TUGAS AKHIR – ME184834

ANALISA RISIKO SCRUBBER VESSEL DAN GAS REMOVAL SYSTEM MENGGUNAKAN METODE RISK-BASED INSPECTION PADA WAYANG WINDU GEOTHERMAL POWER UNIT 2

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INSTITUT TEKNOLOGI SEPULUH NOPEMBER
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Surabaya 2019

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BACHELOR THESIS – ME 184834

RISK ANALYSIS OF SCRUBBER VESSEL ANDGAS REMOVAL SYSTEM USING RISK-BASED INSPECTION METHOD IN WAYANG WINDU GEOTHERMAL POWER UNIT 2

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Surabaya 2019

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ANALISA RISIKO SCRUBBER VESSEL DAN GAS REMOVAL SYSTEM MENGGUNAKAN METODE RISK-BASED INSPECTION PADA WAYANG WINDU GEOTHERMAL POWER UNIT 2

TUGAS AKHIR
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Memperoleh Gelar Sarjana Teknik
pada
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ANALISA RISIKO SCRUBBER VESSEL DAN GAS REMOVAL SYSTEM MENGGUNAKAN METODE RISK-BASED INSPECTION PADA WAYANG WINDU GEOTHERMAL POWER UNIT 2

Nama Mahasiswa : Pradnya Sasmitha Andaka
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2. **Ir. Dwi Priyanta, M.SE.**

ABSTRAK

Star Energy Geothermal Wayang Windu Ltd. mengoperasikan 2 unit pembangkit listrik tenaga panas bumi untuk mensuplai listrik di Pulau Jawa, terutama Provinsi Jawa Barat. Pembangkit listrik tenaga geothermal menggunakan fluida geothermal untuk menggerakkan turbin yang terkopel dengan generator. Fluida geothermal pada fasilitas tersebut memiliki komposisi karbon dioksida (CO_2), hidrogen sulfida (H_2S) dan amonia (NH_3) pada pH di bawah 4,5. Dengan komposisi tersebut, ditambah dengan temperatur dan tekanan yang tinggi, membuat fluida bersifat korosif. Karena itu, lokasi-lokasi yang umum terjadi korosi seperti scrubber vessel dan steam ejector pada gas removal system penting untuk diinspeksi secara berkala. Dalam hal itu, perusahaan menjalankan inspeksi dan overhaul komponen setiap 4 tahun sekali. Namun, inspeksi dan overhaul dilakukan tanpa memperhatikan kondisi komponen baik atau tidak. Untuk mengefektifkan kondisi tersebut, perusahaan memulai untuk melakukan inspeksi berdasarkan kondisi dan risiko dari komponen terkait. Metode yang cocok adalah Risk-Based Inspection (RBI), yang dijelaskan secara sistematis pada API RP 581. Risiko komponen dihitung dari probabilitas dan konsekuensi kegagalan komponen. Sedangkan, untuk parameter perencanaan inspeksi ditetapkan oleh perusahaan dengan target damage factor sebesar 100. Damage factor sendiri merupakan fungsi dari probabilitas kegagalan, dimana nilainya relatif terhadap waktu. Hasil analisa dari steam scrubber dan steam ejector pada saat ini menunjukkan bahwa damage factor keduanya sudah melebihi target dan disarankan diinspeksi sesegera mungkin. Apabila inspeksi dilaksanakan secepatnya, maka disarankan diadakan inspeksi selanjutnya untuk keduanya pada 16 Mei 2021.

