 year

age at RBI Date: 18 year

Step 5.

Determine the number of inspections, and the corresponding inspection using Section 8.6.2 for past inspections performed during the in-service time. Combine the inspections toeffectiveness category the highest effectiveness performed using Section 3.4.3.

Inspection Performed : 2
Inspection Category : 1A
Inspection Effectiveness : Highly Effective

Step 6.

Determine the base DF for sulfide stress cracking D_{fB}^{scc} using Table 6.3 based on the number of, and the highest inspection effectiveness determined in STEP 5, and the severity index S_{VI} from STEP 3.

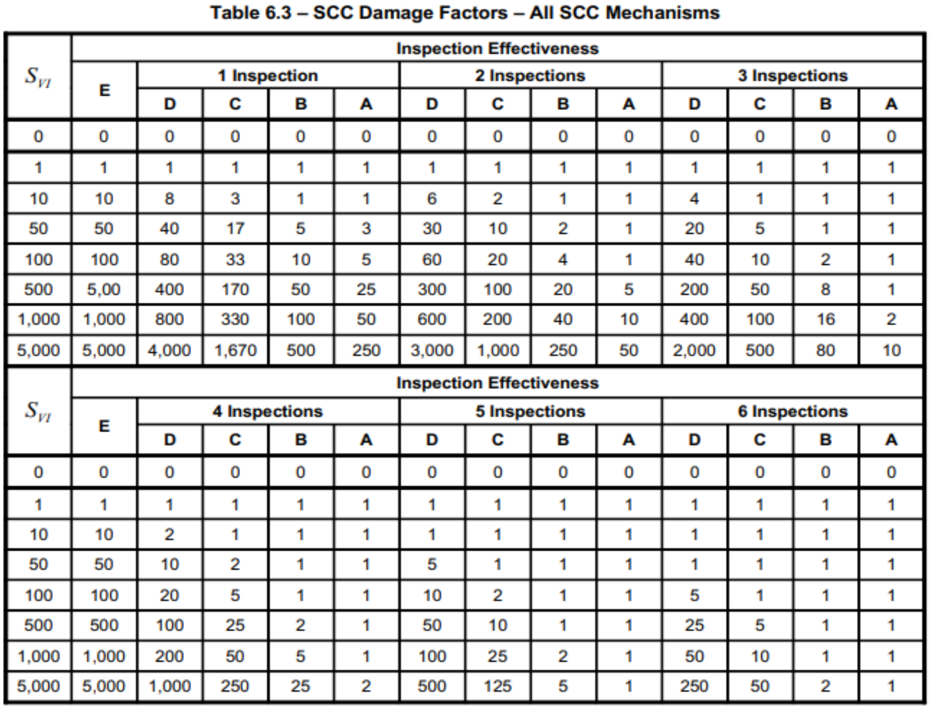


Table 6.3 – SCC Damage Factors – All SCC Mechanisms

S_{VI}	Inspection Effectiveness												
	E	1 Inspection				2 Inspections				3 Inspections			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	8	3	1	1	6	2	1	1	4	1	1	1
50	50	40	17	5	3	30	10	2	1	20	5	1	1
100	100	80	33	10	5	60	20	4	1	40	10	2	1
500	5,00	400	170	50	25	300	100	20	5	200	50	8	1
1,000	1,000	800	330	100	50	600	200	40	10	400	100	16	2
5,000	5,000	4,000	1,670	500	250	3,000	1,000	250	50	2,000	500	80	10

S_{VI}	Inspection Effectiveness												
	E	4 Inspections				5 Inspections				6 Inspections			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	2	1	1	1	1	1	1	1	1	1	1	1
50	50	10	2	1	1	5	1	1	1	1	1	1	1
100	100	20	5	1	1	10	2	1	1	5	1	1	1
500	500	100	25	2	1	50	10	1	1	25	5	1	1
1,000	1,000	200	50	5	1	100	25	2	1	50	10	1	1
5,000	5,000	1,000	250	25	2	500	125	5	1	250	50	2	1

Inspection Effectiveness

Inspection Performed : 2
Inspection Category : 1A

Severity Index

S_{VI} according to susceptibility to SCC : 1

Base Damage factor

Base D_f : 1

Step 7.

Calculate the escalation in the DF based on the time in-service since the last inspection using the age from STEP 4 and Equation (2.27). In this equation, it is assumed that the probability for cracking will increase with time since the last inspection as a result of increased exposure to upset conditions and other non-normal conditions

by using equation 2.27 we can find out the Df.

Damage factor at RBI Date

D_f^{SSC}= $D_{fB}^{SCC}.(Max[age, 1.0])^{1.1}$

D_f^{SCC}= $1.(Max[5,1.0])^{1.1}$

D_f^{SCC}= 5.8730947

Damage factor at RBI Plan Date

D_f^{SSC}= $D_{fB}^{SCC}.(Max[age, 1.0])^{1.1}$

D_f^{SCC}= $1.(Max[11,1.0])^{1.1}$

D_f^{SCC}= 13.980798

step 1.

Determine the environmental severity (potential level of hydrogen flux) for cracking based on the content of the water and its pH using table 9.2.

pH : 5.52

Content of water : 1000 ppm

Table 9.2 – Environmental Severity – HIC/SOHIC-H_2S Cracking

pH of Water	Environmental Severity as a Function of H2S content of Water			
	< 50 ppm	50 to 1,000 ppm	1,000 to 10,000 ppm	> 10,000 ppm
< 5.5	Low	Moderate	High	High
5.5 to 7.5	Low	Low	Low	Moderate
7.6 to 8.3	Low	Moderate	Moderate	Moderate
8.4 to 8.9	Low	Moderate	Moderate*	High*
> 9.0	Low	Moderate	High*	High*
Note: *If cyanides are present, increase the susceptibility to HIC/SOHIC-H_2S one category for pH > 8.3 and H_2S concentrations greater than 1,000 ppm				

Enviromental Severity : Moderate

Step 2

Determine the susceptibility for cracking using *figure 9.1* and *table 9.3* based on the environmental severity from step 1, the maximum brinnel hardness of weldments, and knowledge of whether the component was subject to PWHT.

Table 9.3 – Susceptibility to Cracking – HIC/SOHIC-H_2S

Environmental Severity	Susceptibility to Cracking as a Function of Steel Sulfur Content					
	High Sulfur Steel [(1)] > 0.01% S		Low Sulfur Steel ≤ 0.01% S		Product Form – Seamless/Extruded Pipe	
	As-Welded	PWHT	As-Welded	PWHT	As-Welded	PWHT
High	High	High	High	Medium	Medium	Low
Moderate	High	Medium	Medium	Low	Low	Low
Low	Medium	Low	Low	Low	Low	Low
1. Typically includes A 70, A 201, A 212, A 285, A 515, and most A 516 before about 1990.						

Steel sulfur content: 0.03 %

Environmental severity: Moderate

Post Weld Heat Treatment (PWHT): No

Susceptibility for Cracking: Medium

Step 3.

Based on the susceptibility in STEP 2, determine the severity index, SF/ , fro S_{VI} ble *9.4.*

Table 9.4 – Determination of Severity Index – HIC/SOHIC-H_2S Cracking

Susceptibility	Severity Index – S_{VI}
High	100
Medium	10
Low	1
None	0

Suscpetibility from step 2 : Medium

Severity index : 10

Step 4.

Determine the time in-service, age , since the last Level A, B or C inspection was performed with no cracking detected or cracking was repaired. Cracking detected but not repaired should be evaluated and future inspection recommendations based upon FFS evaluation

Determine the time in service, age, since the last inspection.

age at the RBI Date

$age_{RBI} = RBI\ Date - Last\ Inspection\ Date$

age_{RBI} = 12/02/2019 - 26/11/2014
= 4 year

Step 5

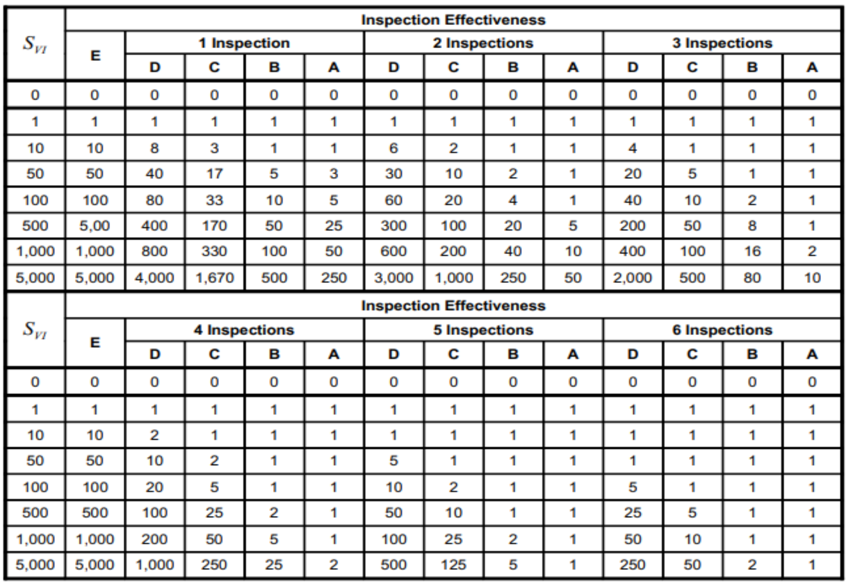
Determine the number of inspections, and the corresponding inspection using Section 9.6.2 for past inspections performed during the in-service time. Combine the inspections toeffectiveness category the highest effectiveness performed using Section 3.4.3.

Damage Mechanism : SCC
Inspection Performed : 2
Inspection Category : A
Inspection Effectiveness : Effective

Step 6.

Determine the base DF for HIC/SOHIC-H_2S using Table 6.3 based on the number of, and the highest inspection effectiveness determined in STEP 5, and the severity index from STEP 3.

Table 6.3 – SCC Damage Factors – All SCC Mechanisms



S_{VI}	Inspection Effectiveness												
	E	1 Inspection				2 Inspections				3 Inspections			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	8	3	1	1	6	2	1	1	4	1	1	1
50	50	40	17	5	3	30	10	2	1	20	5	1	1
100	100	80	33	10	5	60	20	4	1	40	10	2	1
500	5,00	400	170	50	25	300	100	20	5	200	50	8	1
1,000	1,000	800	330	100	50	600	200	40	10	400	100	16	2
5,000	5,000	4,000	1,670	500	250	3,000	1,000	250	50	2,000	500	80	10
S_{VI}	Inspection Effectiveness												
	E	4 Inspections				5 Inspections				6 Inspections			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	2	1	1	1	1	1	1	1	1	1	1	1
50	50	10	2	1	1	5	1	1	1	1	1	1	1
100	100	20	5	1	1	10	2	1	1	5	1	1	1
500	500	100	25	2	1	50	10	1	1	25	5	1	1
1,000	1,000	200	50	5	1	100	25	2	1	50	10	1	1
5,000	5,000	1,000	250	25	2	500	125	5	1	250	50	2	1

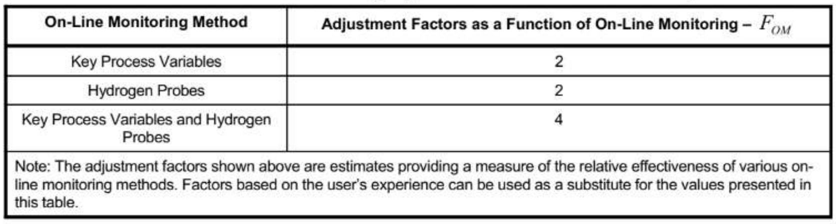
Inspection Effectiveness
Inspection Performed : 2
Inspection Category : 1A

Severity Index
S_{VI} according to susceptibility to SCC : 10

Base Damage factor
Base D_f : 10

Step 7. Determine the on-line adjustment factor, F_{OM} , from Table 9.5.

Table 9.5 – On-Line Monitoring Adjustment Factors for HIC/SOHIC-H_2S



On-Line Monitoring Method	Adjustment Factors as a Function of On-Line Monitoring – F_{OM}
Key Process Variables	2
Hydrogen Probes	2
Key Process Variables and Hydrogen Probes	4
Note: The adjustment factors shown above are estimates providing a measure of the relative effectiveness of various on-line monitoring methods. Factors based on the user's experience can be used as a substitute for the values presented in this table.	

Adjustment Factors:

Key Process Variables : 2

Step 8. Calculate the final DF accounting for escalation based on the time in-service since the last inspection using the age from STEP 4 and Equation (2.28). In this equation, it is assumed that the probability for cracking will increase with time since the last inspection as a result of increased exposure to upset conditions and other non-normal conditions. The equation also applies the adjustment factor for online monitoring

Damage Factor at RBI Date

$$D_f^{HIC\ SOHIC-H2S} = \frac{D_{fB}^{HIC\ SOHIC-H2S}.(Max[age,1.0])^{1.1}}{Fom}$$

$$D_f^{HIC\ SOHIC-H2S} = \frac{1.(Max[4,1.0])^{1.1}}{2}$$

$$D_f^{HIC\ SOHIC-H2S} = 45.94793$$

Damage Factor at RBI Plan Date

$$D_f^{HIC\ SOHIC-H2S} = \frac{D_{fB}^{HIC\ SOHIC-H2S}.(Max[age,1.0])^{1.1}}{Fom}$$

$$D_f^{HIC\ SOHIC-H2S} = \frac{1.(Max[11,1.0])^{1.1}}{2}$$

$$D_f^{HIC\ SOHIC-H2S} = 112.1158$$

Calculating Damage Factor

Damage Factor for Stress Corrosion Cracking

Calculation of damage factor for stress corrosion cracking (SCC) explained in section 3.4.2 - API RP 581 Part 2 3rd Edition. For multipe SCC damage factor mechanisms case, determined using equation (2.6).

$$D_{f-gov}^{scc} = max\begin{bmatrix} D_f^{caustic}, D_f^{amine}, D_f^{scc}, D_f^{HIC/SOHIC-H_2S}, D_f^{ACSCC}, \\ D_f^{PASCC}, D_f^{CLSCC}, D_f^{HSC\_HF}, D_f^{HIC/SOHIC-HF} \end{bmatrix}$$

D_{f-gov}^{scc} = 45.9479342

= 112.1158

Damage Factor for Thinning

D_f^{Thin} = Max[($\frac{(D_{fb}^{Thin}}{F_{OM}}$),0.1]

= 0.201588995

Total Damage Factor

If the external and thinning damage are general, then damage is likely to occur at the same location and
the total DF is given by Equation (2.3)

$$D_{f-total} = D_{f-gov}^{thin} + D_{f-gov}^{extd} + D_{f-gov}^{scc} + D_f^{htha} + D_{f-gov}^{brit} + D_f^{mfat}$$

RBI Date 46.14952 Plan Date 123.5281

Calculating Probability of Failure:

After determining the value of gff, Fms and Df we can calculate the probability of failure using the equation:

Pf (t) = gff . Fms . D f (t)

Pf (t) = 3.06E−0.5 . 0.182390 . 18.43159

Pf (t) = 0.012468978

RBI Date PoF	**RBI Plan Date PoF**
0.012468978	0.083797304

Probability of Failure

the probability of failure can be calculated using the equation of;

Pf (t) = gff . Fms . D f (t)

it can be known that

pf (t) = The PoF as a function of time
gff = General failure frequency
Fms = Management system factor
Df (t) = Total damage factor

Determining General failure frequency (gff)

To determine the value of gff, we can use the recommended list from table 3.1 [1-8] of API RBI 581

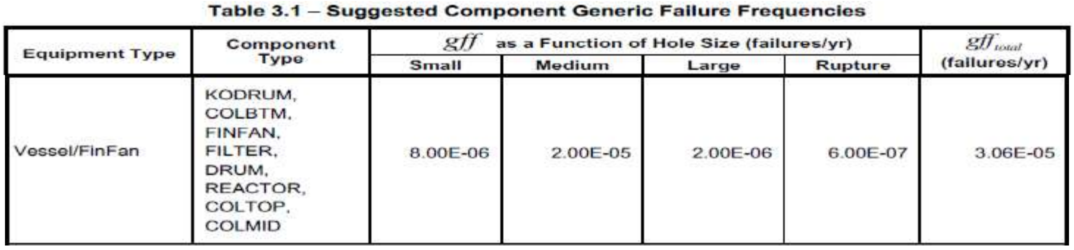


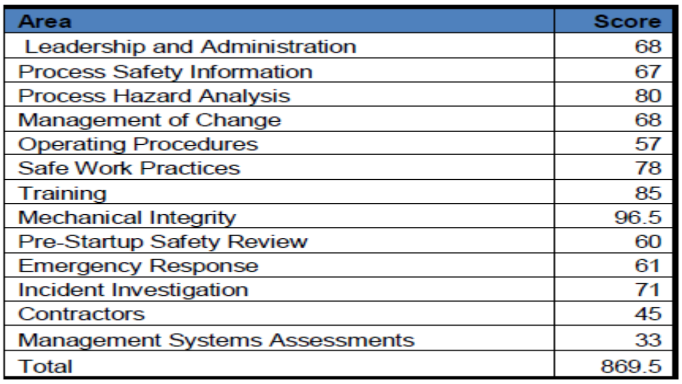
Table 3.1 – Suggested Component Generic Failure Frequencies

Equipment Type	Component Type	gff as a Function of Hole Size (failures/yr)				gff_{total} (failures/yr)
		Small	Medium	Large	Rupture	
Vessel/FinFan	KODRUM, COLBTM, FINFAN, FILTER, DRUM, REACTOR, COLTOP, COLMID	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05

from the table we can determine that the value of gff is: **3.06E-05**

Determining Management system factor (Fms)

To determine the value of Fms, we use a series of question and survey given by API RBI 581 to determine Fms value



Area	Score
Leadership and Administration	68
Process Safety Information	67
Process Hazard Analysis	80
Management of Change	68
Operating Procedures	57
Safe Work Practices	78
Training	85
Mechanical Integrity	96.5
Pre-Startup Safety Review	60
Emergency Response	61
Incident Investigation	71
Contractors	45
Management Systems Assessments	33
Total	869.5

Management system factor score according from the survey, the score is **869.5**

the score must first be converted into percentage using the equation of:

$$pscore = \frac{Score}{1000} \, .100 \text{ [unit is 100\%]}$$

based from equation, the *pscore* is **86.95%**

To determine the value of Fms we can use the equation:

$$Fms = 10^{(-0.02 \, .pscore+1)}$$

$$Fms = 10^{(-0.02 \, .86.95+1)}$$

$$Fms = 0.182390$$

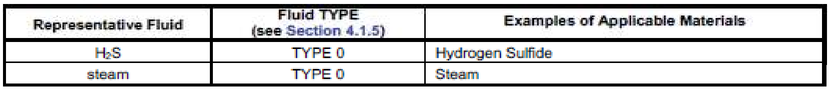
From the equation we can determine that the value of Fms is **0.182390**

Consequence of Failure

Step 1. Determine the release fluid and its properties, including the release phase.

Step 1.1. Select a representative fluid group from table 4.1.

List of representative fluid



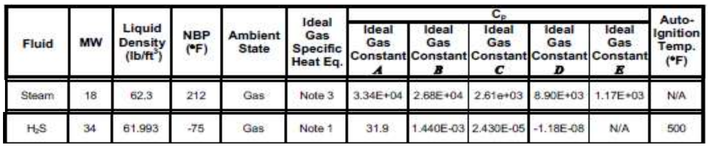
Representative Fluid	Fluid TYPE (see Section 4.1.5)	Examples of Applicable Materials
H_2S	TYPE 0	Hydrogen Sulfide
steam	TYPE 0	Steam

Choosen Representative Fluid : H_2S

Step 1.2 Determine the stored fluid phase

Stored fluid phase: Liquid

Step 1.3 Determine the stored fluid propertioes

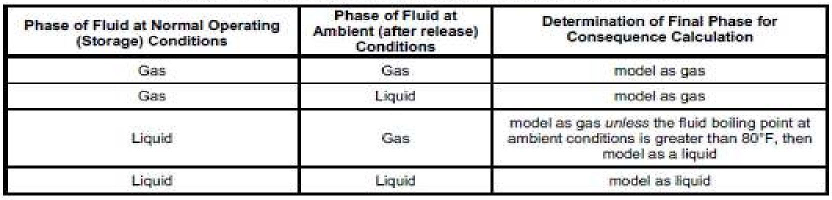


Fluid	MW	Liquid Density (lb/ft^3)	NBP (°F)	Ambient State	Ideal Gas Specific Heat Eq.	C_p Ideal Gas Constant *A*	Ideal Gas Constant *B*	Ideal Gas Constant *C*	Ideal Gas Constant *D*	Ideal Gas Constant *E*	Auto-Ignition Temp. (°F)
Steam	18	62.3	212	Gas	Note 3	3.34E+04	2.68E+04	2.61e+03	8.90E+03	1.17E+03	N/A
H_2S	34	61.993	-75	Gas	Note 1	31.9	1.440E-03	2.430E-05	-1.18E-08	N/A	500

Liquid density : 993.0326 Kg/m^3
NBP : -59.4444 C°
Auto-Ignition Tempt : 260 C°

Step 1.4 Determine the steady state phase of the liquid after release to the atmosphere using table 5.3

Table 4.3 – Level 1 Guidelines for Determining the Phase of a Fluid



Phase of Fluid at Normal Operating (Storage) Conditions	Phase of Fluid at Ambient (after release) Conditions	Determination of Final Phase for Consequence Calculation
Gas	Gas	model as gas
Gas	Liquid	model as gas
Liquid	Gas	model as gas *unless* the fluid boiling point at ambient conditions is greater than 80°F, then model as a liquid
Liquid	Liquid	model as liquid

Discharge Coefficient Liquid : 0.61
Viscosity Correction Factor : 1
Gravitional Constant : 1

The fluid is liquid in the vessel, it’s post release is gas

step 2 Select a set of release hole sizes to determine the possible range of consequences in the risk calculation.