Kata Kunci: Risk-Based Inspection, Scrubber Vessel, Steam Ejector, Wayang Windu

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RISK ANALYSIS OF SCRUBBER VESSEL AND GAS REMOVAL SYSTEM BY USING RISK-BASED INSPECTION METHOD IN WAYANG WINDU GEOTHERMAL POWER UNIT 2

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ABSTRACT

Star Energy Geothermal Wayang Windu Ltd. operates 2 units of geothermal power plants to supply electricity on Java, especially West Java Province. Geothermal power plants utilize geothermal fluids to drive turbines coupled with generators. The properties of geothermal fluids at the facility are acidity level (pH) below 4.5, consist of but not only carbon dioxide (CO_2), hydrogen sulfide (H_2S), ammonia (NH_3). With those properties, plus operating in high temperatures and pressures environment, make the fluids corrosive. Therefore, common locations for corrosions to occur such as scrubber vessels and steam ejectors in gas removal systems are important to be inspected periodically. In that case, the company carries out inspections and component overhauls every 4 years. However, this inspection and overhaul are carried out regardless of whether the components condition is good or not. To keep improving, company begins to conduct inspections based on the condition and risk of each component. The suitable method is Risk-Based Inspection, which is systematically explained in API RP 581. Risk is calculated from the probability and consequences of component failure. Whereas, for inspection planning parameters set by the company with a target for damage factor of 100. Damage factor itself is a function of the probability of failure , where the value is relative to the time. The results of the analysis of the steam scrubber and steam ejectors at the time of this shows that the damage factor of equipment that is already exceeding targets and suggested inspected as soon as possible. If the inspection is carried out as soon as possible, the two components are advised to be inspected again on May 16, 2021

Keywords: Risk-Based Inspection, Scrubber Vessel, Steam Ejector, Wayang Windu

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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 Scrubber Vessel dan Gas Removal System Menggunakan Metode Risk-Based Inspection pada Wayang Windu Geothermal Power Unit 2” 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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2. Ayah, ibu, serta keluarga besar penulis yang selalu memberikan semangat dan doa setiap hari,
3. Bapak Dr. Eng. Muhammad Badrus Zaman, S.T, M.T. selaku Kepala Departemen Teknik Sistem Perkapalan FTK–ITS,
4. Bapak Ir. Dwi Priyanta, M.SE., dan Bapak Nurhadi Siswantoro, S.T, M.T. selaku dosen pembimbing tugas akhir penulis,
5. Ibu Sandri, Bapak Wilis Wirawan, Bapak Joni Hendra Tarigan, beserta para karyawan Star Energy Geothermal Wayang Windu, Ltd. lainnya yang telah memberikan penulis kesempatan untuk mengambil data serta berdiskusi mengenai tugas akhir yang penulis,
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10. Keluarga Kopi Ganes yang memberikan ruang bagi penulis untuk rehat dari penatnya keseharian serta
11. Pihak- pihak lainnya yang berperan dalam penyelesaian tugas akhir ini.

Penulis menyadari bahwa banyaknya 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.

Surabaya, Agustus 2019

Penulis

DAFTAR ISI

DAFTAR GAMBAR

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DAFTAR TABEL

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BAB I
PENDAHULUAN

1.1 Latar Belakang

Untuk memenuhi kebutuhan pasokan listrik di Pulau Jawa, khususnya Provinsi Jawa Barat. Star Energy Geothermal Wayang Windu Limited (SEGWWL) mengoperasikan 2 pembangkit listrik geothermal, dimana pembangkit unit 1 menghasilkan 110 MW dan unit 2 menghasilkan 117 MW. Pembangkit ini terletak di selatan kota Bandung sejauh 40 km pada ketinggian 1700m diatas permukaan laut[1]. Pengelolaan operasi di lokasi tersebut berdasarkan kontrak kerja sama operasi dengan Pertamina untuk mengembangkan sumber daya panas bumi dan Perusahaan Listrik Negara untuk penjualan listrik.

Pembangkit listrik geothermal/tenaga panas bumi adalah pembangkit yang menggunakan uap panas kering untuk menghasilkan energi listrik. Uap panas tersebut dihasilkan dari fluida geothermal yang diekstrak dari dalam tanah. Fluida yang masuk ke pembangkit kemudian dipisahkan antara uap dan cairan. Uap panas selanjutnya dibersihkan dari kontaminan dan digunakan untuk menggerakkan turbin yang terkopel dengan generator. Putaran turbin ini yang kemudian menghasilkan energi listrik. Cairan (brine) yang tidak terpakai kemudian dikembalikan lagi ke dalam tanah.