Step. 2.1

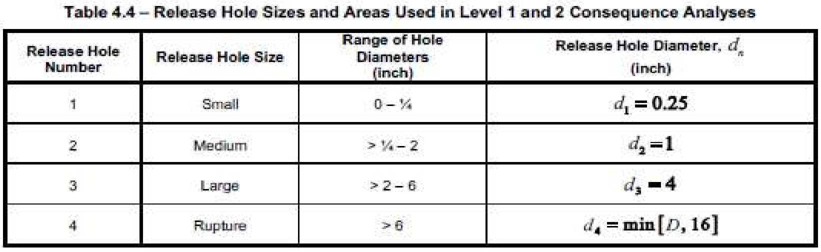
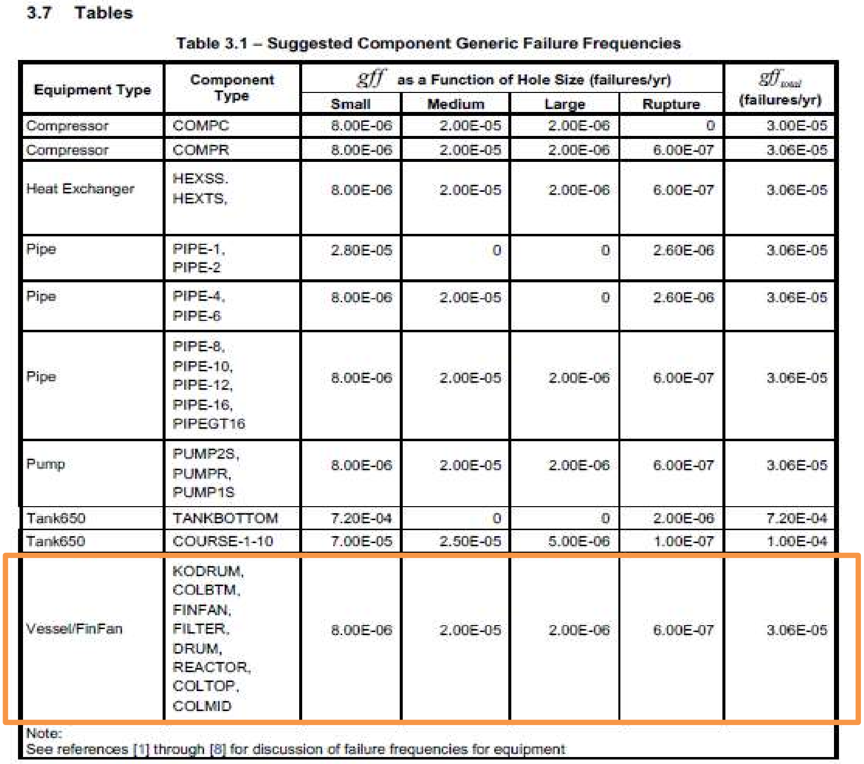


Table 4.4 – Release Hole Sizes and Areas Used in Level 1 and 2 Consequence Analyses

Release Hole Number	Release Hole Size	Range of Hole Diameters (inch)	Release Hole Diameter, d_n (inch)
1	Small	0 – ¼	$d_1 = 0.25$
2	Medium	> ¼ – 2	$d_2 = 1$
3	Large	> 2 – 6	$d_3 = 4$
4	Rupture	> 6	$d_4 = \min[D, 16]$

Step 2.2

Determine the generic failure frequency for the n release hole size from table 3.1 part 2.



3.7 Tables

Table 3.1 – Suggested Component Generic Failure Frequencies

Equipment Type	Component Type	gff as a Function of Hole Size (failures/yr)				gff_{total} (failures/yr)
		Small	Medium	Large	Rupture	
Compressor	COMPC	8.00E-06	2.00E-05	2.00E-06	0	3.00E-05
Compressor	COMPR	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Heat Exchanger	HEXSS. HEXTS,	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Pipe	PIPE-1, PIPE-2	2.80E-05	0	0	2.60E-06	3.06E-05
Pipe	PIPE-4, PIPE-6	8.00E-06	2.00E-05	0	2.60E-06	3.06E-05
Pipe	PIPE-8, PIPE-10, PIPE-12, PIPE-16, PIPEGT16	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Pump	PUMP2S, PUMPR, PUMP1S	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Tank650	TANKBOTTOM	7.20E-04	0	0	2.00E-06	7.20E-04
Tank650	COURSE-1-10	7.00E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04
Vessel/FinFan	KODRUM, COLBTM, FINFAN, FILTER, DRUM, REACTOR, COLTOP, COLMID	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05

Note:
See references [1] through [8] for discussion of failure frequencies for equipment

Step 3. Calculate the theoritical release rate

Step 3.1 Select the appropriate release rate equation using the determined stored fluid phase.

Stored fluid type : Vapour

Step 3.2 Compute the release hole size area A_n in mm^2, using equation (3.8) based on d_n

$$An = \frac{\pi d_n^2}{4} \qquad \text{e.q 3.8}$$

Release for small hole size

$$An = \frac{\pi\,(0.25)^2}{4}$$

$$An = \frac{126.6127}{4}$$

$An = 0.0491$ inch

= 3.00E-05 m^2

Release for medium hole size

$$An = \frac{\pi\,(1)^2}{4}$$

$$An = \frac{2025.802}{4}$$

$An = 0.785$ mm^2

5.00E-04 m^2

Release for Large hole size

$$An = \frac{\pi\,(4\,)^2}{4}$$

$$An = \frac{32412.84}{4}$$

$An = 12.56$ mm^2

0.008 m^2

Release for Rupture hole size

$$An = \frac{\pi\,(16\,)^2}{4}$$

$$An = \frac{72928.89}{4}$$

$An = 201$ mm^2

0.13 m^2

Step 3.3 Calculate Viscosity Correction Factor

Kv_1 = 1 Kv_4 = 1

Kv_2 = 1

Kv_3 = 1

Step 3.4

For release hole, calculate the release rate, Wn, In Kg/s for each release area, An, using the formula:

For Vapour release rate, we must first find the transition pressure (P_{trans}).

$$Ptrans = Patm\left(\frac{k+1}{2}\right)^{\frac{\kappa}{k-1}}$$

$$Ptrans = 1\left(\frac{1.27+1}{2}\right)^{\frac{1.27}{1.27-1}}$$

$$Ptrans = 1.814196$$

$$k = \frac{Cp}{Cp-R}$$

$$k = \frac{39.1}{39.1-8.314}$$

$k =$ 1.270058

Since P_s is greater than $_{Ptrans}$, we can use equation (3.6) to determine vapour flow rate

$$Wn = \frac{C_d}{C_2}.An.Ps\sqrt{\left(\frac{k.MW.gc}{R.Ts}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

For Small hole release size

$$W_1 = \frac{C_d}{C_2}.An.Ps\sqrt{\left(\frac{k.MW.gc}{R.Ts}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

$$W_1 = \frac{0.90}{1}.31.65316.1060\sqrt{\left(\frac{1.27.34.1}{8.314.453.15}\right)\left(\frac{2}{1.27+1}\right)^{\frac{1.27+1}{1.27-1}}}$$

$$W_1 = 31214.71433\sqrt{2.33497E{-}05}$$

$W_1 =$ 0.001949247 Kg/s

For Medium hole release size

$$W_2 = \frac{C_d}{C_2}.An.Ps\sqrt{\left(\frac{k.MW.gc}{R.Ts}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

$$W_2 = \frac{0.90}{1000}.506.4506.1060\sqrt{\left(\frac{1.27.34.1}{8.314.453.15}\right)\left(\frac{2}{1.27+1}\right)^{\frac{1.27+1}{1.27-1}}}$$

$$W_2 = 499435.5\sqrt{2.33497E{-}05}$$

$W_2 =$ 0.093635081 Kg/s

For Large hole release size

$$W_3 = \frac{C_d}{C_2}.An.Ps\sqrt{\left(\frac{k.MW.gc}{R.Ts}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

$$W_3 = \frac{0.90}{1}.8103.21.1060\sqrt{\left(\frac{1.27.34.1}{8.314.453.15}\right)\left(\frac{2}{1.27+1}\right)^{\frac{1.27+1}{1.27-1}}}$$

$$W_3 = 7990968\sqrt{2.33497E{-}05}$$

$W_3 =$ 0.47857007 Kg/s

For Rupture hole release size

$$W_4 = \frac{C_d}{C_2}.An.Ps\sqrt{\left(\frac{k.MW.gc}{R.Ts}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

$$W_4 = \frac{0.90}{0.9674}.18232.22.1060\sqrt{\left(\frac{1.27.34.1}{8.314.453.15}\right)\left(\frac{2}{1.27+1}\right)^{\frac{1.27+1}{1.27-1}}}$$

$$W_4 = 17979675.3\sqrt{2.33497E{-}05}$$

$W_4 =$ 23.9646359676799 Kg/s

Step 4. Estimate the Maximum Mass Avaible for Release (Availble Mass)

Step 4.1 Group components and equipment items into inventory groups

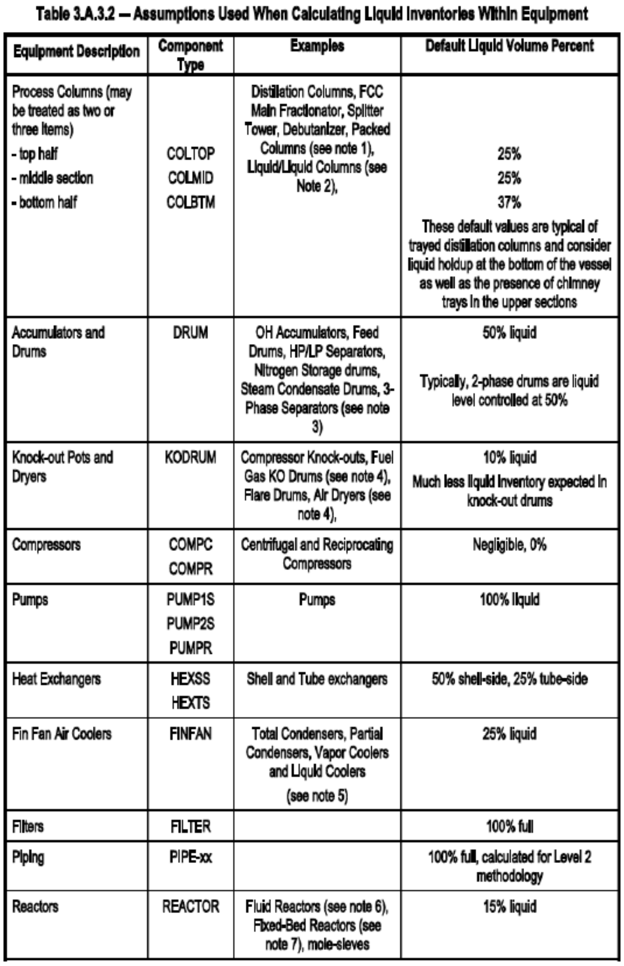


Table 3.A.3.2 – Assumptions Used When Calculating Liquid Inventories Within Equipment

Equipment Description	Component Type	Examples	Default Liquid Volume Percent
Process Columns (may be treated as two or three items) - top half - middle section - bottom half	 COLTOP COLMID COLBTM	Distillation Columns, FCC Main Fractionator, Splitter Tower, Debutanizer, Packed Columns (see note 1), Liquid/Liquid Columns (see Note 2),	25% 25% 37% These default values are typical of trayed distillation columns and consider liquid holdup at the bottom of the vessel as well as the presence of chimney trays in the upper sections
Accumulators and Drums	DRUM	OH Accumulators, Feed Drums, HP/LP Separators, Nitrogen Storage drums, Steam Condensate Drums, 3-Phase Separators (see note 3)	50% liquid Typically, 2-phase drums are liquid level controlled at 50%
Knock-out Pots and Dryers	KODRUM	Compressor Knock-outs, Fuel Gas KO Drums (see note 4), Flare Drums, Air Dryers (see note 4),	10% liquid Much less liquid inventory expected in knock-out drums
Compressors	COMPC COMPR	Centrifugal and Reciprocating Compressors	Negligible, 0%
Pumps	PUMP1S PUMP2S PUMPR	Pumps	100% liquid
Heat Exchangers	HEXSS HEXTS	Shell and Tube exchangers	50% shell-side, 25% tube-side
Fin Fan Air Coolers	FINFAN	Total Condensers, Partial Condensers, Vapor Coolers and Liquid Coolers (see note 5)	25% liquid
Filters	FILTER		100% full
Piping	PIPE-xx		100% full, calculated for Level 2 methodology
Reactors	REACTOR	Fluid Reactors (see note 6), Fixed-Bed Reactors (see note 7), mole-sieves	15% liquid

Step 4.2 Calculate the fluid mass, mass comp, in the component being evaluated

Volume of Cylinder

$$V_{cyl} = \pi R^2 L$$

R = ID/2 = 1.067 m

L = 10.5 m

V_{cyl} = 37.536 m^3

Liquid Volume = (50/100) x V_{cyl} = 18.77 m^3

Vapor Volume = (1-(50/100)) x $_{Vcyl}$ = 18.77 m^3

the mass in component

mass $_{cc}$ = $(V_l \rho_l) + (V_v \rho_v)$

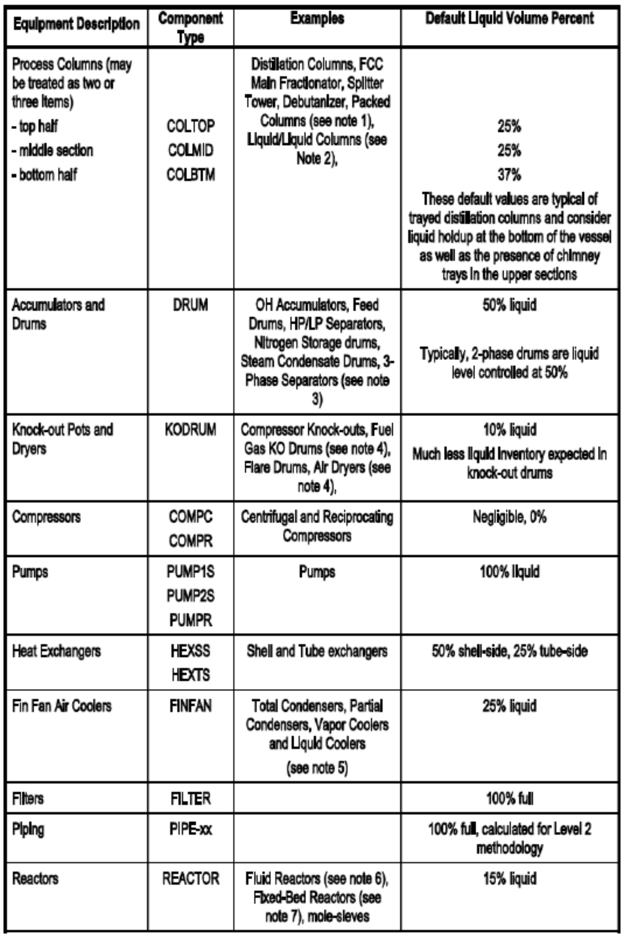
mass $_{cc}$ = 18746 kg

Step 4.3 Calculate fluid mass in each of the other components that are included in the inventory group, mass comp

Step 4. Estimate the Maximum Mass Avaible for Release (Availble Mass)

Step 4.1 Group components and equipment items into inventory groups

Table 3.A.3.2 — Assumptions Used When Calculating Liquid Inventories Within Equipment



Equipment Description	Component Type	Examples	Default Liquid Volume Percent
Process Columns (may be treated as two or three items) - top half - middle section - bottom half	 COLTOP COLMID COLBTM	Distillation Columns, FCC Main Fractionator, Splitter Tower, Debutanizer, Packed Columns (see note 1), Liquid/Liquid Columns (see Note 2),	25% 25% 37% These default values are typical of trayed distillation columns and consider liquid holdup at the bottom of the vessel as well as the presence of chimney trays in the upper sections
Accumulators and Drums	DRUM	OH Accumulators, Feed Drums, HP/LP Separators, Nitrogen Storage drums, Steam Condensate Drums, 3-Phase Separators (see note 3)	50% liquid Typically, 2-phase drums are liquid level controlled at 50%
Knock-out Pots and Dryers	KODRUM	Compressor Knock-outs, Fuel Gas KO Drums (see note 4), Flare Drums, Air Dryers (see note 4),	10% liquid Much less liquid inventory expected in knock-out drums
Compressors	COMPC COMPR	Centrifugal and Reciprocating Compressors	Negligible, 0%
Pumps	PUMP1S PUMP2S PUMPR	Pumps	100% liquid
Heat Exchangers	HEXSS HEXTS	Shell and Tube exchangers	50% shell-side, 25% tube-side
Fin Fan Air Coolers	FINFAN	Total Condensers, Partial Condensers, Vapor Coolers and Liquid Coolers (see note 5)	25% liquid
Filters	FILTER		100% full
Piping	PIPE-xx		100% full, calculated for Level 2 methodology
Reactors	REACTOR	Fluid Reactors (see note 6), Fixed-Bed Reactors (see note 7), mole-sieves	15% liquid

Step 4.2 Calculate the fluid mass, mass comp, in the component being evaluated

Volume of Cylinder

$$V_{cyl} = \pi R^2 L$$

R = ID/2 = 1.067 m

L = 10.5 m

V_{cyl} = 37.536 m^3

Liquid Volume = (50/100) x V_{cyl} = 18.77 m^3

Vapor Volume = (1-(50/100)) x V_{cyl} = 18.77 m^3

the mass in component

mass $_{cc}$ = $(V_l \rho_l) + (V_v \rho_v)$

mass $_{cc}$ = 18746 kg

Step 4.3 Calculate fluid mass in each of the other components that are included in the inventory group, mass comp

Step 4.4 Calculate the fluid mass on the inventory group, *mass* $_{inv}$

$$mass_{inv} = \sum_{i=1}^{N} mass_{\ comp}$$

$$mass_{inv} = \sum_{i=1}^{N} 18639.3$$

$$mass_{inv} = \sum_{i=1}^{1} 18639.3$$

$mass_{inv} =$ **18639.3 Kg**

Step 4.5 Calculate the flow rate from a 203 mm (8 inch) diameter hole, Wmax8, using equations (3.3), (3,6) or (3,7) as applicable, with A_n = A_8 = 32,450 mm2 (50.3 inch2).

$$W_{max\ 8} = \frac{C_d}{C_2} \,.\, A_8 \,.\, Ps \sqrt{\left(\frac{k \,.\, MW \,.\, gc}{R \,.\, Ts}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

$$W_{max\ 8} = \frac{0.90}{1} \,.\, 32450 \,.\, 1060 \sqrt{\left(\frac{1.27 \,.\, 34 \,.\, 1}{8.314 \,.\, 453.15}\right)\left(\frac{2}{1.27+1}\right)^{\frac{1.27+1}{1.27-1}}}$$

$W_{max\ 8}$ _ 3.716 Kg

Step 4.6 for each release hole size, calculate the added fluid mass, *mass* $_{add\ ,\ n\ ,}$, resulting from three minutes of flow from the inventory group using equation (3.10) where W_n is the leakage rate for the release hole size.

$mass_{\text{ add n}} = 180 \,.\, \text{Min}\ [W_n\ , Wmax_{8}$

for small hole release size

$mass_{\text{ add 1}}$ _ $180\ \text{Min}\ [W_n\ , Wmax_{8}$

$mass_{\ addl,\ 1}$ = $180\,.\ Min\ [28959.46 \,.\, 3.716]$

mass $_{\text{add, 1}}$ = 0.35086447 Kg/s

for Medium hole release size

$mass_{\text{ add 2}}$ _ $180\ \text{Min}\ [W_n\ , Wmax_{8}$

$mass_{\ add\ 2}$ _ $180\ Min\ [463351.4\ \ , 3841.08334]$

mass $_{add,\ 2}$ = 16.85 Kg/s

for Large hole release size

$mass_{\text{ add 3}}$ _ $180\ \text{Min}\ [W_n\ , Wmax_{8}$

mass $_{add,3}$ = 84.17

for Rupture hole release size

$mass_{\text{ add 4}}$ _ $180\ \text{Min}\ [W_n\ , Wmax_{8}$

mass $_{add,4}$ = 84.17

Step 4.7 For each release hole size, calculate the avaible mas for release.