Fluida geothermal memiliki karakteristiknya tersendiri di tiap area (area dapat berarti blok, provinsi, ataupun negara). Namun, fluida geothermal memiliki kesamaan komposisi utama ion hidrogen (H), karbon dioksida (CO_2), hidrogen sulfida (H_2S), amonia (NH_3), ion klorida (Cl), dan sulfat (SO_4)[2]. Memperhatikan dari komposisi utamanya ditambah dengan temperatur yang tinggi dan tekanannya, hal itu yang membuat fluida geothermal bersifat korosif. Ini merupakan hal yang perlu diperhatikan, mengingat komponen pembangkit listrik geothermal adalah komponen material logam.

Pada prosesnya, uap geothermal akan dipisahkan dengan cairan geothermal (brine). Uap lalu menuju scrubber untuk mengurangi kelembaban, dan menuju inlet turbin. Uap korosif geothermal bertemperatur tinggi akan berulang kali melewati jalur tersebut yang mengakibatkan menurunnya performa dan meningkatkan risiko korosi. Tidak hanya di lokasi tersebut, gas removal system juga tak luput dari risiko korosi, mengingat terdapat campuran udara, gas, dan uap di sistem pipa tersebut. Korosi dapat berujung pada kebocoran gas geothermal, yang berbahaya bagi lingkungan terlebih lagi kesehatan manusia.

Untuk menghindari korosi dan hambatan lain seperti scaling pada komponen yang mengalirkan fluida geothermal, SEGWWL mengadakan inspeksi dengan interval 4 tahun sekali. Meskipun tidak ada peraturan pemerintah yang mengatur inspeksi berkala perkara pembangkit listrik geothermal, interval waktu tersebut

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[1] Star Energy. 2012. *Wayang Windu Geothermal Energy Overview*. Diakses 5 Februari 2018, https://www.starenergy.co.id/wayang-windu/

[2] Nogara, James., Zarrouk, Sadiq J. 2017. *Corrosion in geothermal environment: Part 1: Fluids and their impact.* Copyright by Elsevier Ltd.

ditentukan dari rekomendasi pihak produsen komponen. SEGWWL telah menerapkan program inspeksi berbasis pipe, vessel, dan pipeline selama setidaknya 10 tahun sebelum tahun 2014. Namun, program inspeksi tersebut kurang efektif karena inspeksi peralatan kritis dan kurang kritis memiliki metode dan interval yang sama[3]. Ditambah, inspeksi dalam interval 4 tahun tersebut juga ikut meng-overhaul komponen-komponen yang masih dalam keadaan baik.

Untuk memperbaiki kondisi tersebut, SEGWWL berusaha untuk terus meningkatkan integritasnya dengan merencanakan inspeksi berdasarkan tingkat kekritisan komponen serta lifetime dari komponen tersebut. Metode yang dinilai cocok adalah Risk-Based Inspection (RBI). Metode RBI adalah metode yang mengacu pada kegagalan komponen. Pada metode ini, tingkat kekritisan suatu komponen ditentukan dengan memperhatikan probabilitas kegagalan dan dampak dari kegagalan komponen tersebut. Tingkatan risiko dari setiap equipment di prioritaskan secara sistematis, karena itu, equipment yang memiliki tingkat risiko yang tinggi dapat di prioritaskan[4]. Pendekatan nilainya pun dilakukan berdasarkan kondisi nyata dan terkini dari material komponen, sehingga dapat memberikan basis yang rasional dan menyeluruh. Melihat potensi tersebut saya menawarkan diri untuk melakukan penelitian tersebut sebagai bahan pertimbangan untuk peningkatkan integritas SEGWWL.

1.2 Rumusan Masalah

Rumusan masalah yang akan dianalisa dalam tugas akhir ini adalah:

1. Bagaimana cara menghitung Probability of Failure (PoF) dan Consequence of Failure (CoF) dari Scrubber Vessel dan komponen Gas Removal System di fasilitas SEGWWL unit 2 menggunakan Risk-Based Inspection (RBI)?
2. Bagaimana menganalisa risiko dari Scrubber Vessel dan komponen Gas Removal System SEGWWL unit 2 tersebut menggunakan RBI?
3. Bagaimana menentukan perencanaan inspeksi yang tepat dari Scrubber Vessel dan komponen Gas Removal System SEGWWL unit 2 menggunakan RBI?

1.3 Batasan Masalah

Penelitian ini dilakukan di SEGWWL unit 2 dengan batasan komponen:

Tabel 1.1 Komponen penelitian

System
Scrubber Vessel VS-81-009 unit 2
Gas Removal System, Ejector EJ 202

Perlu diperhatikan bahwa penelitian pada kedua komponen ini tidak menyertakan analisa segi ekonomis.

[3] Star Energy Geothermal Wayang Windu Ltd. 2014. *Risk Based Inspection Report.*
[4] 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

1.4 Tujuan Penelitian

Berdasarkan masalah yang sudah ditentukan, maka tujuan dari penelitian ini:

1. Menghitung Probability of Failure (PoF) dan Consequence of Failure (Cof) dari Scrubber Vessel dan komponen Gas Removal System di fasilitas SEGWWL unit 2 menggunakan RBI.
2. Menganalisa risiko dari Scrubber Vessel (VS-81-009) dan komponen Gas Removal System (Steam Ejector EJ-202) SEGWWL unit 2.
3. Merancang perancanaan inspeksi dari Scrubber Vessel dan komponen Gas Removal System (Steam Ejector EJ-202) SEGWWL unit 2.

1.5 Manfaat

Manfaat yang dapat diperoleh dari penelitian ini adalah:

- Meningkatkan kemampuan mahasiswa dalam memahami dan merancang inspeksi berdasarkan metode Risk-Based Inspection.
- Mahasiswa dapat menjalin relasi profesional dengan Star Energy Geothermal Wayang Windu Ltd.
- Sebagai bahan referensi untuk jadwal inspeksi terhadap sistem dan peratalan terkait di fasilitas pembangkit listrik geothermal wayang windu unit 2.
- Sebagai bahan referensi untuk peningkatan mutu kerja, dan penghematan biaya pemeliharaan aset Star Energy Geothermal Wayang Windu Ltd.

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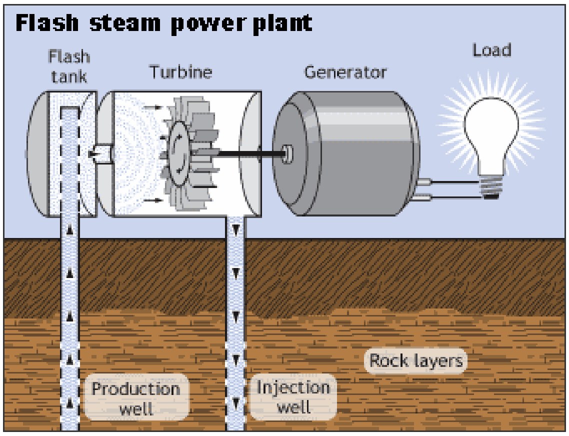
BAB II
STUDI LITERATUR

2.1 Pembangkit Listrik Tenaga Panas Bumi

Pembangkit listrik tenaga panas bumi atau juga dikenal dengan pembangkit listrik tenaga geothermal adalah pembangkit listrik yang menggunakan fluida geothermal untuk menghasilkan energi listrik. Fluida geothermal yang diekstrak, kemudian dipisahkan antara uap dan cairan. Cairan (brine) yang terpisahkan akan diarahkan kembali ke tanah agar dapat menaikkan temperaturnya kembali. Uap panas yang diambil kemudian dibersihkan dan digunakan untuk menggerakkan turbin. Gerakan turbin inilah yang menghasilkan energi listrik. Dilihat dari cara mengambil dan menggunakan uap geothermal, pembangkit listrik tenaga geothermal dapat dibagi menjadi 3 jenis. Yaitu flash steam power plant, dry steam power plant, dan binary steam power plant.