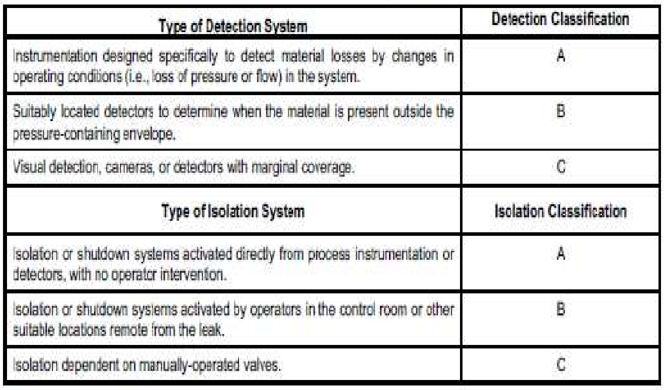
$$Mass_{\ avail} = \min[\ \{mass_{\ comp} + mass_{\ add}\}, mass_{\ Inv}]$$

$Mass_{\ avail} =$ 18746 kg

Step 6. Estimeate the impact of detection and isolation systems on release magnitude.

Step 6.1 Determine the detection and isolation systems present in the unit

Table 4.5 – Detection and Isolation System Rating Guide



Type of Detection System	Detection Classification
Instrumentation designed specifically to detect material losses by changes in operating conditions (i.e., loss of pressure or flow) in the system.	A
Suitably located detectors to determine when the material is present outside the pressure-containing envelope.	B
Visual detection, cameras, or detectors with marginal coverage.	C
Type of Isolation System	**Isolation Classification**
Isolation or shutdown systems activated directly from process instrumentation or detectors, with no operator intervention.	A
Isolation or shutdown systems activated by operators in the control room or other suitable locations remote from the leak.	B
Isolation dependent on manually-operated valves.	C

Step 6.2 Using table 4.5, select the appropriate classification (A,B,C) for the detection system.

Detection System C

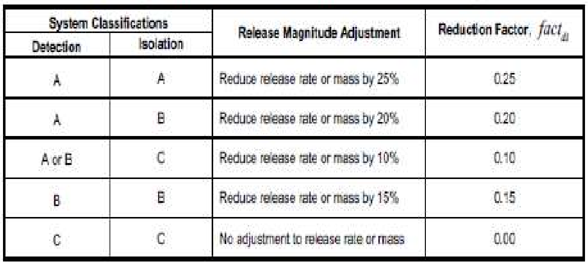
Step 6.3 Using table 4.5, select the appropriate classification (A,B,C) for the isolation system.

Isolation System C

Step 6.4

Using table 4.6 and the classification determined in step 6.2 and step 6.3, determine the release reductio factor

Table 4.6 – Adjustments to Release Based on Detection and Isolation Systems



System Classifications		Release Magnitude Adjustment	Reduction Factor, $fact_{di}$
Detection	Isolation		
A	A	Reduce release rate or mass by 25%	0.25
A	B	Reduce release rate or mass by 20%	0.20
A or B	C	Reduce release rate or mass by 10%	0.10
B	B	Reduce release rate or mass by 15%	0.15
C	C	No adjustment to release rate or mass	0.00

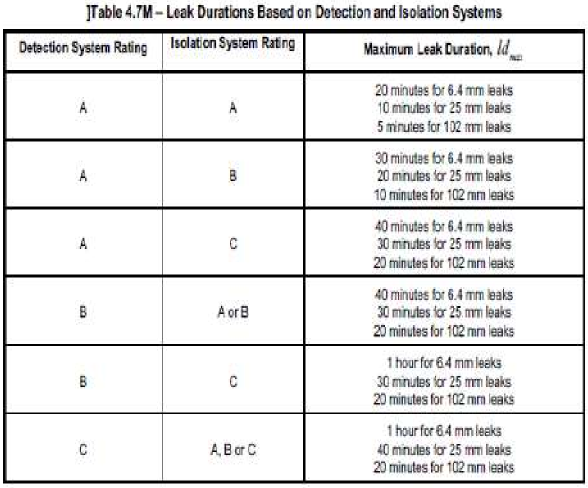
Detection System C

Isolation System C

$fact_{di}$ = 0.00

Step 6.5

Using table 4.7 and the classification determined in step 6.2 and 6.3, determine the total leak durations for each of the selected release hole sizes, $Id_{max,n}$



]Table 4.7M – Leak Durations Based on Detection and Isolation Systems

Detection System Rating	Isolation System Rating	Maximum Leak Duration, ld_{max}
A	A	20 minutes for 6.4 mm leaks 10 minutes for 25 mm leaks 5 minutes for 102 mm leaks
A	B	30 minutes for 6.4 mm leaks 20 minutes for 25 mm leaks 10 minutes for 102 mm leaks
A	C	40 minutes for 6.4 mm leaks 30 minutes for 25 mm leaks 20 minutes for 102 mm leaks
B	A or B	40 minutes for 6.4 mm leaks 30 minutes for 25 mm leaks 20 minutes for 102 mm leaks
B	C	1 hour for 6.4 mm leaks 30 minutes for 25 mm leaks 20 minutes for 102 mm leaks
C	A, B or C	1 hour for 6.4 mm leaks 40 minutes for 25 mm leaks 20 minutes for 102 mm leaks

Detection Sys	A		
Isolation Syste	B		
$Id_{max,1}$	6.4 mn	60	minutes
$Id_{max,2}$	25 mm	40	minutes
$Id_{max,3}$	102 mı	20	minutes

Step 7 Determine the release rate and mass for consequence analysis

Step 7.1

For each release hole size, calculate the adjusted release rate, $_{rate\ n}$. using equation (3.13)

$$rate_n = Wn\ (1 - factdi)$$

Small Hole size

$$rate_1 = W_1\ (1 - factdi)$$

$$rate_1 = 3746.761958\ \ (1 - factdi)$$

rate $_1$ = 0.00195 kg/s

Medium Hole size

$$rate_2 = W_2\ (1 - factdi)$$

$$rate_2 = 59948.2\ \ (1 - factdi)$$

rate $_2$ = 0.09364 kg/s

Large Hole size

$$rate_3 = W_3\ (1 - factdi)$$

$$rate_3 = 959171.184\ \ (1 - factdi)$$

rate $_3$ = 0.47857 kg/s

Large Hole size

$$rate_4 = W_4\ (1 - factdi)$$

$$rate_4 = 2158134.87\ \ (1 - factdi)$$

rate $_4$ = 23.9646 kg/s

Step 7.2

For each release hole size, calculate the leak duration, **id_n**, of the release using equation (3.15), based on the avaible mass, ***$mass_{avail,n}$***

$$Id_n = \min\left[\left\{\frac{mass_{availn}}{rate_n}\right\}, \{60.idmax_{,n}\}\right]$$

Small Hole size

$$Id_1 = \min\left[\left\{\frac{mass_{avail1}}{rate_1}\right\}, \{60.idmax_{,1}\}\right]$$

= 3600

Medium Hole size

$$Id_2 = \min\left[\left\{\frac{mass_{avail2}}{rate_2}\right\}, \{60.idmax_{,2}\}\right]$$

= 1200

Large Hole size

$$Id_3 = \min\left[\left\{\frac{mass_{avail3}}{rate_3}\right\}, \{60.idmax_{,3}\}\right]$$

= 600

Large Hole size

$$Id_4 = \min\left[\left\{\frac{mass_{avail4}}{rate_4}\right\}, \{60.idmax_{,4}\}\right]$$

= 600

Step 7.3

For each release hole size, calculate the release mass, massn, using equation (3.14) based on the release rate, raten, from step 3.2, the lead duration idn, from step 7.2 and the available mass, massavailn, from step 4.6

$$mass_n = \min[\{rate_n . idn\}, massavailn]$$

Small Hole Size

$$mass_1 = \min[\{rate_1 . id_1\}, massavail_{1]}$$

$mass_1$ = 7.01729

Medium Hole Size

$$mass_2 = \min[\{rate_2 . id_2\}, massavail_{2]}$$

$mass_2$ = 112.362

Large Hole Size

$$mass_3 = \min[\{rate_3 . id_3\}, massavail_{3]}$$

$mass_3$ = 287.142

Rupture Hole Size

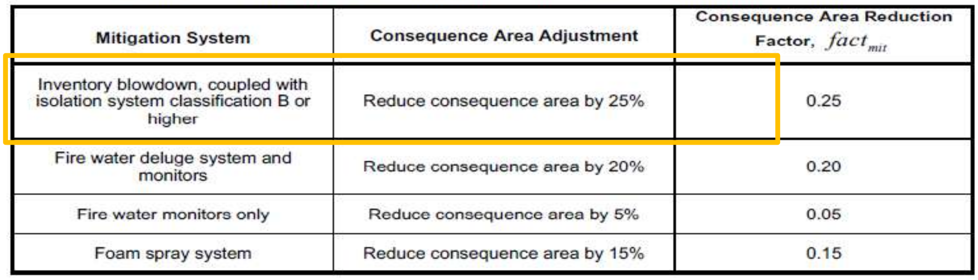
$$mass_4 = \min[\{rate_4 . id_4\}, massavail_{4]}$$

$mass_4$ = 14378.8

Step 8 Determining Flammable and Explosive Consequences

Step 8.1 Select the consequence area mitigation reduction factor, ***fact*** $_{mit}$**,** from table 4.10

Table 4.10 – Adjustments to Flammable Consequence for Mitigation Systems



Mitigation System	Consequence Area Adjustment	Consequence Area Reduction Factor, $fact_{mit}$
Inventory blowdown, coupled with isolation system classification B or higher	Reduce consequence area by 25%	0.25
Fire water deluge system and monitors	Reduce consequence area by 20%	0.20
Fire water monitors only	Reduce consequence area by 5%	0.05
Foam spray system	Reduce consequence area by 15%	0.15

$fact_{mit}$ = 0

Step 8.2 For each release hole size, calculate the energy efficiency correction factor, *eneff* $_n$ using equation 3.18

$$eneff_n = 4.log_{10}[C_4.massn] - 15$$

for small hole size

$$eneff_1 = 4.log_{10}[C_4.mass_1] - 15$$

eneff $_1$ = 1.758311923 1.758

for medium hole size

$$eneff_2 = 4.log_{10}[C_4.mass_2] - 15$$

eneff $_2$ = 6.576113718

for large hole size

$$eneff_3 = 4.log_{10}[C_4.mass_2] - 15$$

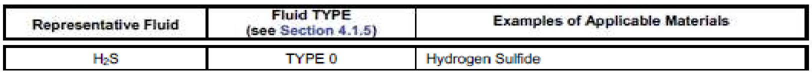
eneff $_3$ = 8.206021514

for rupture hole size

$$eneff_3 = 4.log_{10}[C_4.mass_2] - 15$$

eneff $_3$ = 15.00452272

Step 8.3 Determine the fluid type, either Type 0 or Type 1 from table 4.1



Representative Fluid	Fluid TYPE (see Section 4.1.5)	Examples of Applicable Materials
H_2S	TYPE 0	Hydrogen Sulfide

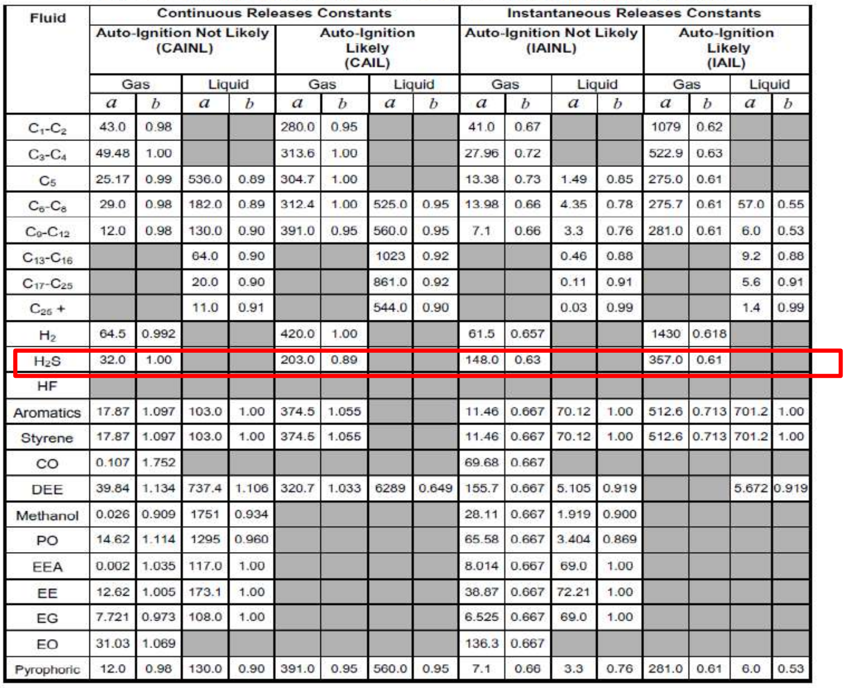
H_2S = Type 0

Step 8.4 For each release hole size, calculate the component damage consequence area.

Step 1.4 will be needed to assure selection of the correct constant

Determine the appropriate constants *a* and *b* from the table 4.8.

Table 4.8 – Component Damage Flammable Consequence Equation Constants



Fluid	Continuous Releases Constants								Instantaneous Releases Constants							
	Auto-Ignition Not Likely (CAINL)				Auto-Ignition Likely (CAIL)				Auto-Ignition Not Likely (IAINL)				Auto-Ignition Likely (IAIL)			
	Gas		Liquid		Gas		Liquid		Gas		Liquid		Gas		Liquid	
	a	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*
C_1-C_2	43.0	0.98			280.0	0.95			41.0	0.67			1079	0.62		
C_3-C_4	49.48	1.00			313.6	1.00			27.96	0.72			522.9	0.63		
C_5	25.17	0.99	536.0	0.89	304.7	1.00			13.38	0.73	1.49	0.85	275.0	0.61		
C_6-C_8	29.0	0.98	182.0	0.89	312.4	1.00	525.0	0.95	13.98	0.66	4.35	0.78	275.7	0.61	57.0	0.55
C_9-C_{12}	12.0	0.98	130.0	0.90	391.0	0.95	560.0	0.95	7.1	0.66	3.3	0.76	281.0	0.61	6.0	0.53
C_{13}-C_{16}			64.0	0.90			1023	0.92			0.46	0.88			9.2	0.88
C_{17}-C_{25}			20.0	0.90			861.0	0.92			0.11	0.91			5.6	0.91
C_{25} +			11.0	0.91			544.0	0.90			0.03	0.99			1.4	0.99
H_2	64.5	0.992			420.0	1.00			61.5	0.657			1430	0.618		
H_2S	32.0	1.00			203.0	0.89			148.0	0.63			357.0	0.61		
HF																
Aromatics	17.87	1.097	103.0	1.00	374.5	1.055			11.46	0.667	70.12	1.00	512.6	0.713	701.2	1.00
Styrene	17.87	1.097	103.0	1.00	374.5	1.055			11.46	0.667	70.12	1.00	512.6	0.713	701.2	1.00
CO	0.107	1.752							69.68	0.667						
DEE	39.84	1.134	737.4	1.106	320.7	1.033	6289	0.649	155.7	0.667	5.105	0.919			5.672	0.919
Methanol	0.026	0.909	1751	0.934					28.11	0.667	1.919	0.900				
PO	14.62	1.114	1295	0.960					65.58	0.667	3.404	0.869				
EEA	0.002	1.035	117.0	1.00					8.014	0.667	69.0	1.00				
EE	12.62	1.005	173.1	1.00					38.87	0.667	72.21	1.00				
EG	7.721	0.973	108.0	1.00					6.525	0.667	69.0	1.00				
EO	31.03	1.069							136.3	0.667						
Pyrophoric	12.0	0.98	130.0	0.90	391.0	0.95	560.0	0.95	7.1	0.66	3.3	0.76	281.0	0.61	6.0	0.53

$a = a_{cmd_{\square}}^{AINL-CONT}$ $b = b_{cmd_{\square}}^{AINL-CONT}$

a = 32.0 *b* = 1.00

Determining Consequence Area for *AINL-CONT*

$$CA_{cmd,n_{\square}}^{AINL-CONT} = a\,(rate)^{b}\,.(1 - factmil{}_{)}$$

for small hole size

$CA_{cmd,1}^{AINL\text{-}CONT}$ = 0.0624 m^2

for medium hole size

$CA_{cmd,2}^{AINL\text{-}CONT}$ = 2.9963 m^2

for large hole size

$CA_{cmd,3}^{AINL\text{-}CONT}$ = 15.314 m^2

for rupture hole size

$CA_{cmd,4}^{AINL\text{-}CONT}$ = 766.87 m^2

Step 8.5 For each release hole size, compute the component damage consequence areas for Autoignition likely Continous Release (*AIL-CONT*)

$a = a_{cmd_{\square}}^{AIL-CONT}$ $b = b_{cmd_{\square}}^{AIL-CONT}$

a = 203.0 *b* = 0.89

Determining Consequence Area for *AINL-CONT*

for small hole size

$CA_{cmd,1}^{AIL\text{-}CONT}$ = 0.7861 m^2

for medium hole size

$CA_{cmd,2}^{AIL\text{-}CONT}$ = 24.665 m^2

for large hole size

$CA_{cmd,3}^{AIL\text{-}CONT}$ = 105.35 m^2

for rupture hole size

$CA_{cmd,4}^{AIL\text{-}CONT}$ = 3430.2 m^2

Step 8.6 For each release hole size, compute the component damage consequence areas for Auto-Ignition Not Likely, Instantaneous Release (*AINL-INST*)

$$a \ = \ a_{cmd\square}^{AINL-INST}$$

$a =$ 148.0 $b =$ 0.63

Determining Consequence Area for ANIL-*CONT*

$$CA_{cmd,n\square}^{AINL-INST} = a\ (mass)^{b} \ . (\frac{1\ - factmil}{eneff_{n}})$$

for small hole size

$CA_{cmd,1}^{AINL-INST}$ = 287.25 m^2

for medium hole size

$CA_{cmd,2}^{AINL-INST}$ = 440.74 m^2

for large hole size

$CA_{cmd,3}^{AINL-INST}$ = 637.87 m^2

for rupture hole size

$CA_{cmd,4}^{AINL-INST}$ = 4105.9 m^2

Step 8.7 For each release hole size, compute the component damage consequence areas for Auto-Ignition Likely, Continous Release (*AIL-CONT*)

$$a \ = \ a_{cmd\square}^{AIL-CONT} \qquad b \ = b_{cmd\square}^{AIL-CONT}$$

$a =$ 357.0 $b =$ 0.61

Determining Consequence Area for AIL-*CONT*

$$CA_{cmd,n\square}^{AIL-INST} = a\ (mass)^{b} \ . (\frac{1\ - factmil}{eneff_{n}})$$

for small hole size

$CA_{cmd,1}^{AIL-INST}$ = 666.4 m^2

for medium hole size

$CA_{cmd,2}^{AIL-INST}$ = 967.34 m^2

for large hole size

$CA_{cmd,3}^{AIL-INST}$ = 1374 m^2

for rupture hole size

$CA_{cmd,4}^{AIL-INST}$ = 8178.2 m^2

Step 9.1

For each release hole size selected in step 2.2, calculate the effective duration of release using equation (3.67)

$$Id_n^{tox} = \min\left(3600, \left\{\frac{mass}{W}\right\}, \{60 \,.\, Idmax, n\}\right)$$

For small hole size

$$Id_1^{tox} = \min\left(3600, \left\{\frac{mass_1}{W}\right\}, \{60 \,.\, Idmax_{,1}\}\right)$$

= 3600

For medium hole size

$$Id_1^{tox} = \min\left(3600, \left\{\frac{mass_1}{W}\right\}, \{60 \,.\, Idmax_{,1}\}\right)$$

= 1200

For small hole size

$$Id_1^{tox} = \min\left(3600, \left\{\frac{mass_1}{W}\right\}, \{60 \,.\, Idmax_{,1}\}\right)$$

= 600

Step 9.2

Determine the toxic percentage of the toxic component, *mfractox i* n the release material, if the release fluid is pure fluid, mfactox = 1.0.

H_2S = 1.55%

$mfrac^{tox}$ = 0.0155

Step 9.3

For each release hole size, calculate the release rate, ratentox, and release mass, xmassntox, to be used in toxic consequence analysis.

For H_2S

$$rate_n^{tox} = mfractox \,.\, Wn$$

for Small hole size

$$rate_1^{tox} = mfractox \,.\, W_1$$

= 3E-05 Kg/s

for Medium hole size

$$rate_2^{tox} = mfractox \,.\, W_2$$

= 0.0015 Kg/s

for Large hole size

$$rate_3^{tox} = mfractox \,.\, W_3$$

= 0.0074 Kg/s

for Rupture hole size

$$rate_3^{tox} = mfractox \,.\, W_3$$

= 0.3715 Kg/s

Step 9.4

For each release hole size calculate the toxic consequence area for each of the release hole size

HF Acid and H25 — Calculate Cit7n using Equation (3.63) for a continuous release or Equation
(3.64) for an instantaneous release. The constants used in these equations are from Table 4.11.

$$CA_{inj,n}^{tox-INST} = C_8 \,.\, 10(C.\log_{10}[C_{4B}.\, mass_n^{tox}]$$

for small hole size

$$mass_1^{tox} = mfractox\,.\, mass_1$$

= 0.1088

$$CA_{inj,n}^{tox-INST} = C_8 \,.\, 10(C.\log_{10}[C_{4B}.\, mass_n^{tox}]$$

= -0.5573

for medium hole size

$$mass_2^{tox} = mfractox\,.\, mass_2$$

= 1.7416

$$CA_{inj,n}^{tox-INST} = C_8 \,.\, 10(C.\log_{10}[C_{4B}.\, mass_n^{tox}]$$

= 0.5252

for large hole size

$$mass_2^{tox} = mfractox\,.\, mass_2$$

= 4.4507

$$CA_{inj,n}^{tox-INST} = C_8 \,.\, 10(C.\log_{10}[C_{4B}.\, mass_n^{tox}]$$

= 0.8914

for Rupture hole size

$$mass_2^{tox} = mfractox\,.\, mass_2$$

= 222.87

$$CA_{inj,n}^{tox-INST} = C_8 \,.\, 10(C.\log_{10}[C_{4B}.\, mass_n^{tox}]$$

= 2.4189

Step 9.5 If there are additional toxic components in the released fluid mixture,
STEPs 9.2 through 9.4
should be repeated for each toxic component.

there is no other additional toxic components.