2.1.1. Flash steam power plant

Flash steam power plant adalah pembangkit listrik geothermal yang digunakan ketika sumur geothermal menghasilkan campuran dari uap dan cairan (brine) geothermal. Uap kemudian dipisahkan dan dijernihkan sehingga menghasilkan uap panas kering yang digunakan untuk menggerakkan turbin. Brine yang terpisah dan kondensat dari uap selama proses akan dikembalikan ke sumur.



Gambar 2.1 Flash steam power plant[5]

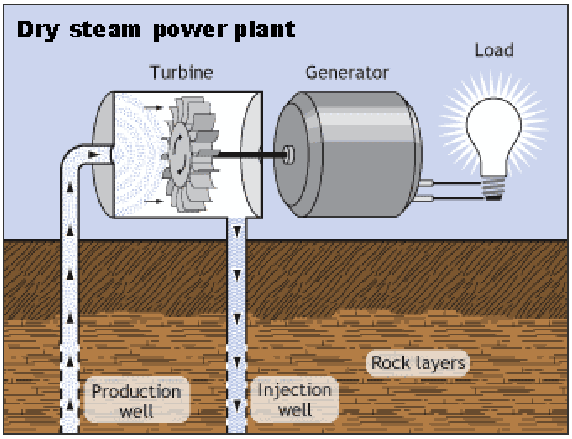
Gambar 2.1 menunjukkan ilustrasi sederhana dari flash steam power plant. Fluida geothermal diekstrak dari production well, dan dipisahkan antara uap panas dan brine. Uap panas kemudian digunakan untuk menggerakkan turbin

[5] U.S. Department of Energy. *Electricity Generation*. Diakses 5 Februari 2018, https://www.energy.gov/eere/geothermal/electricity-generation

yang terhubung dengan generator. Uap yang telah terpakai kemudian dikondensasikan dan dialirkan ke injection well.

2.1.2. Dry steam power plant

Dry steam power plant adalah pembangkit listrik geothermal menggunakan uap panas geothermal langsung dari production well. Umumnya pembangkit listrik geothermal tipe flash, dikonversi menjadi tipe dry saat production well mulai mengering. Penelitian yang dilakukan oleh Cesar R. Chamorro, et al menunjukkan bahwa pembangkit listrik geothermal tipe dry adalah yang paling efisien dari tipe-tipe lainnya[6].



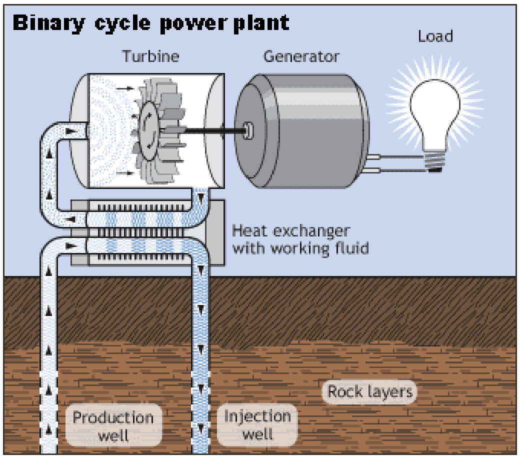
Gambar 2.2 Dry steam power plant[5]

Gambar 2.2 menunjukkan ilustrasi sederhana dari dry steam power plant. Turbin yang terkopel dengan generator digerakkan dengan uap panas yang diambil langsung dari production well.

2.1.3. Binary steam power plant

Tipe binary sedikit berbeda dari tipe flash dan tipe dry karena fluida geothermal dari production well tidak digunakan untuk menggerakkan turbin yang terkopel dengan generator. Binary steam power plant menggunakan energi panas dari fluida geothermal yang diekstrak dari production well untuk memanaskan fluida cairan lain agar menjadi uap panas. Uap panas tersebut kemudian digunakan untuk menggerakkan turbin. Terhindarnya kontak langsung antara fluida geothermal dengan pipa-pipa pembangkit listrik dapat mencegah korosi ataupun pengendapan mineral di dinding-dinding dalam pipa. Itu adalah salah satu keunggulan dari binary steam power plant.