Step 9.6 Determine the final toxic consequence areas for personnel injury in accordance with
Equation (3.68)

$$CA_{inj}^{tox} = \left(\frac{\sum_{n=1}^{4} gff_n \,.\, CA_{inj,n}^{tox}}{gff_{total}} \right)$$

CA_{inj}^{tox} = 0.30324 m^2

Step 10 Calculation of Non-Flammable, Non-Toxic Consequence Area

Step 10.1 For each release hole size, calculate the non-flammable, non-toxic consequence area

$$CA_{inj,n}^{CONT} = C_9 \, . \, raten$$

$$CA_{inj,n}^{INST} = C_{10} \, (massn)^{0.6384}$$

Small hole size

$$CA_{inj,1}^{CONT} = C_9 \, . \, rate_1$$

= 2E-04

$$CA_{inj,1}^{INST} = C_{10} \, (mass_1)^{0.6384}$$

= 33.8

Medium hole size

$$CA_{inj,1}^{CONT} = C_9 \, . \, rate_1$$

= 0.012

$$CA_{inj,1}^{INST} = C_{10} \, (mass_1)^{0.6384}$$

= 361.4

Largel hole size

$$CA_{inj,1}^{CONT} = C_9 \, . \, rate_1$$

= 0.059

$$CA_{inj,1}^{INST} = C_{10} \, (mass_1)^{0.6384}$$

= 361.4

Step 10.2 For each release hole size, calculate the instantaneous/continous blending factor, for steam use equation (3.71)

$$fact_n^{IC} = \min\left[\left\{\frac{Raten}{C5}\right\}, 1.0\right]$$

Small hole size

$$fact_1^{IC} = \min\left[\left\{\frac{Rate_1}{C_5}\right\}, 1.0\right]$$

= 7.73511E-05

Medium hole size

$$fact_1^{IC} = \min\left[\left\{\frac{Rate_1}{C_5}\right\}, 1.0\right]$$

= 0.003715678

Large hole size

$$fact_1^{IC} = \min\left[\left\{\frac{Rate_1}{C_5}\right\}, 1.0\right]$$

= 0.019

Step 10.3

For each release hole size, calculate the blended non-flammable, non-toxic personnel injury consequence area for steam or acid leaks using equation (3.88) based on the consequence area from Step 10.1 and the blending factor from 10.2.

$$CA_{inj,n}^{leak} = CA_{inj,n}^{INST} \, . fact_n^{IC} + CA_{inj,n}^{CONT} \, (1 - fact_n^{IC})$$

Small hole size

$$CA_{inj,1}^{leak} = CA_{inj,1}^{INST} \, . fact_1^{IC} + CA_{inj,1}^{CONT} \, (1 - fact_1^{IC})$$

= 0.003

Medium hole size

$$CA_{inj,2}^{leak} = CA_{inj,2}^{INST} \, . fact_2^{IC} + CA_{inj,2}^{CONT} \, (1 - fact_2^{IC})$$

= 1.354

Large hole size

$$CA_{inj,1}^{leak} = CA_{inj,1}^{INST} \, . fact_1^{IC} + CA_{inj,1}^{CONT} \, (1 - fact_1^{IC})$$

= 354.5

Step 10.4

Determine the final non-flammable, non-toxic consequence areas for personnel injury using Equation (3.80) based on consequence areas calculated for each release hole size in STEP 10.3.
Note that there is no need to calculate a final non-flammable, non-toxic consequence area for componDetermdamage area for the Level 1 non-flammable releases (steam or acid/caustic).

$$CA_{inj}^{nfnt} = \left(\frac{\sum_{n=1}^{4} gff_n \, . CA_{inj,n}^{nfnt}}{gff_{total}}\right)$$

$CA_{inj}^{nfnt} =$ 24.05822469 m^2

Step 11.1 Calculate the final component damage consequence area, Cacmd

Note that since the component damage consequence areas for toxic releases, $CAcmd^{tox}$, and non-flammable, non-toxic releases, $CAcmd^{nfnt}$, are both equal to zero. Then, the final component damage consequence area is equal to the consequence area calculated for flammable releases, $CAcmd^{flam}$.

……………………………………………. (equation 47)

$CA_{cmd} = CA_{cmd}^{flam}$ = 652.1247212 m^2

Step 11.2 Calculate the final personnel injury consequence area,

CA_{inj} = max $\left[CA_{inj}^{flam}, CA_{inj}^{tox}, CA_{inj}^{nfnt}\right]$

…………………….. (equation 48)

CA_{inj} = max $\left[CA_{inj}^{flam}, CA_{inj}^{tox}, CA_{inj}^{nfnt}\right]$

= 223 m^2

Step 11.3 Calculate the final consequence area, CA, using equation below:

CA=max$\left[CA_{cmd}, CA_{inj}\right]$

= 652.1 m^2

Risk Analysis

Determining RBI Date

Age at RBI date

$$age = RBI\ Date - Last\ Inspection\ Date$$

= 12-Feb-2019 - 22-Nov-2014

= 5 year

Age at RBI plan date

$$age = Plan\ date - Last\ Inspection\ Date$$

= 01-Jan-23 - 22-Nov-14

= 9 year

$\text{Risk}_{\text{RBIDate}}$ Age at RBI date

$$Risk_{RBIDate} = PoF\ .\max(CAinj, CAequip)$$

= 20.459347 m_2

$\text{Risk}_{\text{RBIDate}}$ Age at RBI plan date

$$Risk_{PlanDate} = PoF\ .\max(CAinj, CAequip)$$

= 54.646294 m_2

R(t) Age at RBI date

$$Risk_{RBIDate} = PoF\ \ .\ CoF$$

= 8.1313291 m_2

R(t) Age at RBI plan date

$$Risk_{PlanDate} = PoF\ \ .\ CoF$$

= 54.646294 m_2

Probability Range

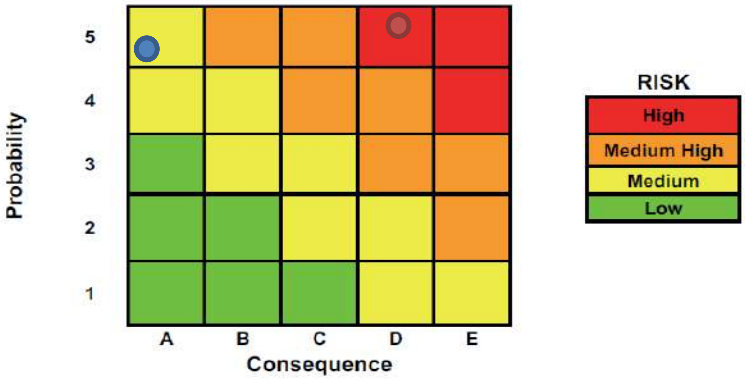
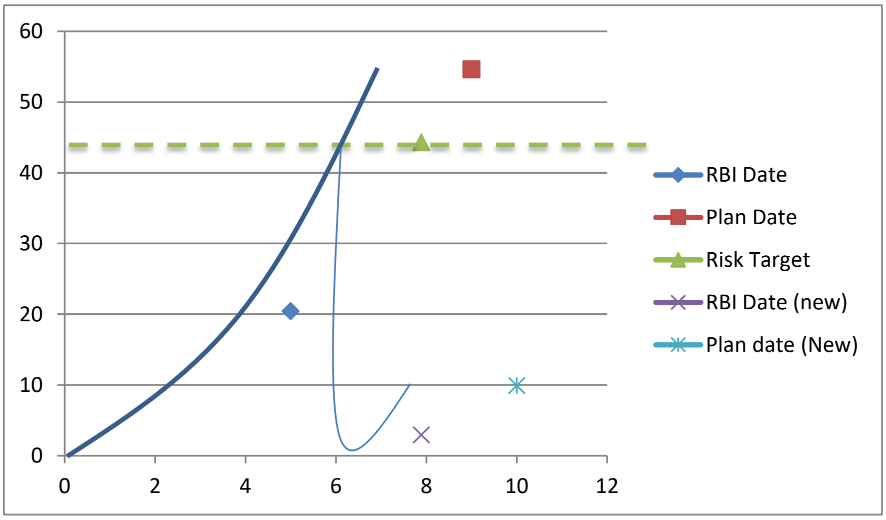


Figure 4.3 – Balanced Risk Matrix Example

Inspection Planning

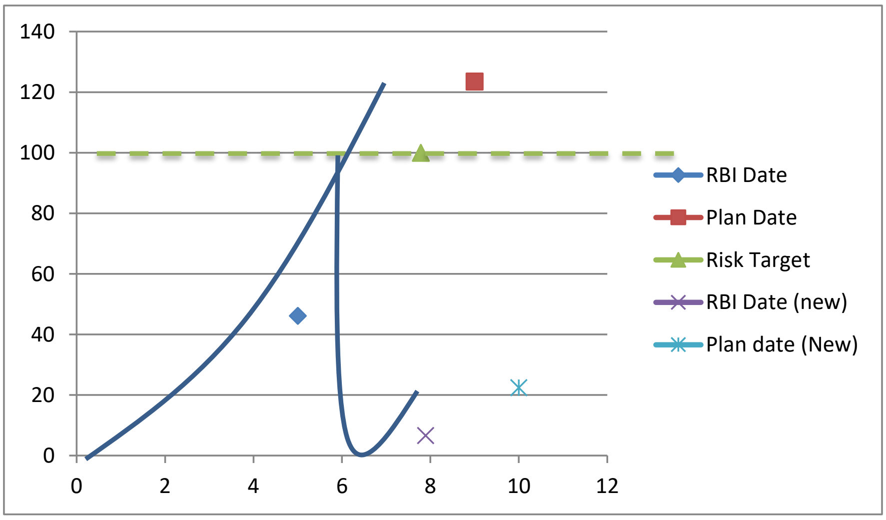
Step 1 Estimate Target Date

Item	Date	Time since RBI Assessment	Risk Area (m^2/yr)
RBI Date	02/12/2019	5	20.45934724
Risk Target	12/05/2019	7.89	44.33273807
Plan Date	02/12/2023	9	54.6462938



Target date = 7.89 year after RBI Assessment
= 03/02/2002

Item	Date	Time since RBI Assessment	Damage Factor
RBI Date	02/12/2019	5	46.1495232
Risk Target	03/02/2022	7.25	100
Plan Date	02/12/2023	9	123.528109



Target date = 7.25 Year after RBI Assessment
= 03/02/2022

Lampiran 7

Calculation for MD-5 Well Pipes

“Halaman ini sengaja dikosongkan”

Calculation of Thinning Damage Factor

Basic Data	Value	Unit	Comments
Start Date	01/01/2000		The date the component was placed in service.
Thickness	30.47	mm	The thickness used for DF calculation that is either the furnished thickness or the measured thickness.
Corrosion Allowance	3.00	mm	The corrosion allowance is the specified design or actual corrosion allowance upon being placed in the current servicce.
Design Tempearture	5-265	^{o}C	The design temperature, shell side and tube side for heat exchanger.
Design Pressure	7100	Kpa	The design pressure, shell side and tubbe side for heat exchanger.
Operating Tempearture	196.6	^{o}C	The highest expected operating temperature expected during operation including normal and unusual operating conditions, shell side and tube side for heat exchanger.
Operating Pressure	1060	Kpa	The highest expected operating pressure expected during operation including normal and unusual operating conditions, shell side and tube side for heat exchanger.
Design Code			The designing of the component containing the component.
Equipment Type			The type of equipment.
Component Type			The type of component.
Geometry Data			Component geometry data depending on the type of component.
Material Specification			The specification of the material of construction, the ASME SA or SB specification for pressure vessel components or for ASTM specification for piping and tankage components. Data entry is based on the material specification, grade, year, UNS Number, class/condition/temper/size/thickness; this data is readdily available in the ASME Code.
Yield Strength	415,000	Kpa	The design yield strength of the material based on material specification.
Tensile Strength	245,000	Kpa	The design tensile strength of the material based on material specification.
Weld Joint Efficiency	1.00	mm	Weld joint efficiency per the Code of construction.
Heat Tracing	Yes		Is the component heat traced? (Yes or No)

STEP 1 Determining the furnished thickness, t, and age for the component from the installation date.

t = 5 inch
= 12.7 mm
age = 14 years (it is assumed from the default date for the first installement in a plant on January 1st 2000 (01/01/2000) until November 26th 2014 (26/11/2014)).

STEP 2 Determining the corrosion rate for base material, $C_{r,bm}$ based on the material construction and environment, and cladding/weld overlay corrosion rate, $C_{r,cm}$.

Based on the explanation from Section 4.5.2 that the corrosion rate is **CALCULATED** using the approach of Annex 2B. Then, first of all, the corrosion screening question must be done as follows:

Table 2.B.1.1-Screening Questions for Corrosion Rate Calculations

No.	Type of Corrosion	Screening Question		Yes/No	Action
1.	Hydrochloric Acid (HCl) Corrosion	1.	Does the process contain HCl?	N	No
		2.	Is free water present in the process stream (including initial condensing condition)?	Y	
		3.	Is the pH < 7.0?	Y	
			Actual relatively pH is 5.66		
2.	High Temperature Sulfidic/Naphtenic Acid Corrosion	1.	Does the process contain oil with sulfur compounds?	N	No
		2.	Is the operating temperature > 204^{o}C (400^{o}F)?	N	
			The operating temperature is 187^{o}C.		
3.	Sulfuric Acid Corrosion	1.	Does the process contain H_2SO_4	N	No
4.	High Temperature H_2S/H_2 Corrosion	1.	Does the process contain H_2S and Hydrogen?	Y	No
		2.	Is the operating temperature > 204^{o}C (400^{o}F)?	N	
			The operating temperature is 187^{o}C.		
5.	Hydrifluoric Corrosion	1.	Does the process contain HF	N	No
6.	Sour Water Corrsion	1.	Is free water with H_2S present?	Y	Yes
7.	Amine Corrosion	1.	Is equipment exposed to acid gas treaating amines (MEA, DEA, DIPA, or MDEA)?	N	No
8.	High Temperature Oxidation Corrosion	1.	Is the temperature ≥ 482^{o}C (900^{o}F)?	N	No
			The operating temperature is 187^{o}C.		
		2.	Is the oxygen present?	N	
9.	Acid Sour Water Corrosion	1.	Is free water with H_2S present and pH < 7.0?	Y	No
			Actual relatively pH is 5.66		
		2.	Does the proocess contain < 50 ppm chlorides?	N	
10.	Cooling Water	1.	Is equipment in cooling water service?	N	No
11.	Soil Side Corrosion	1.	Is equipment in contact with soil (buried or partially buried)?	N	No
		2.	Is the material of construction carbon steel?	N	
12.	CO_2 Corrosion	1.	Is the free water with CO_2 present (including consideration for dew point condensation)?	Y	No
		2.	Is the material of construction carbon steel or < 13% Cr?	N	
13.	AST Bottom	1.	Is the equipment item an AST tank bottom?	N	No

pH = 5.56
T = 196.6 C
= 385.88 F
P = 2895.9 Kpa
H2S Concentr = 7.935979788 % mole
Material = Carbon Steel (SA 516-70)

Basically, there are 3 types of Corrosion Rate (Cr) calculation which are based on the RLA data from the last inspection, based on the calculation referred to the API 581 Annex 2B, and the last is based on worst case scenario.

1. Corrosion Rate (Cr) from the RLA data
   Cr = 0.000394 inch/year
   = 0.012000 mm/year

2. Corrosion Rate (Cr) based on the Annex 2B High temperature corrosion rate

The steps required to determine the corrosion rate are shown in Figure 2.B.7.1. The corrosion rate may be determined using the basic data in Table 2.B.7.1 in conjunction with the baseline corrosion rates and equations in Table 2.B.7.2 to correct for H_2S partial pressure

Basic Data	Comments
NH_4HS concentration (wt%)	Determine the NH_4HS concentration of the condensed water. It is suggested to determine this value with ionic process models. However, approximate values may be calculated from analyses of H_2S and NH_3 as follows
	If wt% H_2S < 2 x (wt% NH_3), wt% NH_4HS =1.5 x (wt% H_2S)
	If wt% H_2S > 2 x (wt% NH_3), wt% NH_4HS =3.0 x (wt% H_2S)
Strean Velocity	The vapor phase velocity should be used in a two-phase system. The liquid phase velocity should be used in a liquid full system.
H_2S partial pressure, psia [kPa]	Determine the partial pressure of H_2S by multiplying the mole% of H_2S in the gas phase by the total system pressure.

Determining NH4HS Concentration

to determine NH_4HS concentration, we must first determine if wt% H_2S is lower or higher than wt% of NH_3.

wt% H_2S = 0.01
wt% NH_3 = 0.00047639
2 X wt% NH_3 = 0.00095278

Since the value of H_2S is higher than NH_3, the wt% of NH_4HS can be determined by the formula of: wt% NH_4HS = 3.0 x (wt% H_2S)

If wt% H_2S > 2 x (wt% NH_3), wt% NH_4HS =3.0 x (wt% H_2S)
NH_4HS= 3.0 x (wt% H_2S)
NH_4HS = 0.03

to determine the Cr, we must first do a calculation to correct the H_2S partial pressure.

$$\text{Adjusted } CR = \max\left[\left\{\left(\frac{Baseline\ CR}{276}\right).(pH2S - 345) + Baseline\ CR\right\},0\right]$$

Adjusted CR = 0.287

STEP 3 Determine the time in service, age_{tk}, since the last known inspection, t_{rdi}.

Because of the manufactured-thickness is not provided. Then, the thickness used in this calculation is coming from the last inspection as long as as the Production Separator installed in setvice life).

t_{rdi} = 0.5 inch

= 30.47 mm

age_{tk} = 4 year (Last inspection was held on November 2014)

STEP 4 For cladding/weld overlay pressure vessel components, calculate the age from the date starting thickness from STEP 3 required to corrode away the cladding/weld overlay material, age_{rc}, using equation below:

$$age_{rc} = \max\left[\left(\frac{t_{rdi}-tbm}{C_{r\,cm}}\right), 0.0\right]$$ …………………………………………… (equation 57)

This equipment does not have cladding, so this step are skipped

STEP 5 Determine the t_{min}

Actually there are 4 methods used to determine the minimum thickness of the equipment (t_{min}). Based on the condition, the method used by the author is the first method which is for cylindrical, spherical, or head components, determine the allowable Stress, S, weld joint efficiency, E, and the minimum thickness, t_{min}.

t_{min} = 9.515748031 inch

= 24.17 mm

S = 1179 psig

= 8128922.04 Pa

= 8128.92204 Kpa

E = 1

STEP 6 Determine the A_{rt} Parameter

For component without clading/weld overlay then use the equation below.

$$A_{rt} = \frac{Cr_{b,m}.\,age_{tk}}{t_{rdi}}$$ ……………………………………………….. (equation 58)

= 0.037708747 (For calculated corrosion rate based on ANNEX 2B)

$$A_{rt} = \frac{Cr_{b,m}.\,age_{tk}}{t_{rdi}}$$

= 0.00157532 (For corrosion rate based on RLA Data)

STEP 7 Calculate the Flow Stress, FS^{Thin}, using E from STEP 5 and equation below.

$$FS^{Thin} = \frac{(YS+TS)}{2}.\,E.1,1$$ ……………………………………………….. (equation 59)

Where;

YS = 415,000 KPa

TS = 245,000 KPa

E = 1

https://www.csecplates.com/astm-a283-grade-c-plate-stockists-suppliers.html

$$FS^{Thin} = \frac{(YS+TS)}{2}.\,E.1,1$$

= 363000

STEP 8 Calculate the strength ratio parameter, , SR_P^{Thin} the appropriate equation.

$$SR_P^{Thin} = \frac{S.E}{FS^{Thin}}.\frac{Max\,(t_{min},t_c)}{t_{rdi}}$$ …………………………………………… (equation 60)

Where;

t_c = is the minimum structural thickness of the component base material

= 9.515748031 inch

= 24.17 mm

$$SR_P^{Thin} = \frac{S.E}{FS^{Thin}}.\frac{Max\,(t_{min},t_c)}{t_{rdi}}$$

= 0.042618608

STEP 9 Determine the number of inspections for each of the correspondesing inspection effectiveness, $N_A^{Thin}, N_B^{Thin}, N_C^{Thin}, N_D^{Thin}$ sing Section 4.5.6 of the API RP 581 Part 2 for past inspections performed during in-service time.

N_A^{Thin} = 0
N_B^{Thin} = 0
N_C^{Thin} = 0
N_D^{Thin} = 0

STEP 10 Calculate the inspection effectiveness factors, $I_1^{Thin}, I_2^{Thin}, I_3^{Thin}$ g equation 61 below, prior probabilities, , from Table 4.5. The Conditional Probabilities (for each inspection effectiveness level), $Pr_{p1}^{Thin}, Pr_{p2}^{Thin}$ and Pr_{p3}^{Thin} le 4.6, and the number of inspection, $N_B^{Thin}, N_C^{Thin}, N_D^{Thin}$ veness level from STEP 9.

N_A^{Thin}

$$I_1^{Thin} = Pr_{P1}^{Thin}(Co_{P1}^{ThinA})^{N_A^{Thin}}(Co_{P1}^{ThinB})^{N_B^{Thin}}(Co_{P1}^{ThinC})^{N_C^{Thin}}(Co_{P1}^{ThinD})^{N_D^{T}}$$

$$I_2^{Thin} = Pr_{P2}^{Thin}(Co_{P2}^{ThinA})^{N_A^{Thin}}(Co_{P2}^{ThinB})^{N_B^{Thin}}(Co_{P2}^{ThinC})^{N_C^{Thin}}(Co_{P2}^{ThinD})^{N_A^{T}}$$

$$I_3^{Thin} = Pr_{P3}^{Thin}(Co_{P3}^{ThinA})^{N_A^{Thin}}(Co_{P3}^{ThinB})^{N_B^{Thin}}(Co_{P3}^{ThinC})^{N_C^{Thin}}(Co_{P3}^{ThinD})^{N_A^{T}}$$

Table 4.5 - Prior Probability for Thinning Corrosion Rate

Damage State	Low Confidence Data	Medium Confidence Data	High Conf. Data
Pr_{P1}^{Thin}	0.5	0.7	0.8
Pr_{P2}^{Thin}	0.3	0.2	0.15
Pr_{P3}^{Thin}	0.2	0.1	0.05

Table 4.6 - Conditional Probability for Inspection Effectiveness

Conditional P. of Inspection	E-None or Ineffective	D-Poorly Effective	C-Fairly Effective	B-Usually Effective	A-Highly Effective
Co_{P1}^{Thin}	0.33	0.4	0.5	0.7	0.9
Co_{P2}^{Thin}	0.33	0.33	0.3	0.2	0.09
Co_{P3}^{Thin}	0.33	0.27	0.2	0.1	0.01

$$I_1^{Thin} = Pr_{P1}^{Thin}(Co_{P1}^{ThinA})^{N_A^{Thin}}(Co_{P1}^{ThinB})^{N_B^{Thin}}(Co_{P1}^{ThinC})^{N_C^{Thin}}(Co_{P1}^{ThinD})^{N_D^{T}}$$
= 0.50

$$I_2^{Thin} = Pr_{P2}^{Thin}(Co_{P2}^{ThinA})^{N_A^{Thin}}(Co_{P2}^{ThinB})^{N_B^{Thin}}(Co_{P2}^{ThinC})^{N_C^{Thin}}(Co_{P2}^{ThinD})^{N_A^{T}}$$
= 0.30

$$I_3^{Thin} = Pr_{P3}^{Thin}(Co_{P3}^{ThinA})^{N_A^{Thin}}(Co_{P3}^{ThinB})^{N_B^{Thin}}(Co_{P3}^{ThinC})^{N_C^{Thin}}(Co_{P3}^{ThinD})^{N_A^{T}}$$
= 0.20

STEP 11 Calculate the Posteroir Probability, $Po_{p1}^{Thin}, Po_{p2}^{Thin}$ and Po_{p3}^{Thin} 6 below.

$$Po_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$ …………………………………… (equation 64)
= 0.5

$$Po_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$ …………………………………… (equation 65)
= 0.3

$$Po_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$ …………………………………… (equation 66)
= 0.2

STEP 12 Calculate the parameters, $ß_1$, $ß_2$, and $ß_3$ using equation 67,68,69 below and also assigning $COV_{\Delta t} = 0.20$, $COV_{sf} = 0.20$, and $COV_P = 0.05$.

$$ß_1^{Thin} = \frac{1-D_{S1}\,.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S1}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S1}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}} \quad \text{.........} \quad \text{(equation 67)}$$

$$ß_2^{Thin} = \frac{1-D_{S2}\,.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S2}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S2}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}} \quad \text{..........} \quad \text{(equation 68)}$$

$$ß_3^{Thin} = \frac{1-D_{S3}\,.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S3}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S3}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}} \quad \text{..........} \quad \text{(equation 69)}$$

Where;

$COV_{\Delta t}$ = The thinning coefficient of variance ranging from $0.1 \le COV_{\Delta t} \le 0.2$
= 0.2
COV_{sf} = The flow stress coefficient of variance
= 0.2
COV_P = Pressure coeffficient of variance
= 0.05
D_{s1} = Damage State 1
= 1
D_{s2} = Damage State 2
= 2
D_{s3} = Damage State 3
= 4

BASED ON CORROSION RATE FROM RLA DATA

$$ß_1^{Thin} = \frac{1-D_{S1}\,.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S1}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S1}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

= 4.7863

$$ß_2^{Thin} = \frac{1-D_{S2}\,.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S2}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S2}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

= 4.785936189

$$ß_3^{Thin} = \frac{1-D_{S3}\,.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S3}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S3}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

= 4.785184424

STEP 13 For tank bottom components, determine the base damage factor for thining using Table 4.8. and based on A_{rt} parameter from STEP 6.

Because component observed in this case of analysis is including into Pressure Vessel (Production Separator), then, this step of ccalculation can be skipped.

STEP 14 For all components (excluding tank bottoms covered in STEP 13), calculate the base damage factor, D_{fB}^{Thin}.

$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi(-\beta_1^{Thin})\right)+\left(Po_{P2}^{Thin}\Phi(-\beta_2^{Thin})\right)+\left(Po_{P3}^{Thin}\Phi(-\beta_3^{Thin})\right)}{1.56E-0.4}$ ……… (equation 70)

BASED ON CORROSION RATE FROM RLA DATA

$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi(-\beta_1^{Thin})\right)+\left(Po_{P2}^{Thin}\Phi(-\beta_2^{Thin})\right)+\left(Po_{P3}^{Thin}\Phi(-\beta_3^{Thin})\right)}{1.56E-0.4}$

= 0.241025096

STEP 15 Determine the DF for thinning, , using equation equatiD_f^{Thin}elow.

$D_f^{Thin} = \mathrm{Max}[(\frac{(D_{fb}^{Thin}.\,F_{IP}\,.\,F_{DL}\,.F_{WD}.F_{AM}\,.F_{SM})}{F_{OM}}),0.1]$ …………………… (equation 71)

Where;

F_{IP} = DF adjustent for injection points (for piping circuit)
= 0
F_{DL} = DF adjustment for dead legs (for piping only used to intermittent service)
= 0
F_{WD} = DF adjustment for welding construction (for only AST Bottom)
= 0
F_{AM} = DF adjustment for AST maintenance per API STD 653 (for only AST)
= 0
F_{SM} = DF adjustment for settlement (for only AST Bottom)
= 0
F_{OM} = DF adjustment for online monitoring based on Table 4.9
= 1

BASED ON CORROSION RATE FROM RLA DATA

$D_f^{Thin} = \mathrm{Max}[(\frac{(D_{fb}^{Thin}.}{F_{OM}}),0.1]$

= 0.241025096

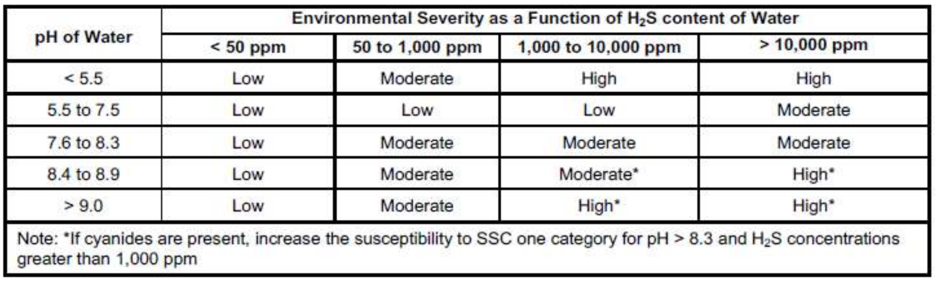
Calculation of SCC-Sulfide Stress Cracking Damage Factor

Step 1.

Determine the environemental severity (potential level of hydrogen flux) for cracking based on the H2S Content of water and its pH using Table 8.2

pH : 5.52
Content of water : 1000 ppm

Table 8.2 – Environmental Severity – SSC



pH of Water	Environmental Severity as a Function of H_2S content of Water			
	< 50 ppm	50 to 1,000 ppm	1,000 to 10,000 ppm	> 10,000 ppm
< 5.5	Low	Moderate	High	High
5.5 to 7.5	Low	Low	Low	Moderate
7.6 to 8.3	Low	Moderate	Moderate	Moderate
8.4 to 8.9	Low	Moderate	Moderate*	High*
> 9.0	Low	Moderate	High*	High*

Note: *If cyanides are present, increase the susceptibility to SSC one category for pH > 8.3 and H_2S concentrations greater than 1,000 ppm

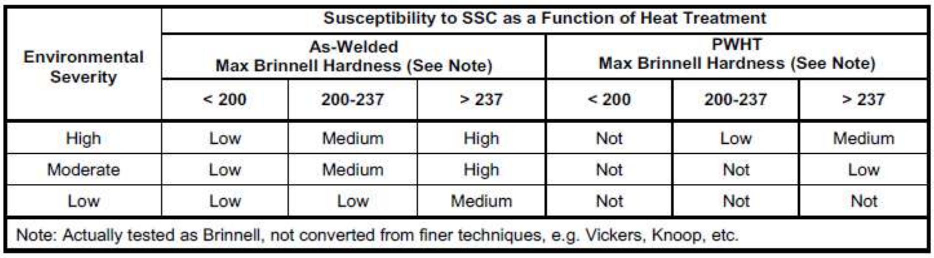
Environmental Severity of H2S : Moderate

Step 2

Determine the susceptibility for cracking using *figure 8.1* and *table 8.3* based on the environmental severity from step 1, the maximum brinnel hardness of weldments, and knowledge of whether the component was subject to PWHT.

Enviromental Severity of H2S : Moderate

Table 8.3 – Susceptibility to SSC – SSC



Environmental Severity	Susceptibility to SSC as a Function of Heat Treatment					
	As-Welded Max Brinnell Hardness (See Note)			PWHT Max Brinnell Hardness (See Note)		
	< 200	200-237	> 237	< 200	200-237	> 237
High	Low	Medium	High	Not	Low	Medium
Moderate	Low	Medium	High	Not	Not	Low
Low	Low	Low	Medium	Not	Not	Not

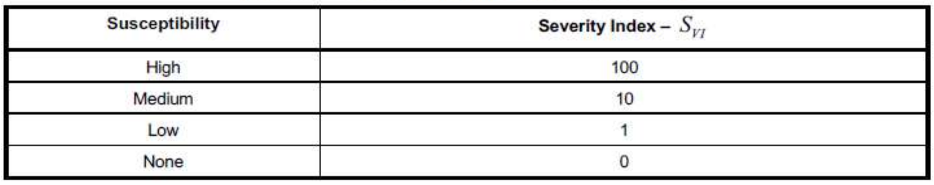
Note: Actually tested as Brinnell, not converted from finer techniques, e.g. Vickers, Knoop, etc.

Susceptibility to SCC : Low
PWTH : No

Step 3.

Based on the susceptibility in step 3, determine the severity index, frcS_{VI} *table 8.4.*

Table 8.4 – Determination of Severity Index – SSC



Susceptibility	Severity Index – S_{VI}
High	100
Medium	10
Low	1
None	0

Svi according to susceptibility to SCC : 1

Step 4.

Determine the time in-service, age , since the last Level A, B or C inspection was performed with no cracking detected or cracking was repaired. Cracking detected but not repaired should be evaluated and future inspection recommendations based upon FFS evaluation

In-service age : 14 year

age at the RBI Date

$$age_{RBI} = RBI\ Date - Last\ Inspection\ Date$$

age_{RBI} = 12/02/2019 - 26/11/2014

= 4 year

age at RBI Date: 18 year

Step 5.

Determine the number of inspections, and the corresponding inspection using Section 8.6.2 for past inspections performed during the in-service time. Combine the inspections toeffectiveness category the highest effectiveness performed using Section 3.4.3.

Inspection Performed : 2

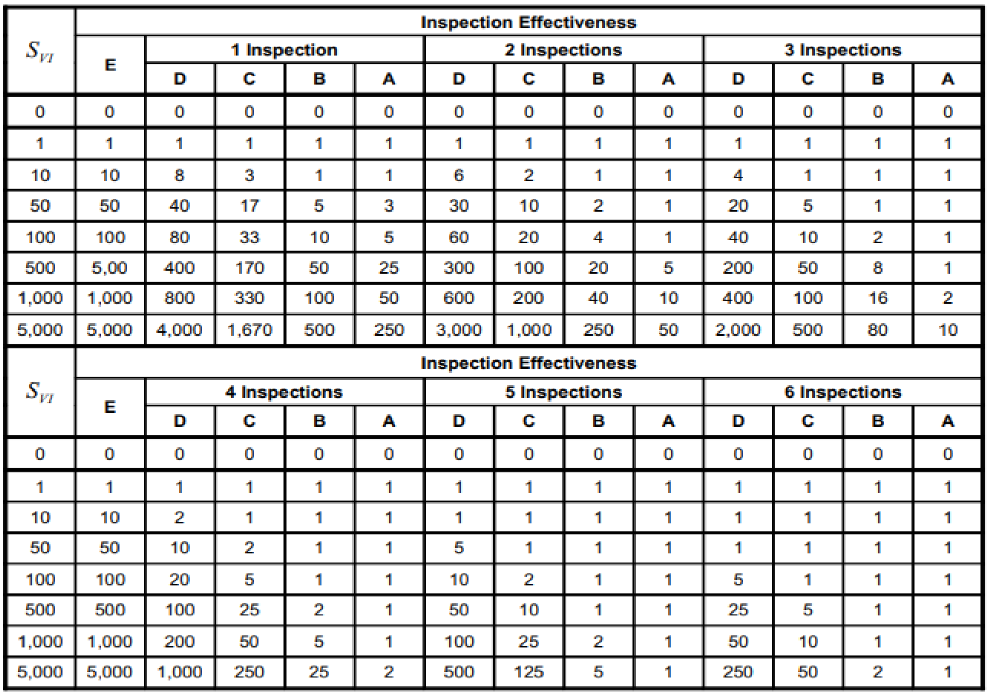
Inspection Category : E

Inspection Effectiveness : Ineffective

Step 6.

Determine the base DF for sulfide stress cracking D_{fB}^{ssc} using Table 6.3 based on the number of, and the highest inspection effectiveness determined in STEP 5, and the severity index S_{VI} from STEP 3.

Table 6.3 – SCC Damage Factors – All SCC Mechanisms



S_{VI}	Inspection Effectiveness												
	E	1 Inspection				2 Inspections				3 Inspections			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	8	3	1	1	6	2	1	1	4	1	1	1
50	50	40	17	5	3	30	10	2	1	20	5	1	1
100	100	80	33	10	5	60	20	4	1	40	10	2	1
500	5,00	400	170	50	25	300	100	20	5	200	50	8	1
1,000	1,000	800	330	100	50	600	200	40	10	400	100	16	2
5,000	5,000	4,000	1,670	500	250	3,000	1,000	250	50	2,000	500	80	10

S_{VI}	Inspection Effectiveness												
	E	4 Inspections				5 Inspections				6 Inspections			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	2	1	1	1	1	1	1	1	1	1	1	1
50	50	10	2	1	1	5	1	1	1	1	1	1	1
100	100	20	5	1	1	10	2	1	1	5	1	1	1
500	500	100	25	2	1	50	10	1	1	25	5	1	1
1,000	1,000	200	50	5	1	100	25	2	1	50	10	1	1
5,000	5,000	1,000	250	25	2	500	125	5	1	250	50	2	1

Inspection Effectiveness

Inspection Performed : 2

Inspection Category : E

Severity Index

S_{VI} according to susceptibility to SCC : 1

Base Damage factor

Base D_f : 1

Step 7.

Calculate the escalation in the DF based on the time in-service since the last inspection using the age from STEP 4 and Equation (2.27). In this equation, it is assumed that the probability for cracking will increase with time since the last inspection as a result of increased exposure to upset conditions and other non-normal conditions

by using equation 2.27 we can find out the Df.

Damage factor at RBI Date

D_f^{SSC}= $D_{fB}^{SCC}.(Max[age, 1.0])^{1.1}$

D_f^{SCC}= $1.(Max[5,1.0])^{1.1}$

D_f^{SCC}= 5.8730947

Damage factor at RBI Plan Date

D_f^{SSC}= $D_{fB}^{SCC}.(Max[age, 1.0])^{1.1}$

D_f^{SCC}= $1.(Max[11,1.0])^{1.1}$

D_f^{SCC}= 13.980798

Calculation of SCC-HIC/SOHIC-H_2S Cracking Damage Factor

step 1.

Determine the environmental severity (potential level of hydrogen flux) for cracking based on the content of the wH_2Sr and its pH using table 9.2.

pH : 5.52
Content of water : 1000 ppm

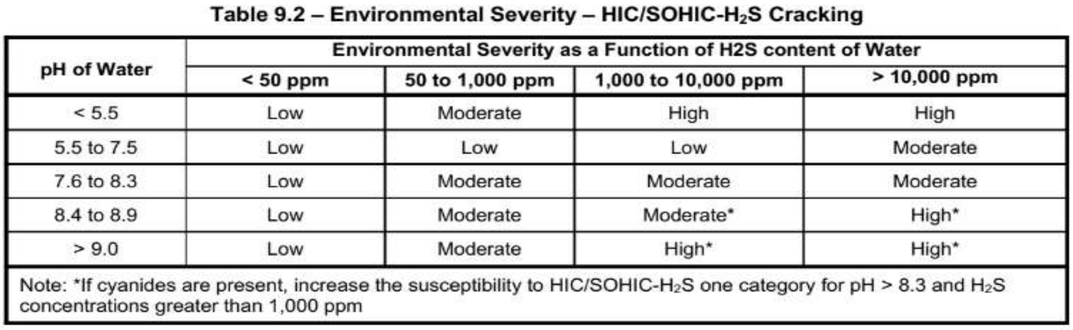


Table 9.2 – Environmental Severity – HIC/SOHIC-H_2S Cracking

pH of Water	Environmental Severity as a Function of H2S content of Water			
	< 50 ppm	50 to 1,000 ppm	1,000 to 10,000 ppm	> 10,000 ppm
< 5.5	Low	Moderate	High	High
5.5 to 7.5	Low	Low	Low	Moderate
7.6 to 8.3	Low	Moderate	Moderate	Moderate
8.4 to 8.9	Low	Moderate	Moderate*	High*
> 9.0	Low	Moderate	High*	High*

Note: *If cyanides are present, increase the susceptibility to HIC/SOHIC-H_2S one category for pH > 8.3 and H_2S concentrations greater than 1,000 ppm

Enviromental Severity : Moderate

Step 2

Determine the susceptibility for cracking using *figure 9.1* and *table 9.3* based on the environmental severity from step 1, the maximum brinnel hardness of weldments, and knowledge of whether the component was subject to PWHT.

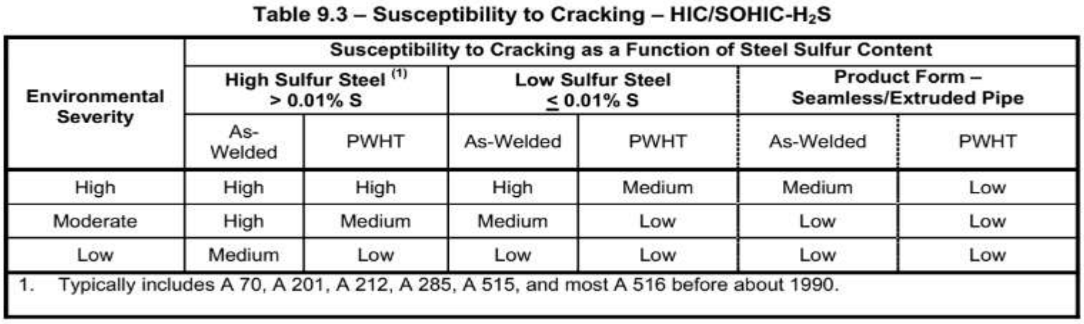


Table 9.3 – Susceptibility to Cracking – HIC/SOHIC-H_2S

Environmental Severity	Susceptibility to Cracking as a Function of Steel Sulfur Content					
	High Sulfur Steel [(1)] > 0.01% S		Low Sulfur Steel ≤ 0.01% S		Product Form – Seamless/Extruded Pipe	
	As-Welded	PWHT	As-Welded	PWHT	As-Welded	PWHT
High	High	High	High	Medium	Medium	Low
Moderate	High	Medium	Medium	Low	Low	Low
Low	Medium	Low	Low	Low	Low	Low

1. Typically includes A 70, A 201, A 212, A 285, A 515, and most A 516 before about 1990.

Steel sulfur content: 0.03 %
Environmental severity: Moderate
Post Weld Heat Treatment (PWHT): No
Susceptibility for Cracking: Medium

Step 3.