[6] Chamorro, Cesar R., et al. 2011. *World geothermal power production status: Energy, environmental and economic study of high enthalpy technologies*.



Gambar 2.3 Binary cycle power plant[5]

Gambar 2.3 menunjukkan ilustrasi sederhana dari binary cycle power plant. Fluida geothermal mengalir melalui heat exchanger untuk memanaskan cairan kerja agar menjadi uap panas dan menggerakkan turbin.

2.2 Star Energy Geothermal Wayang Windu Ltd.

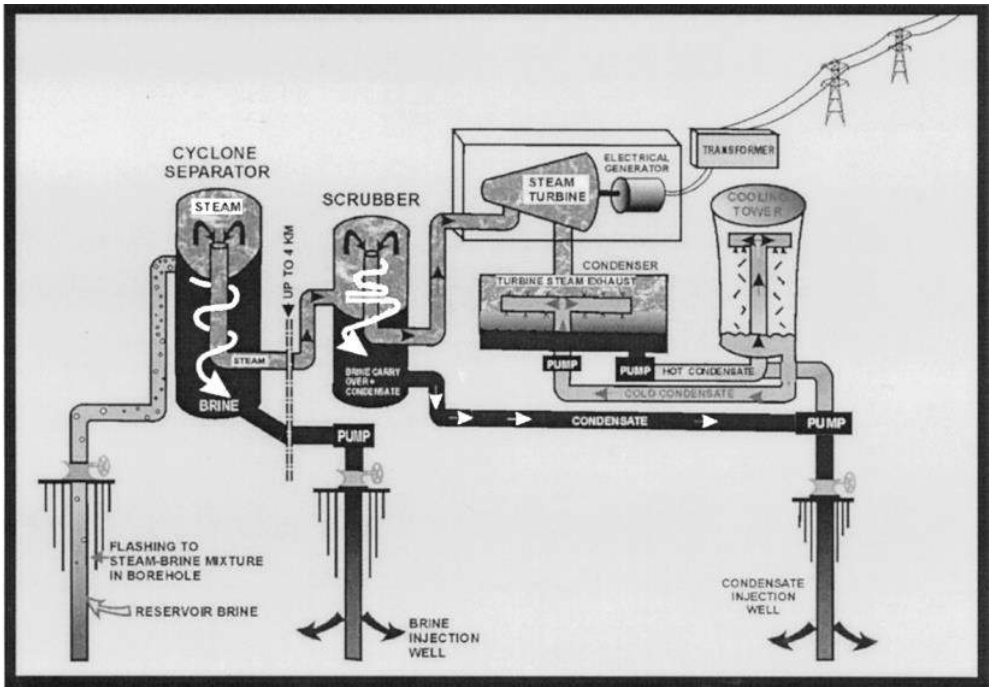
Star Energy Geothermal Wayang Windu Limited (SEGWWL) mengoperasikan 2 pembangkit listrik geothermal, dimana pembangkit unit 1 menghasilkan 110 MW dan unit 2 menghasilkan 117 MW. Pembangkit ini terletak di selatan kota Bandung sejauh 40 km pada ketinggian 1700m diatas permukaan laut[1] . Pengelolaan operasi di lokasi tersebut berdasarkan kontrak kerja sama operasi dengan Pertamina untuk mengembangkan sumber daya panas bumi pada lahan seluas 12960 hektar, dan Perusahaan Listrik Negara untuk penjualan listrik. Berikut adalah foto dari fasilitas geothermal Wayang Windu, ditunjukkan oleh gambar 2.4.