Based on the susceptibility in STEP 2, determine the severity index, SF/ , S_{VI} Table *9.4.*

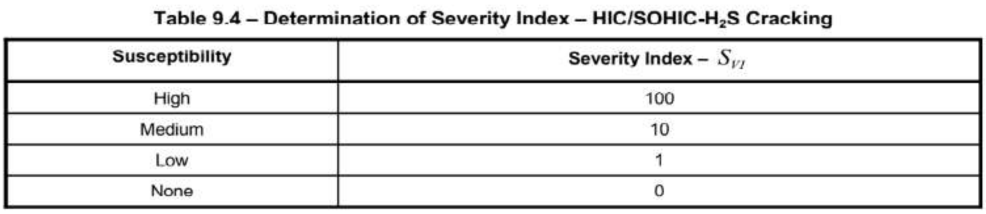


Table 9.4 – Determination of Severity Index – HIC/SOHIC-H_2S Cracking

Susceptibility	Severity Index – S_{VI}
High	100
Medium	10
Low	1
None	0

Suscpetibility from step 2 : Medium
Severity index : 10

Step 4.

Determine the time in-service, age , since the last Level A, B or C inspection was performed with no cracking detected or cracking was repaired. Cracking detected but not repaired should be evaluated and future inspection recommendations based upon FFS evaluation

Determine the time in service, age, since the last inspection.

age at the RBI Date

age_{RBI} = $RBI\ Date - Last\ Inspection\ Date$

age_{RBI} = 12/02/2019 - 26/11/2014

= 4 year

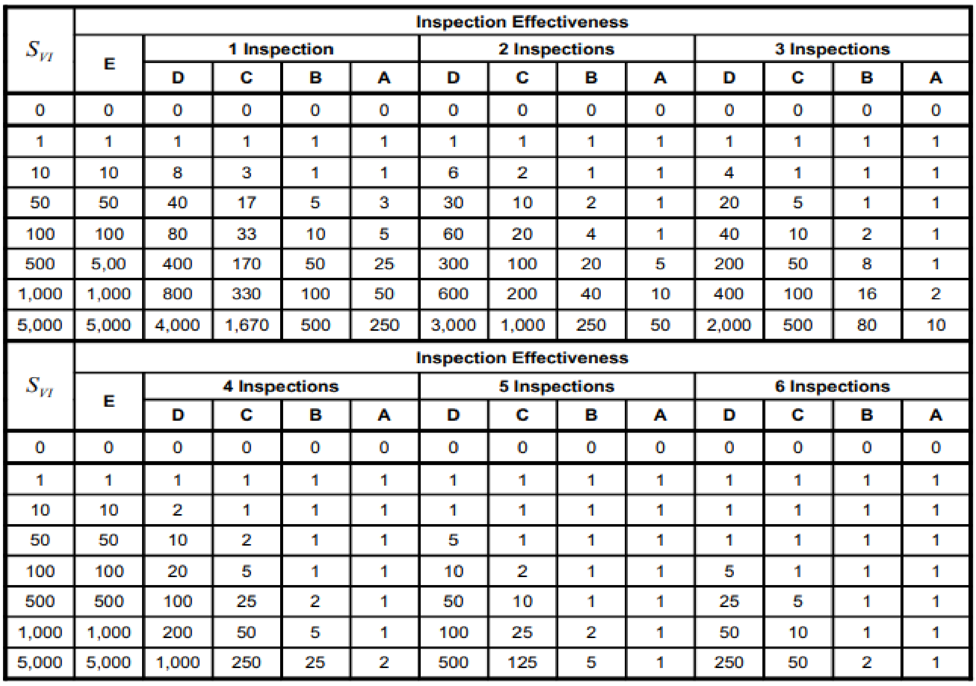
Step 5

Determine the number of inspections, and the corresponding inspection using Section 9.6.2 for past inspections performed during the in-service time. Combine the inspections toeffectiveness category the highest effectiveness performed using Section 3.4.3.

Damage Mechanism	:	HIC/SOHIC
Inspection Performed	:	1
Inspection Category	:	C
Inspection Effectiveness	:	Highly Effective

Step 6. Determine the base DF for HIC/SOHIC-H_2S using D_{fB}^{scc} ble 6.3 based on the number of, and the highest inspection effectiveness determined in STEP 5, and the severity index from STEP S_{VI} 3.

Table 6.3 – SCC Damage Factors – All SCC Mechanisms



S_{VI}	Inspection Effectiveness												
	E	1 Inspection				2 Inspections				3 Inspections			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	8	3	1	1	6	2	1	1	4	1	1	1
50	50	40	17	5	3	30	10	2	1	20	5	1	1
100	100	80	33	10	5	60	20	4	1	40	10	2	1
500	5,00	400	170	50	25	300	100	20	5	200	50	8	1
1,000	1,000	800	330	100	50	600	200	40	10	400	100	16	2
5,000	5,000	4,000	1,670	500	250	3,000	1,000	250	50	2,000	500	80	10
S_{VI}	Inspection Effectiveness												
	E	4 Inspections				5 Inspections				6 Inspections			
		D	C	B	A	D	C	B	A	D	C	B	A
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	10	2	1	1	1	1	1	1	1	1	1	1	1
50	50	10	2	1	1	5	1	1	1	1	1	1	1
100	100	20	5	1	1	10	2	1	1	5	1	1	1
500	500	100	25	2	1	50	10	1	1	25	5	1	1
1,000	1,000	200	50	5	1	100	25	2	1	50	10	1	1
5,000	5,000	1,000	250	25	2	500	125	5	1	250	50	2	1

Inspection Effectiveness

Inspection Performed	:	1
Inspection Category	:	C

Severity Index

S_{VI} according to susceptibility to SCC : 10

Base Damage factor

Base D_f : 3

Step 7.

Determine the on-line adjustment factor, F_{OM} , from Table 9.5.

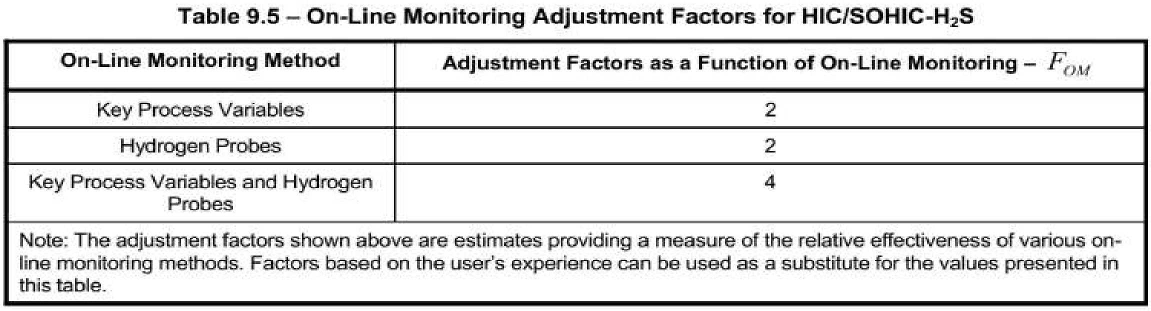


Table 9.5 – On-Line Monitoring Adjustment Factors for HIC/SOHIC-H_2S

On-Line Monitoring Method	Adjustment Factors as a Function of On-Line Monitoring – F_{OM}
Key Process Variables	2
Hydrogen Probes	2
Key Process Variables and Hydrogen Probes	4
Note: The adjustment factors shown above are estimates providing a measure of the relative effectiveness of various on-line monitoring methods. Factors based on the user's experience can be used as a substitute for the values presented in this table.	

Adjustment Factors:

Key Process Variables	:	2

Step 8.

Calculate the final DF accounting for escalation based on the time in-service since the last inspection using the age from STEP 4 and Equation (2.28). In this equation, it is assumed that the probability for cracking will increase with time since the last inspection as a result of increased exposure to upset conditions and other non-normal conditions. The equation also applies the adjustment factor for online monitoring

Damage Factor at RBI Date

$$D_f^{HIC\ SOHIC-H2S} = \frac{D_{fB}^{HIC\ SOHIC-H2S}.(Max[age,1.0])^{1.1}}{Fom}$$

$$D_f^{HIC\ SOHIC-H2S} = \frac{1.(Max[4,1.0])^{1.1}}{2}$$

$$D_f^{HIC\ SOHIC-H2S} = 4.594793$$

Damage Factor at RBI Plan Date

$$D_f^{HIC\ SOHIC-H2S} = \frac{D_{fB}^{HIC\ SOHIC-H2S}.(Max[age,1.0])^{1.1}}{Fom}$$

$$D_f^{HIC\ SOHIC-H2S} = \frac{1.(Max[11,1.0])^{1.1}}{2}$$

$$D_f^{HIC\ SOHIC-H2S} = 13.9808$$

Probability of Failure

the probability of failure can be calculated using the equation of;

$Pf(t) = gff \cdot Fms \cdot Df(t)$

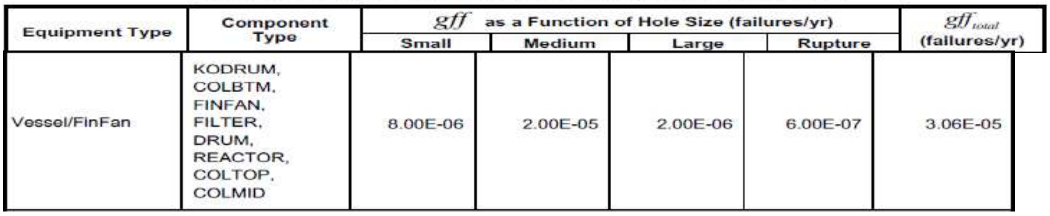
it can be known that

pf (t) = The PoF as a function of time
gff = General failure frequency
Fms = Management system factor
Df (t) = Total damage factor

Determining General failure frequency (gff)

To determine the value of gff, we can use the recommended list from table 3.1 [1-8] of API RBI 581

Table 3.1 – Suggested Component Generic Failure Frequencies

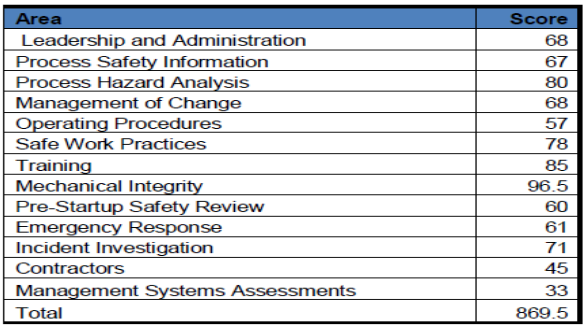


Equipment Type	Component Type	gff as a Function of Hole Size (failures/yr)				gff_{total} (failures/yr)
		Small	Medium	Large	Rupture	
Vessel/FinFan	KODRUM, COLBTM, FINFAN, FILTER, DRUM, REACTOR, COLTOP, COLMID	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05

from the table we can determine that the value of gff is: **3.06E-05**

Determining Management system factor (Fms)

To determine the value of Fms, we use a series of question and survey given by API RBI 581 to determine Fms value



Area	Score
Leadership and Administration	68
Process Safety Information	67
Process Hazard Analysis	80
Management of Change	68
Operating Procedures	57
Safe Work Practices	78
Training	85
Mechanical Integrity	96.5
Pre-Startup Safety Review	60
Emergency Response	61
Incident Investigation	71
Contractors	45
Management Systems Assessments	33
Total	869.5

Management system factor score according from the survey, the score is **869.5**

the score must first be converted into percentage using the equation of:

$$pscore = \frac{Score}{1000} . 100 \text{ [unit is 100\%]}$$

based from equation, the *pscore* is **86.95%**

To determine the value of Fms we can use the equation:

$$Fms = 10^{(-0.02 . pscore+1)}$$

$$Fms = 10^{(-0.02 . 86.95+1)}$$

$$Fms = 0.182390$$

From the equation we can determine that the value of Fms is **0.182390**

Calculating Damage Factor

Damage Factor for Stress Corrosion Cracking

Calculation of damage factor for stress corrosion cracking (SCC) explained in section 3.4.2 - API RP 581 Part 2 3rd Edition.
For multipe SCC damage factor mechanisms case, determined using equation (2.6).

$$D_{f-gov}^{scc} = max\begin{bmatrix} D_f^{caustic}, D_f^{amine}, D_f^{scc}, D_f^{HIC/SOHIC-H_2S}, D_f^{ACSCC}, \\ D_f^{PASCC}, D_f^{CLSCC}, D_f^{HSC\_HF}, D_f^{HIC/SOHIC-HF} \end{bmatrix}$$

D_{f-gov}^{scc} = 5.873094715 13.9808

Damage Factor for Thinning

D_f^{Thin} = Max[($\frac{(D_{fb}^{Thin}}{F_{OM}}$),0.1]

= 0.241025096

Total Damage Factor

If the external and thinning damage are general, then damage is likely to occur at the same location and the total DF is given by Equation (2.3)

$$D_{f-total} = D_{f-gov}^{thin} + D_{f-gov}^{extd} + D_{f-gov}^{scc} + D_f^{htha} + D_{f-gov}^{brit} + D_f^{mfat}$$

6.11412 28.0062

Calculating Probability of Failure:

After determining the value of gff, Fms and Df we can calculate the probability of failure using the equation:

Pf (t) = gff . Fms . D f (t)

Pf (t) = 3.06E−0.5 . 0.182390 . 18.43159

Pf (t) = 0.012468978

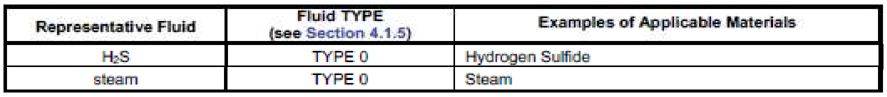
RBI Date PoF	Risk Target
0.004157	0.067982
RBI Plan Date PoF	
0.018998	

Consequence of Failure

Step 1. Determine the release fluid and its properties, including the release phase.

Step 1.1. Select a representative fluid group from table 4.1.

List of representative fluid



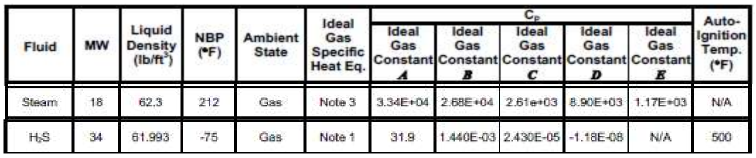
Representative Fluid	Fluid TYPE (see Section 4.1.5)	Examples of Applicable Materials
H_2S	TYPE 0	Hydrogen Sulfide
steam	TYPE 0	Steam

Choosen Representative Fluid : H_2S

Step 1.2 Determine the stored fluid phase

Stored fluid phase: Liquid

Step 1.3 Determine the stored fluid propertioes

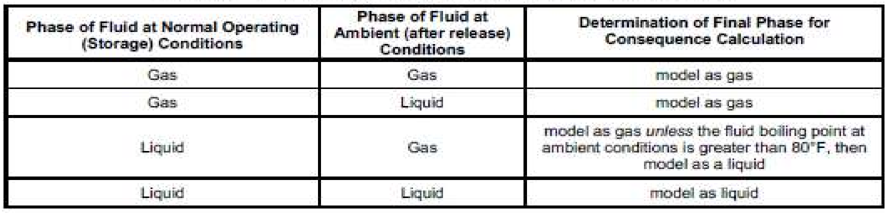


Fluid	MW	Liquid Density (lb/ft^3)	NBP (°F)	Ambient State	Ideal Gas Specific Heat Eq.	C_p Ideal Gas Constant *A*	Ideal Gas Constant *B*	Ideal Gas Constant *C*	Ideal Gas Constant *D*	Ideal Gas Constant *E*	Auto-Ignition Temp. (°F)
Steam	18	62.3	212	Gas	Note 3	3.34E+04	2.68E+04	2.61e+03	8.90E+03	1.17E+03	N/A
H_2S	34	61.993	-75	Gas	Note 1	31.9	1.440E-03	2.430E-05	-1.18E-08	N/A	500

Liquid density : 993.0326 Kg/m^3
NBP : -59.4444 C°
Auto-Ignition Tempt : 260 C°

Step 1.4 Determine the steady state phase of the liquid after release to the atmosphere using table 5.3

Table 4.3 – Level 1 Guidelines for Determining the Phase of a Fluid



Phase of Fluid at Normal Operating (Storage) Conditions	Phase of Fluid at Ambient (after release) Conditions	Determination of Final Phase for Consequence Calculation
Gas	Gas	model as gas
Gas	Liquid	model as gas
Liquid	Gas	model as gas *unless* the fluid boiling point at ambient conditions is greater than 80°F, then model as a liquid
Liquid	Liquid	model as liquid

Discharge Coefficient Liquid : 0.61
Viscosity Correction Factor : 1
Gravitional Constant : 1

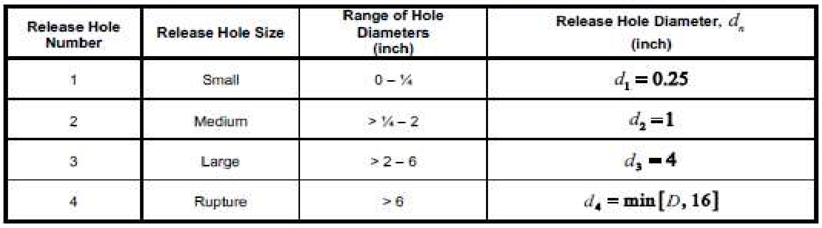
The fluid is liquid in the vessel, it’s post release is gas

step 2

Select a set of release hole sizes to determine the possible range of consequences in the risk calculation.

Step. 2.1

Table 4.4 – Release Hole Sizes and Areas Used in Level 1 and 2 Consequence Analyses



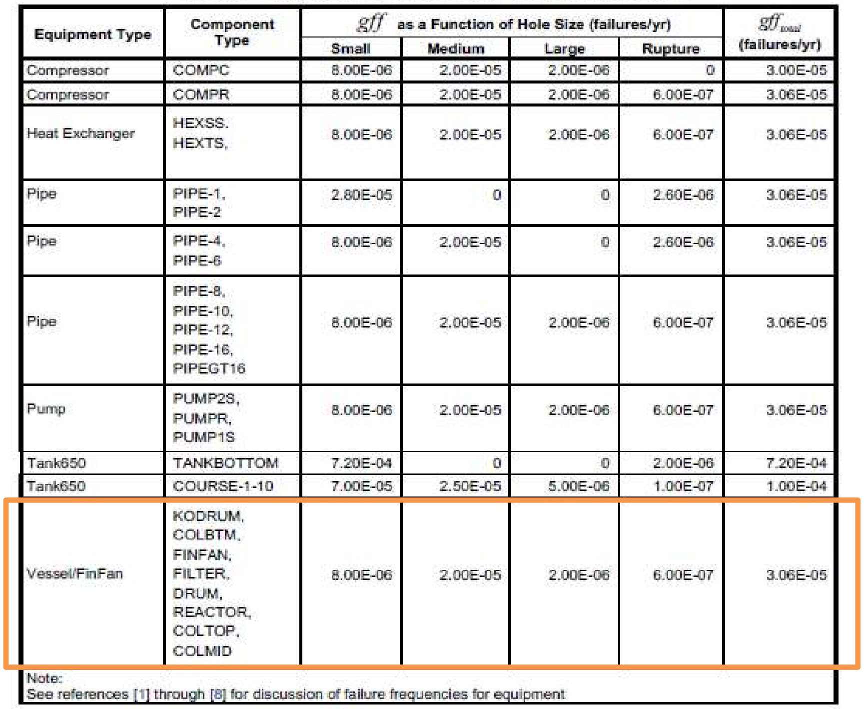
Release Hole Number	Release Hole Size	Range of Hole Diameters (inch)	Release Hole Diameter, d_n (inch)
1	Small	0 – ¼	$d_1 = 0.25$
2	Medium	> ¼ – 2	$d_2 = 1$
3	Large	> 2 – 6	$d_3 = 4$
4	Rupture	> 6	$d_4 = \min[D, 16]$

Step 2.2

Determine the generic failure frequency for the n release hole size from table 3.1 part 2.

3.7 Tables

Table 3.1 – Suggested Component Generic Failure Frequencies



Equipment Type	Component Type	gff as a Function of Hole Size (failures/yr)				gff_{total} (failures/yr)
		Small	Medium	Large	Rupture	
Compressor	COMPC	8.00E-06	2.00E-05	2.00E-06	0	3.00E-05
Compressor	COMPR	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Heat Exchanger	HEXSS. HEXTS,	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Pipe	PIPE-1, PIPE-2	2.80E-05	0	0	2.60E-06	3.06E-05
Pipe	PIPE-4, PIPE-6	8.00E-06	2.00E-05	0	2.60E-06	3.06E-05
Pipe	PIPE-8, PIPE-10, PIPE-12, PIPE-16, PIPEGT16	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Pump	PUMP2S, PUMPR, PUMP1S	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
Tank650	TANKBOTTOM	7.20E-04	0	0	2.00E-06	7.20E-04
Tank650	COURSE-1-10	7.00E-05	2.50E-05	5.00E-06	1.00E-07	1.00E-04
Vessel/FinFan	KODRUM, COLBTM, FINFAN, FILTER, DRUM, REACTOR, COLTOP, COLMID	8.00E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05

Note:
See references [1] through [8] for discussion of failure frequencies for equipment

Step 3. Calculate the theoritical release rate

Step 3.1 Select the appropriate release rate equation using the determined stored fluid phase.