Gambar 2.4 Foto dari Star Energy Geothermal Wayang Windu[1]

Gambar 2.4 menunjukkan kondisi fasilitas pada usianya yang di bawah 5 tahun. Pembangunan fasilitas pembangkit listrik wayang windu dimulai pada tahun

1997. Awalnya pembangunan bertujuan untuk membangun 2 unit yang identik (unit 1 dan unit 2) dengan kapasitas masing-masing 110 MW. Namun karena krisis ekonomi Indonesia yang berlangsung pada waktu yang sama, perkembangan konstruksi unit 2 terhambat dan ditunda. Pada dekade berikutnya, tepatnya pada tahun 2007 pembangunan unit 2 kembali dilanjutkan. Pada proyek ini, perusahaan merencanakan peningkatan desain berdasarkan data dan pengalaman dari pengoperasian dan pemeliharaan pembangkit-pembangkitnya. Pembangunannya pun selesai pada Februari 2009, 2 minggu lebih awal dari rencana pembangunannya. Unit 2 pun segera dan diresmikan oleh menteri energi dan sumber daya pada 2 Maret 2009. Peruntukmanya pun lebih baik dari unit 1 karena unit 2 dapat menghasilkan 117 MW energi listrik[7].

Fasilitas pembangkit listrik geothermal wayang windu unit 2 adalah pembangkit tipe flash. Ilustrasi sederhana dari sistem pembangkit wayang windu unit 2 ditunjukkan pada gambar 2.5 berikut.



Gambar 2.5 Ilustrasi diagram fasilitas wayang windu unit 2[8]

Fluida geothermal didapatkan dari reservoir brine di dalam tanah. Fluida geothermal bertemperatur tinggi dan bertekanan tersebut kemudian dipisahkan oleh separator. Cairan geothermal (brine) yang terpisah kemudian dipompa menuju brine injection well. Sedangkan uap geothermal yang terpisah kemudian dialirkan menuju scrubber

[7] Yamaguchi, Naoko. 2010. *Design of Wayang Windu Unit 2 Geothermal Power Station*. World Geothermal Congress 2010, Bali.
[8] Willaimson, Kenneth H., et al. 2001. *Geothermal Power Technology*. Copyright by IEEE

untuk mengurangi kelembabannya, dan menghasilkan uap panas kering[9]. Uap panas kering dan kondensat *carry-over brine* pun terpisah. Kondensat *carry-over brine* kemudian dialirkan menuju condensate injection well. Uap panas kering yang terpisah tersebut mengalir menuju inlet turbin dan menggerakkan turbin. Setelah melewati turbin, uap panas menjadi jenuh dan dialirkan menuju condenser untuk dikondensasikan. Kondensat panas kemudian dialirkan menuju cooling tower untuk didinginkan, dan dialirkan kembali menuju condenser sebagai media pendinginan. Namun tidak semua kondensat panas dialirkan menuju cooling tower, sebagian langsung dialirkan menuju condensat injection well.

2.3 Scrubber Vessel dan Gas Removal System

Scrubber vessel adalah bejana tekan (pressure vessel) yang secara umum berfungsi untuk membersihkan gas dari adanya cairan sehingga didapatkan pure gas. Scrubber vessel biasanya dipasang setelah separator, dan hasil keluaran scrubber vessel dialirkan menuju bagian produksi[10]. Namun, fungsi scrubber pada pembangkit listrik tenaga panas bumi tidak hanya itu, tetapi juga membersihkan uap panas kering dari mineral-mineral terlarut. Terdapat bagian dari scrubber vessel yang umum mengalami korosi, yaitu[2]:

- Di pipa uap, dimana kontaminasi awal atau kontak awal pipa dengan *carry-over brine*. Secara perlahan melarutkan material oleh uap kondensat karena korosi.
- Di inlet turbin, dimana terdapat uap kering dengan temperatur yang tinggi.

Di poin-poin tersebutlah, lokasi pada scrubber yang umum mengalami korosi.

Selain dari scrubber vessel, terdapat pula bagian dari fasilitas geothermal yang umum mengalami korosi. Bagian tersebut adalah pada gas removal system dimana terdapat campuran dari udara, gas, air, dan uap[2]. Gas removal system memiliki fungsi sebagai jalur pelepasan gas ke atmosfir. Pada fasilitas Wayang Windu Unit 2, uap panas hasil scrubber yang berlebih, serta uap basah (telah melewati turbin) yang tidak berhasil dikondensasikan akan melewati gas removal system untuk dikondensasikan ulang. Hasil kondensat akan dialirkan ke condensate injection well, sedangkan uap/gas yang tidak terkondensat akan dilepas ke atmosfir.