Stored fluid type : Liquid

Step 3.2 Compute the release hole size area A_n in mm^2, using equation (3.8) based on d_n

$$An = \frac{\pi d_n^2}{4} \qquad \text{e.q 3.8}$$

Release for small hole size

$$An = \frac{\pi\ (0.25)^2}{4}$$

$$An = \frac{126.6127}{4}$$

$An = 0.0491$ inch

= 3.00E-05 m^2

Release for medium hole size

$$An = \frac{\pi\ (1)^2}{4}$$

$$An = \frac{2025.802}{4}$$

$An = 0.785$ mm^2

5.00E-04 m^2

Release for Large hole size

$$An = \frac{\pi\ (4\ )^2}{4}$$

$$An = \frac{32412.84}{4}$$

$An = 12.56$ mm^2

0.008 m^2

Release for Rupture hole size

$$An = \frac{\pi\ (16\ )^2}{4}$$

$$An = \frac{72928.89}{4}$$

$An = 201$ mm^2

0.13 m^2

Step 3.3

Calculate Viscosity Correction Factor

Kv_1 = 1

Kv_2 = 1

Kv_3 = 1

Kv_4 = 1

Step 3.4

For release hole, calculate the release rate, Wn, In Kg/s for each release area, An, using the formula:

For Vapour release rate, we must first find the transition pressure (P_{trans}).

$$Ptrans = Patm\left(\frac{k+1}{2}\right)^{\frac{\kappa}{k-1}}$$

$$Ptrans = 1\left(\frac{1.27+1}{2}\right)^{\frac{1{\cdot}27}{1{\cdot}27-1}}$$

$$Ptrans = 1.814196$$

$$k = \frac{Cp}{Cp-R}$$

$$k = \frac{39.1}{39.1-8.314}$$

$k =$ 1.270058

Since P_s is greater than $_{Ptrans}$, we can use equation (3.6) to determine vapour flow rate

$$Wn = \frac{C_d}{C_2}.An.Ps\sqrt{\left(\frac{k.MW.gc}{R.Ts}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

For Small hole release size

$$W_1 = \frac{C_d}{C_2}.An.Ps\sqrt{\left(\frac{k.MW.gc}{R.Ts}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

$$W_1 = \frac{0.90}{1}.31.65316.1060\sqrt{\left(\frac{1.27.34.1}{8.314.453.15}\right)\left(\frac{2}{1.27+1}\right)^{\frac{1.27+1}{1.27-1}}}$$

$$W_1 = 31214.71433\sqrt{2.33497E{-}05}$$

$W_1 =$ 0.001949247 Kg/s

For Medium hole release size

$$W_2 = \frac{C_d}{C_2}.An.Ps\sqrt{\left(\frac{k.MW.gc}{R.Ts}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

$$W_2 = \frac{0.90}{1000}.506.4506.1060\sqrt{\left(\frac{1.27.34.1}{8.314.453.15}\right)\left(\frac{2}{1.27+1}\right)^{\frac{1.27+1}{1.27-1}}}$$

$$W_2 = 499435.5\sqrt{2.33497E{-}05}$$

$W_2 =$ 0.093635081 Kg/s

For Large hole release size

$$W_3 = \frac{C_d}{C_2} \, . An \, . Ps \sqrt{\left(\frac{k \, . MW \, . gc}{R \, . Ts}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

$$W_3 = \frac{0.90}{1} \, . 8103.21 \, . 1060 \sqrt{\left(\frac{1.27 \, . 34 \, . 1}{8.314 \, . 453.15}\right)\left(\frac{2}{1.27+1}\right)^{\frac{1.27+1}{1.27-1}}}$$

$$W_3 = 7990968 \sqrt{2.33497\text{E}{-05}}$$

$W_3 =$ 0.47857007 Kg/s

For Rupture hole release size

$$W_4 = \frac{C_d}{C_2} \, . An \, . Ps \sqrt{\left(\frac{k \, . MW \, . gc}{R \, . Ts}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

$$W_4 = \frac{0.90}{0.9674} \, . 18232.22 \, . 1060 \sqrt{\left(\frac{1.27 \, . 34 \, . 1}{8.314 \, . 453.15}\right)\left(\frac{2}{1.27+1}\right)^{\frac{1.27+1}{1.27-1}}}$$

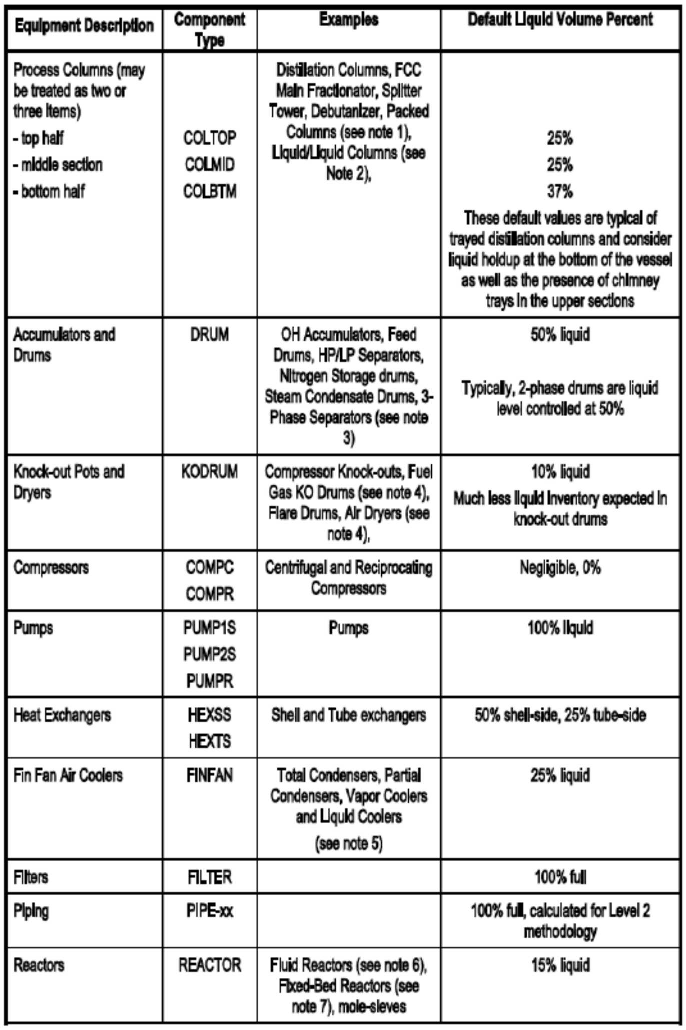
$$W_4 = 17979675.3 \sqrt{2.33497\text{E}{-05}}$$

$W_4 =$ 23.9646359676799 Kg/s

Step 4. Estimate the Maximum Mass Avaible for Release (Availble Mass)

Step 4.1 Group components and equipment items into inventory groups

Table 3.A.3.2 — Assumptions Used When Calculating Liquid Inventories Within Equipment



Equipment Description	Component Type	Examples	Default Liquid Volume Percent
Process Columns (may be treated as two or three items) - top half - middle section - bottom half	COLTOP COLMID COLBTM	Distillation Columns, FCC Main Fractionator, Splitter Tower, Debutanizer, Packed Columns (see note 1), Liquid/Liquid Columns (see Note 2),	25% 25% 37% These default values are typical of trayed distillation columns and consider liquid holdup at the bottom of the vessel as well as the presence of chimney trays in the upper sections
Accumulators and Drums	DRUM	OH Accumulators, Feed Drums, HP/LP Separators, Nitrogen Storage drums, Steam Condensate Drums, 3-Phase Separators (see note 3)	50% liquid Typically, 2-phase drums are liquid level controlled at 50%
Knock-out Pots and Dryers	KODRUM	Compressor Knock-outs, Fuel Gas KO Drums (see note 4), Flare Drums, Air Dryers (see note 4),	10% liquid Much less liquid inventory expected in knock-out drums
Compressors	COMPC COMPR	Centrifugal and Reciprocating Compressors	Negligible, 0%
Pumps	PUMP1S PUMP2S PUMPR	Pumps	100% liquid
Heat Exchangers	HEXSS HEXTS	Shell and Tube exchangers	50% shell-side, 25% tube-side
Fin Fan Air Coolers	FINFAN	Total Condensers, Partial Condensers, Vapor Coolers and Liquid Coolers (see note 5)	25% liquid
Filters	FILTER		100% full
Piping	PIPE-xx		100% full, calculated for Level 2 methodology
Reactors	REACTOR	Fluid Reactors (see note 6), Fixed-Bed Reactors (see note 7), mole-sieves	15% liquid

Step 4.2 Calculate the fluid mass, mass comp, in the component being evaluated

Volume of Cylinder

$$V_{cyl} = \pi R^2 L$$

R = ID/2 = 0.229 m

L = 12.5 m

V_{cyl} = 2.05831 m^3

Liquid Volume = (100%) x V_{cyl} = 2.058 m^3

the mass in component

mass $_{c}$ = $(V_l \rho_l) + (V_v \rho_v)$

mass $_{c}$ = 2043.97 kg

Step 4.3 Calculate fluid mass in each of the other components that are included in the inventory group, mass comp

Step 4.4 Calculate the fluid mass on the inventory group, *mass* $_{inv}$

$$mass_{inv} = \sum_{i=1}^{N} mass_{\ comp}$$

$$mass_{inv} = \sum_{i=1}^{N} 18639.3$$

$$mass_{inv} = \sum_{i=1}^{1} 18639.3$$

$mass_{inv}$ = **18639.3 Kg**

Step 4.5

Calculate the flow rate from a 203 mm (8 inch) diameter hole, Wmax8, using equations (3.3), (3,6) or (3,7) as applicable, with A_n = A_8 = 32,450 mm2 (50.3 inch2).

$$W_{max\ 8} = \frac{C_d}{C_2} \, . A_8 \, . Ps \sqrt{\left(\frac{k \, . MW \, . gc}{R \, . Ts}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

$$W_{max\ 8} = \frac{0.90}{1} \, .32450 \, .1060 \sqrt{\left(\frac{1.27 \, .34 \, .1}{8.314 \, .453.15}\right)\left(\frac{2}{1.27+1}\right)^{\frac{1.27+1}{1.27-1}}}$$

$W_{max\ 8}$ _ 3.716 Kg

Step 4.6

for each release hole size, calculate the added fluid mass, *mass* *add , n , ,* resulting from three minutes of flow from the inventory group using equation (3.10) where W_n is the leakage rate for the release hole size.

$$mass_{\text{add n}} = 180 \, . \text{Min} \, [W_n \, , Wmax_{8_1}$$

for small hole release size

$$mass_{\text{add 1}} \ \_ \ 180 \ \text{Min} \, [W_n \, , Wmax_{8_1}$$

$$mass_{addl,\,1} = 180 \, . \, Min \, [28959.46 \, . \, 3.716]$$

mass $_{\text{add, 1}}$ = 0.35086447 Kg/s

for Medium hole release size

$$mass_{\text{add 2}} \ \_ \ 180 \ \text{Min} \, [W_n \, , Wmax_{8_1}$$

$$mass_{add\ 2} \ \_ \ 180 \ Min \, [463351.4 \ \ , 3841.08334]$$

mass $_{\textit{add, 2}}$ = 16.85 Kg/s

Determine the release type (continous or instantaneous) to determine the method used for modeling dispersion and consequence.

Step 5.1

For each release hole size, calculate the time reqired to release 4536 kg of fluid

$$t_n = \frac{C_3}{W_n}$$

$$t_n = \frac{4536}{W_n}$$

Small Hole size

$$t_1 = \frac{4536}{W_1}$$

$$t_1 = \frac{4536}{3746.761958}$$

t_1 = 2327052.38 s

Medium Hole size

$$t_2 = \frac{4536}{W_2}$$

$$t_2 = \frac{4536}{59948.2}$$

t_2 = 48443.3821 s

Large Hole size

$$t_3 = \frac{4536}{W_3}$$

$$t_3 = \frac{4536}{959171.2}$$

t_3 = 9478.23586 s

Rupture Hole size

$$t_4 = \frac{4536}{W_2}$$

$$t_4 = \frac{4536}{2158134.87}$$

t_4 = 189.278903 s

Step 5.2

For each release size if the release type is instantaneous or continous using the following criteria

1). SMALL RELEASE HOLE SIZE AREA

d1 = 0.25 inch

t1 = 2.33E+06 s (Continous)

2). MEDIUM RELEASE HOLE SIZE AREA

d2 = 1 inch

t2 = 48443.3821 s (Continous)

3). LARGE RELEASE HOLE SIZE AREA

d3 = 4 inch

t3 = 9478.23586 s (Continous)

4). RUPTURE RELEASE HOLE SIZE AREA

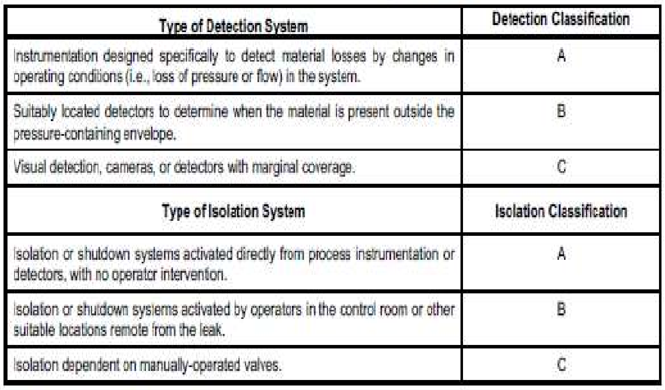
d4 = 16 inch

t4 = 189.278903 s (Continous)

Step 6. Estimeate the impact of detection and isolation systems on release magnitude.

Step 6.1 Determine the detection and isolation systems present in the unit

Table 4.5 – Detection and Isolation System Rating Guide



Type of Detection System	Detection Classification
Instrumentation designed specifically to detect material losses by changes in operating conditions (i.e., loss of pressure or flow) in the system.	A
Suitably located detectors to determine when the material is present outside the pressure-containing envelope.	B
Visual detection, cameras, or detectors with marginal coverage.	C
Type of Isolation System	**Isolation Classification**
Isolation or shutdown systems activated directly from process instrumentation or detectors, with no operator intervention.	A
Isolation or shutdown systems activated by operators in the control room or other suitable locations remote from the leak.	B
Isolation dependent on manually-operated valves.	C

Step 6.2 Using table 4.5, select the appropriate classification (A,B,C) for the detection system.

Detection System C

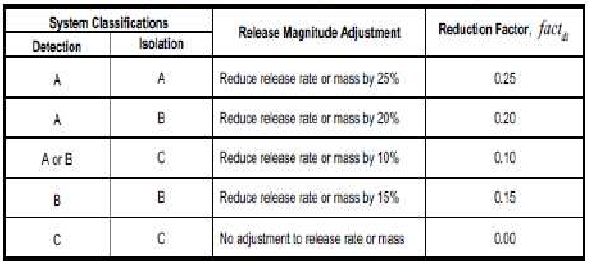
Step 6.3 Using table 4.5, select the appropriate classification (A,B,C) for the isolation system.

Isolation System C

Step 6.4

Using table 4.6 and the classification determined in step 6.2 and step 6.3, determine the release reductio factor

Table 4.6 – Adjustments to Release Based on Detection and Isolation Systems

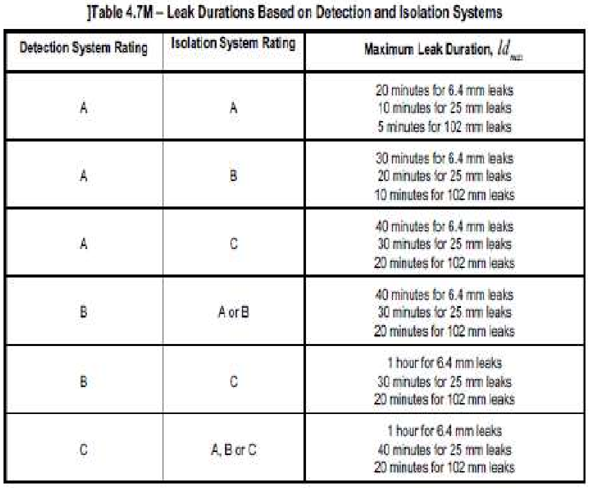


System Classifications		Release Magnitude Adjustment	Reduction Factor, $fact_{di}$
Detection	Isolation		
A	A	Reduce release rate or mass by 25%	0.25
A	B	Reduce release rate or mass by 20%	0.20
A or B	C	Reduce release rate or mass by 10%	0.10
B	B	Reduce release rate or mass by 15%	0.15
C	C	No adjustment to release rate or mass	0.00

Detection System C
Isolation System C
$fact_{di}$ = 0.00

Step 6.5

Using table 4.7 and the classification determined in step 6.2 and 6.3, determine the total leak durations for each of the selected release hole sizes, $Id_{max,n}$



]Table 4.7M – Leak Durations Based on Detection and Isolation Systems

Detection System Rating	Isolation System Rating	Maximum Leak Duration, ld_{max}
A	A	20 minutes for 6.4 mm leaks 10 minutes for 25 mm leaks 5 minutes for 102 mm leaks
A	B	30 minutes for 6.4 mm leaks 20 minutes for 25 mm leaks 10 minutes for 102 mm leaks
A	C	40 minutes for 6.4 mm leaks 30 minutes for 25 mm leaks 20 minutes for 102 mm leaks
B	A or B	40 minutes for 6.4 mm leaks 30 minutes for 25 mm leaks 20 minutes for 102 mm leaks
B	C	1 hour for 6.4 mm leaks 30 minutes for 25 mm leaks 20 minutes for 102 mm leaks
C	A, B or C	1 hour for 6.4 mm leaks 40 minutes for 25 mm leaks 20 minutes for 102 mm leaks

Detection Sys	A		
Isolation Syste	B		
$Id_{max,1}$	6.4 mn	60	minutes
$Id_{max,2}$	25 mm	40	minutes
$Id_{max,3}$	102 mı	20	minutes

Step 7 Determine the release rate and mass for consequence analysis

Step 7.1

For each release hole size, calculate the adjusted release rate, $_{rate\ n}$. using equation (3.13)

$$rate_n = Wn\,(1 - factdi)$$

Small Hole size

$$rate_1 = W_1\,(1 - factdi)$$

$$rate_1 = 3746.761958\ \ (1 - factdi)$$

$rate_1$ = 0.00195 kg/s

Medium Hole size

$$rate_2 = W_2\,(1 - factdi)$$

$$rate_2 = 59948.2\ \ (1 - factdi)$$

$rate_2$ = 0.09364 kg/s

Large Hole size

$$rate_3 = W_3\,(1 - factdi)$$

$$rate_3 = 959171.184\ \ (1 - factdi)$$

$rate_3$ = 0.47857 kg/s

Large Hole size

$$rate_4 = W_4\,(1 - factdi)$$

$$rate_4 = 2158134.87 \quad (1 - factdi)$$

rate $_4$ = 23.9646 kg/s

Step 7.2

For each release hole size, calculate the leak duration, **id**$_n$, of the release using equation (3.15), based on the avaible mass, ***mass*** $_{avail,n}$

$$Id_n = \min\left[\left\{\frac{mass_{availn}}{rate_n}\right\}, \{60.\,idmax_{,n}\}\right]$$

Small Hole size

$$Id_1 = \min\left[\left\{\frac{mass_{avail1}}{rate_1}\right\}, \{60.\,idmax_{,1}\}\right]$$

3600

= 3600

Medium Hole size

$$Id_2 = \min\left[\left\{\frac{mass_{avail2}}{rate_2}\right\}, \{60.\,idmax_{,2}\}\right]$$

= 1200

Large Hole size

$$Id_3 = \min\left[\left\{\frac{mass_{avail3}}{rate_3}\right\}, \{60.\,idmax_{,3}\}\right]$$

= 600

Large Hole size

$$Id_4 = \min\left[\left\{\frac{mass_{avail4}}{rate_4}\right\}, \{60.\,idmax_{,4}\}\right]$$

= 85.291

Step 7.3

For each release hole size, calculate the release mass, massn, using equation (3.14) based on the release rate, raten, from step 3.2, the lead duration idn, from step 7.2 and the available mass, massavailn, from step 4.6

$$mass_n = \min[\{rate_n \, . \, idn\}, massavailn]$$

Small Hole Size

$$mass_1 = \min[\{rate_1 \, . \, id_1\}, massavail_{1]}$$

$mass_1$ = 7.01729

Medium Hole Size

$$mass_2 = \min[\{rate_2 \, . \, id_2\}, massavail_{2]}$$

$mass_2$ = 112.362

Large Hole Size

$$mass_3 = \min[\{rate_3 \, . \, id_3\}, massavail_{3]}$$

$mass_3$ = 287.142

Rupture Hole Size

$$mass_4 = \min[\{rate_4 \, . \, id_4\}, massavail_{4]}$$

$mass_3$ = 2043.97

Step 8 Determining Flammable and Explosive Consequences

Step 8.1 Select the consequence area mitigation reduction factor, ***fact*** $_{mit}$***,*** from table 4.10

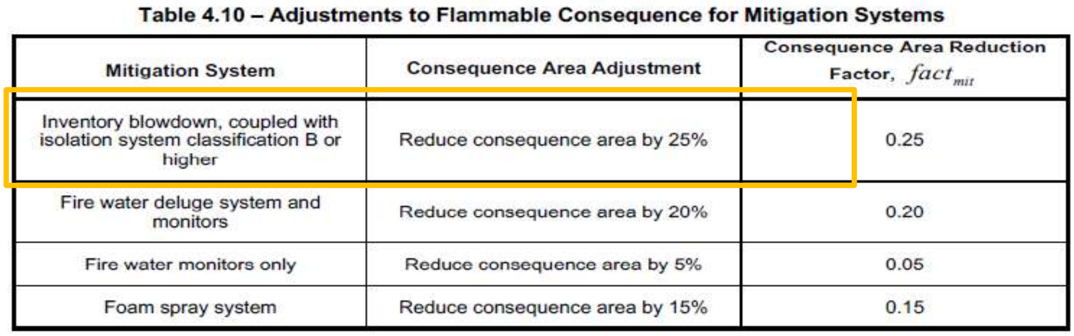


Table 4.10 – Adjustments to Flammable Consequence for Mitigation Systems

Mitigation System	Consequence Area Adjustment	Consequence Area Reduction Factor, $fact_{mit}$
Inventory blowdown, coupled with isolation system classification B or higher	Reduce consequence area by 25%	0.25
Fire water deluge system and monitors	Reduce consequence area by 20%	0.20
Fire water monitors only	Reduce consequence area by 5%	0.05
Foam spray system	Reduce consequence area by 15%	0.15

$fact_{mit}$ = 0.25

Step 8.2 For each release hole size, calculate the energy efficiency correction factor, *eneff* $_n$ using equation 3.18

$$eneff_n = 4.log_{10}[C_4.massn] - 15$$

for small hole size

$$eneff_1 = 4.log_{10}[C_4.mass_1] - 15$$

eneff $_1$ = 1.758311923 1.758

for medium hole size

$$eneff_2 = 4.log_{10}[C_4.mass_2] - 15$$

eneff $_2$ = 6.576113718

for large hole size

$$eneff_3 = 4.log_{10}[C_4.mass_2] - 15$$

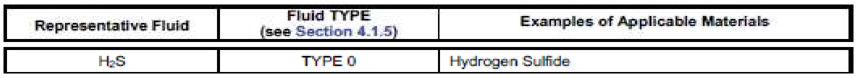
eneff $_3$ = 8.206021514

for rupture hole size

$$eneff_3 = 4.log_{10}[C_4.mass_2] - 15$$

eneff $_3$ = 11.6155309

Step 8.3 Determine the fluid type, either Type 0 or Type 1 from table 4.1



Representative Fluid	Fluid TYPE (see Section 4.1.5)	Examples of Applicable Materials
H_2S	TYPE 0	Hydrogen Sulfide

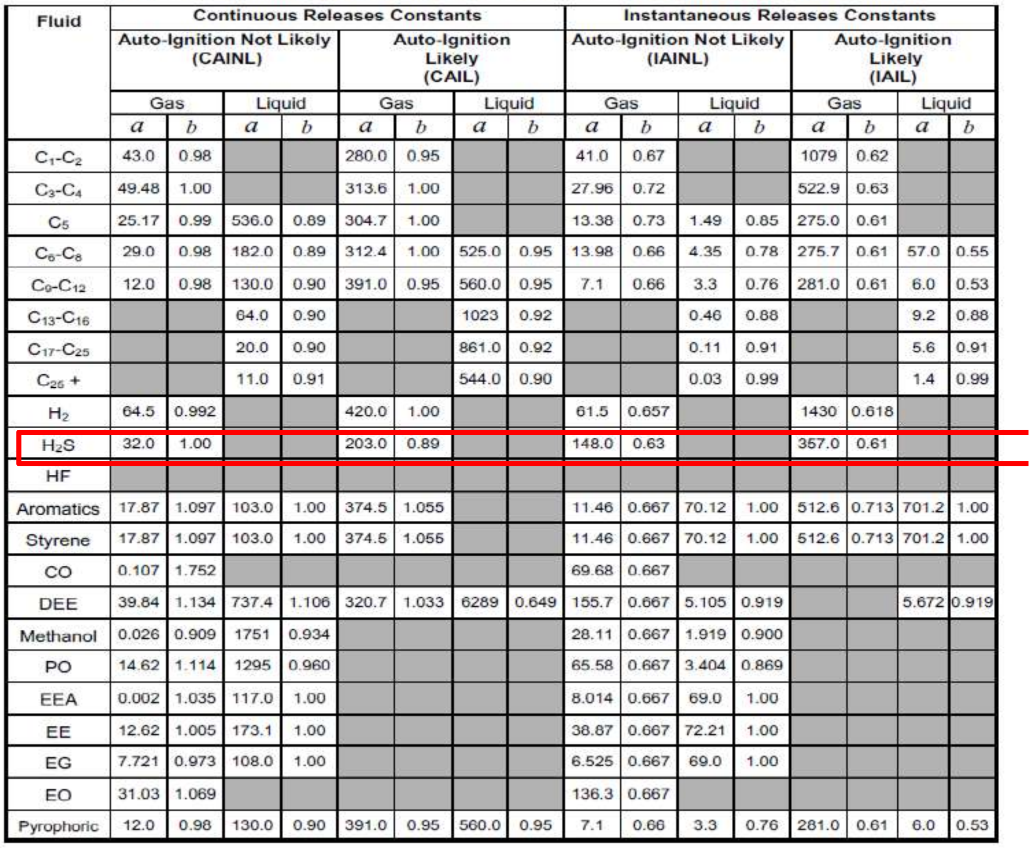
H_2S = Type 0

Step 8.4 For each release hole size, calculate the component damage consequence area.

Step 1.4 will be needed to assure selection of the correct constant

Determine the appropriate constants *a* and *b* from the table 4.8.

Table 4.8 – Component Damage Flammable Consequence Equation Constants



Fluid	Continuous Releases Constants								Instantaneous Releases Constants							
	Auto-Ignition Not Likely (CAINL)				Auto-Ignition Likely (CAIL)				Auto-Ignition Not Likely (IAINL)				Auto-Ignition Likely (IAIL)			
	Gas		Liquid		Gas		Liquid		Gas		Liquid		Gas		Liquid	
	a	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*
C_1-C_2	43.0	0.98			280.0	0.95			41.0	0.67			1079	0.62		
C_3-C_4	49.48	1.00			313.6	1.00			27.96	0.72			522.9	0.63		
C_5	25.17	0.99	536.0	0.89	304.7	1.00			13.38	0.73	1.49	0.85	275.0	0.61		
C_6-C_8	29.0	0.98	182.0	0.89	312.4	1.00	525.0	0.95	13.98	0.66	4.35	0.78	275.7	0.61	57.0	0.55
C_9-C_{12}	12.0	0.98	130.0	0.90	391.0	0.95	560.0	0.95	7.1	0.66	3.3	0.76	281.0	0.61	6.0	0.53
C_{13}-C_{16}			64.0	0.90			1023	0.92			0.46	0.88			9.2	0.88
C_{17}-C_{25}			20.0	0.90			861.0	0.92			0.11	0.91			5.6	0.91
C_{25} +			11.0	0.91			544.0	0.90			0.03	0.99			1.4	0.99
H_2	64.5	0.992			420.0	1.00			61.5	0.657			1430	0.618		
H_2S	32.0	1.00			203.0	0.89			148.0	0.63			357.0	0.61		
HF																
Aromatics	17.87	1.097	103.0	1.00	374.5	1.055			11.46	0.667	70.12	1.00	512.6	0.713	701.2	1.00
Styrene	17.87	1.097	103.0	1.00	374.5	1.055			11.46	0.667	70.12	1.00	512.6	0.713	701.2	1.00
CO	0.107	1.752							69.68	0.667						
DEE	39.84	1.134	737.4	1.106	320.7	1.033	6289	0.649	155.7	0.667	5.105	0.919			5.672	0.919
Methanol	0.026	0.909	1751	0.934					28.11	0.667	1.919	0.900				
PO	14.62	1.114	1295	0.960					65.58	0.667	3.404	0.869				
EEA	0.002	1.035	117.0	1.00					8.014	0.667	69.0	1.00				
EE	12.62	1.005	173.1	1.00					38.87	0.667	72.21	1.00				
EG	7.721	0.973	108.0	1.00					6.525	0.667	69.0	1.00				
EO	31.03	1.069							136.3	0.667						
Pyrophoric	12.0	0.98	130.0	0.90	391.0	0.95	560.0	0.95	7.1	0.66	3.3	0.76	281.0	0.61	6.0	0.53

$a = a_{cmd}^{AINL-CONT}$ $b = b_{cmd}^{AINL-CONT}$

a = 32.0 b = 1.00

Determining Consequence Area for *AINL-CONT*

$$CA_{cmd,n}^{AINL-CONT} = a\,(rate)^{b}\,.(1-factmil)$$

for small hole size

$CA_{cmd,1}^{AINL-CONT}$ = 0.0468 m^2

for medium hole size

$CA_{cmd,2}^{AINL-CONT}$ = 2.2472 m^2

for large hole size

$CA_{cmd,3}^{AINL-CONT}$ = 11.486 m^2

for rupture hole size

$CA_{cmd,4}^{AINL-CONT}$ = 575.15 m^2

Step 8.5

For each release hole size, compute the component damage consequence areas for Autoignition likely Continous Release (*AIL-CONT*)

$a = a_{cmd\,\square}^{AIL-CONT}$ $\qquad$ $b = b_{cmd\,\square}^{AIL-CONT}$

a = 203.0 $\qquad$ *b* = 0.89

Determining Consequence Area for *AINL-CONT*

for small hole size

$CA_{cmd,1}^{AIL\text{-}CONT} = 0.5896\ \mathrm{m}^2$

for medium hole size

$CA_{cmd,2}^{AIL\text{-}CONT} = 18.499\ \mathrm{m}^2$

for large hole size

$CA_{cmd,3}^{AIL\text{-}CONT} = 79.015\ \mathrm{m}^2$

for rupture hole size

$CA_{cmd,4}^{AIL\text{-}CONT} = 2572.6\ \mathrm{m}^2$

Step 8.6

For each release hole size, compute the component damage consequence areas for Auto-Ignition Not Likely, Instantaneous Release (*AINL-INST*)

$a = a_{cmd\,\square}^{AINL-INST}$ $\qquad$ $b = b_{cmd\,\square}^{AINL-INST}$

a = 148.0 $\qquad$ *b* = 0.63

Determining Consequence Area for ANIL-*CONT*

$$CA_{cmd,n\,\square}^{AINL-INST} = a\ (mass)^b \,.\, (\frac{1\ - factmil}{eneff_n})$$

for small hole size

$CA_{cmd,1}^{AINL\text{-}INST} = 215.43\ \mathrm{m}^2$

for medium hole size

$CA_{cmd,2}^{AINL\text{-}INST} = 330.56\ \mathrm{m}^2$

for large hole size

$CA_{cmd,3}^{AINL\text{-}INST} = 478.4\ \mathrm{m}^2$

for rupture hole size

$CA_{cmd,4}^{AINL\text{-}INST} = 1163.8\ \mathrm{m}^2$

Step 8.7 For each release hole size, compute the component damage consequence areas for Auto-Ignition Likely, Continous Release (*AIL-CONT*)

$a = a_{cmd}^{AIL-CONT}$ $\qquad$ $b = b_{cmd}^{AIL-CONT}$

a = 357.0 $\qquad$ *b* = 0.61

Determining Consequence Area for AIL-*CONT*

$$CA_{cmd,n}^{AIL-INST} = a\,(mass)^{b} \,.\, (\frac{1 - factmil}{eneff_n})$$

for small hole size

$CA_{cmd,1}^{AIL-INST}$ = 499.8 m^2

for medium hole size

$CA_{cmd,2}^{AIL-INST}$ = 725.5 m^2

for large hole size

$CA_{cmd,3}^{AIL-INST}$ = 1030.5 m^2

for rupture hole size

$CA_{cmd,4}^{AIL-INST}$ = 2410.3 m^2

Step 9.1

For each release hole size selected in step 2.2, calculate the effective duration of release using equation (3.67)

$$Id_n^{tox} = \min\left(3600, \left\{\frac{mass}{W}\right\}, \{60\,.\,Idmax, n\}\right)$$

For small hole size

$$Id_1^{tox} = \min\left(3600, \left\{\frac{mass_1}{W}\right\}, \{60\,.\,Idmax_{,\,1}\}\right)$$

= 3600

For medium hole size

$$Id_1^{tox} = \min\left(3600, \left\{\frac{mass_1}{W}\right\}, \{60\,.\,Idmax_{,\,1}\}\right)$$

= 1200

For small hole size

$$Id_1^{tox} = \min\left(3600, \left\{\frac{mass_1}{W}\right\}, \{60\,.\,Idmax_{,\,1}\}\right)$$

= 600

Step 9.2

Determine the toxic percentage of the toxic component, *mfractox i* n the release material, if the release fluid is pure fluid, mfactox = 1.0.

H_2S = 1.55%

$mfrac^{tox}$ = 0.0155

Step 9.3

For each release hole size, calculate the release rate, ratentox, and release mass, xmassntox, to be used in toxic consequence analysis.

For H_2S

$$rate_n^{tox} = mfractox\,.\,Wn$$

for Small hole size

$$rate_1^{tox} = mfractox\,.\,W_1$$

= 3E-05 Kg/s

for Medium hole size

$rate_2^{tox} = mfractox\,.W_2$

= 0.0015 Kg/s

for Large hole size

$rate_3^{tox} = mfractox\,.W_3$

= 0.0074 Kg/s

for Rupture hole size

$rate_3^{tox} = mfractox\,.W_3$

= 0.3715 Kg/s

Step 9.4

For each release hole size calculate the toxic consequence area for each of the release hole size

HF Acid and H25 — Calculate Cit7n using Equation (3.63) for a continuous release or Equation (3.64) for an instantaneous release. The constants used in these equations are from Table 4.11.

$$CA_{inj,n}^{tox-INST} = C_8\,.\,10(C.\log_{10}[C_{4B}.\,mass_n^{tox}]$$

for small hole size

$mass_1^{tox} = mfractox\,.mass_1$

= 0.1088

$CA_{inj,n}^{tox-INST} = C_8 \, . \, 10(C. \log_{10}[C_{4B}. mass_n^{tox}]$
= -0.5573

for medium hole size

$mass_2^{tox} = mfractox \, . \, mass_2$

= 1.7416

$CA_{inj,n}^{tox-INST} = C_8 \, . \, 10(C. \log_{10}[C_{4B}. mass_n^{tox}]$
= 0.5252

for large hole size

$mass_2^{tox} = mfractox \, . \, mass_2$

= 4.4507

$CA_{inj,n}^{tox-INST} = C_8 \, . \, 10(C. \log_{10}[C_{4B}. mass_n^{tox}]$
= 0.8914

for Rupture hole size

$mass_2^{tox} = mfractox \, . \, mass_2$

= 31.682

$CA_{inj,n}^{tox-INST} = C_8 \, . \, 10(C. \log_{10}[C_{4B}. mass_n^{tox}]$
= 1.6574

Step 9.5 If there are additional toxic components in the released fluid mixture, STEPs 9.2 through 9.4 should be repeated for each toxic component.

there is no other additional toxic components.

Step 9.6 Determine the final toxic consequence areas for personnel injury in accordance with Equation (3.68)

$$CA_{inj}^{tox} = \left(\frac{\sum_{n=1}^{4} gff_n \, . \, CA_{inj,n}^{tox}}{gff_{total}} \right)$$

CA_{inj}^{tox} = 0.28831 m^2

Step 10 Calculation of Non-Flammable, Non-Toxic Consequence Area

Step 10.1 For each release hole size, calculate the non-flammable, non-toxic consequence area

$$CA_{inj,n}^{CONT} = C_9 \, . raten$$

$$CA_{inj,n}^{INST} = C_{10} \, (massn)^{0.6384}$$

Small hole size

$$CA_{inj,1}^{CONT} = C_9 \, . rate_1$$

= 2E-04

$$CA_{inj,1}^{INST} = C_{10} \, (mass_1)^{0.6384}$$

= 33.8

Medium hole size

$$CA_{inj,1}^{CONT} = C_9 \, . rate_1$$

= 0.012

$$CA_{inj,1}^{INST} = C_{10} \, (mass_1)^{0.6384}$$

= 361.4

Largel hole size

$$CA_{inj,1}^{CONT} = C_9 \, . rate_1$$

= 0.059

$$CA_{inj,1}^{INST} = C_{10} \, (mass_1)^{0.6384}$$

= 361.4

Step 10.2

For each release hole size, calculate the instantaneous/continous blending factor, for steam use equation (3.71)

$$fact_n^{IC} = \min\left[\left\{\frac{Raten}{C5}\right\}, 1.0\right]$$

Small hole size

$$fact_1^{IC} = \min\left[\left\{\frac{Rate_1}{C_5}\right\}, 1.0\right]$$

= 8E-05

Medium hole size

$$fact_1^{IC} = \min\left[\left\{\frac{Rate_1}{C_5}\right\}, 1.0\right]$$

= 0.004

Large hole size

$$fact_1^{IC} = \min\left[\left\{\frac{Rate_1}{C_5}\right\}, 1.0\right]$$

= 0.019

Step 10.3

For each release hole size, calculate the blended non-flammable, non-toxic personnel injury consequence area for steam or acid leaks using equation (3.88) based on the consequence area from Step 10.1 and the blending factor from 10.2.

$$CA_{inj,n}^{leak} = CA_{inj,n}^{INST} \, . fact_n^{IC} + CA_{inj,n}^{CONT} \, (1 - fact_n^{IC})$$

Small hole size

$$CA_{inj,1}^{leak} = CA_{inj,1}^{INST} \, . fact_1^{IC} + CA_{inj,1}^{CONT} \, (1 - fact_1^{IC})$$

= 0.003

Medium hole size

$$CA_{inj,2}^{leak} = CA_{inj,2}^{INST} \, . fact_2^{IC} + CA_{inj,2}^{CONT} \, (1 - fact_2^{IC})$$

= 1.354

Large hole size

$$CA_{inj,1}^{leak} = CA_{inj,1}^{INST} \, . fact_1^{IC} + CA_{inj,1}^{CONT} \, (1 - fact_1^{IC})$$

= 354.5

Step 10.4

Determine the final non-flammable, non-toxic consequence areas for personnel injury using Equation (3.80) based on consequence areas calculated for each release hole size in STEP 10.3.
Note that there is no need to calculate a final non-flammable, non-toxic consequence area for componDetermdamage area for the Level 1 non-flammable releases (steam or acid/caustic).

$$CA_{inj}^{nfnt} = \left(\frac{\sum_{n=1}^{4} gff_n \, . CA_{inj,n}^{nfnt}}{gff_{total}} \right)$$

$CA_{inj}^{nfnt} =$ 24.05822469 m^2

Step 11.1 Calculate the final component damage consequence area, Cacmd

Note that since the component damage consequence areas for toxic releases, CAcmd^{tox}, and non-flammable, non-toxic releases, CAcmd^{nfnt}, are both equal to zero. Then, the final component damage consequence area is equal to the consequence area calculated for flammable releases, CAcmd^{flam}.

$CA_{cmd} = CA_{cmd}^{flam}$ ………………………………………… (equation 47)

= 184.845769 m^2

Step 11.2 Calculate the final personnel injury consequence area, CA_{inj}

$CA_{inj} = \max\left[CA_{inj}^{flam}, CA_{inj}^{tox}, CA_{inj}^{nfnt}\right]$ ………………….. (equation 48)

$CA_{inj} = \max\left[CA_{inj}^{flam}, CA_{inj}^{tox}, CA_{inj}^{nfnt}\right]$

= 167.2848602 m^2

Step 11.3 Calculate the final consequence area, CA, using equation below:

$CA = \max\left[CA_{cmd}, CA_{inj}\right]$

= 184.8 m^2

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BIODATA PENULIS

Penulis lahir di Bandung pada tanggal 26 September 1997 dengan nama Adhitya Wicaksana dan merupakan anak pertama dari dua bersaudara pasangan Billy Komar dan Sandriana Tadjoeddin. Penulis menempuh pendidikan mulai dari SD Taman Kopo Indah III, Kabupaten Bandung (2003-2009), SMPN 1 Margahayu (2010-2012), dan SMAN 1 Margahayu (2013-2015), penulis memutuskan untuk kuliah di luar kota dan diterima di Departemen Teknik Sistem Perkapalan, Fakultas Teknologi Kelautan, Institut Teknologi Sepuluh Nopember melalui jalur SBMPTN. Selama menempuh masa studi peenulis aktif di kepanitiaan UKM Kendo ITS, Sebagai Wakil Ketua Departemen Internal 2016/2017 dan Ketua Departemen Internal 2017, Ketua Forum Daerah Bandung-ITS 2015, Member Marine Operation and Maintenance Laboratory, asisten laboratorium MEAS. Penulis pernah melaksanakan kerja praktek di PT. Dok dan Perkapalan Surabaya, dan PT. Dirgantara Indonesia (Persero)