2.4 Peraturan Pemerintah Indonesia Tentang Panas Bumi

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[11]:

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[9] Murakami, Hiroshi., et al. 2000. *Construction of The Largest Geothermal Power Plant untuk Wayang Windu Project, Indonesia*. World Geothermal Congress 2000, Kyushu – Tohoku.
[10] Nugraha, Adi. 2016. *Studi Aplikasi Risk-Based Inspection (RBI) menggunakan API 581 pada fuel gas scrubber*. Institut Teknologi Sepuluh Nopember, Surabaya.
[11] Undang-Undang Republik Indonesia Nomor 21 Tahun 2014 Tentang Panas Bumi

- 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[3]. Pertimbangan ini pun sesuai dengan Undang-Undang Nomor 1 Tahun 1970 Tentang Keselamatan kerja, Bab III Syarat-syarat keselamatan kerja, Pasal 3 yaitu[12]:

- 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.

2.5 Risk-Based Inspection (RBI)

Risk-Based Inspection (RBI) adalah metode inspeksi yang berfokus pada risiko kegagalan alat atau komponen. Metode ini merupakan metode yang komprehensif dan fleksibel, karena perencanaan inspeksi dan tindakan mitigasi lainnya mempertimbangkan risiko kegagalan dari masing-masing komponen. Risiko kegagalan didapatkan dari Probability of Failure (PoF) dan Consequence of Failure (CoF).

Tingkatan risiko dari komponen diproritaskan secara sistematis sehingga inspeksi dapat difokuskan pada komponen berisiko tinggi. Apabila risiko kegagalan dari salah satu komponen yang diinspeksi rendah, maka dapat disesuaikan dan menghemat biaya. Inilah yang menyebabkan RBI digunakan secara luas di dunia. Proses pengerjaan RBI secara garis besar divisualisasikan pada gambar 2.6 berikut.

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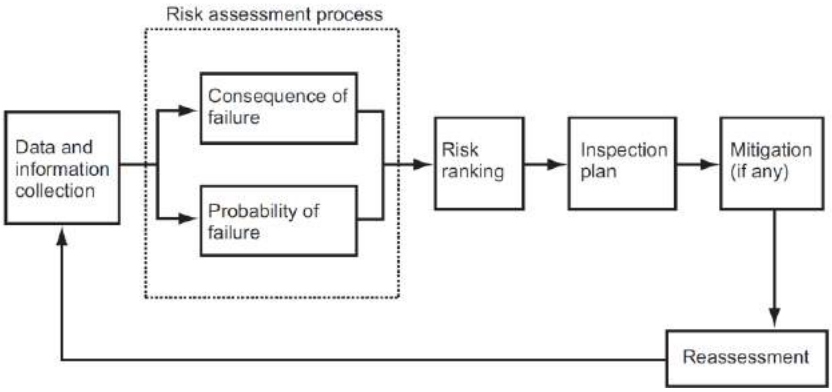
[12] Undang-Undang Republik Indonesia Nomor 1 Tahun 1970 Tentang Keselamatan Kerja



Gambar 2.6 Risk based inspection planning method[13]

Gambar 2.6 menjelaskan mengenai proses perencanan dari RBI. Diawali dari mengumpulkan data mengenai komponen yang diinspeksi, seperti karakteristik materi yang digunakan, sejarah kegagalan, kondisi terkini, dan data lainnya. Kemudian dilakukan perhitungan terhadap probabilitas kegagalan dan dampak dari kegagalan tersebut. Kedua hal itu dapat menentukan tingkatan risiko dari masing-masing komponen. Setelah mengetahui risiko tersebut, kemudian perencanaan inspeksi dan tindakan mitigasi (jika ada) dapat ditentukan.

2.5.1. Kelebihan dari RBI

Hasil utama dari penerapan metode RBI adalah rencana yang membahas pengelolaan risiko pada tingkat equipment. Rencana tersebut memperhatikan risiko dari segi kesalamatan/kesehatan/lingkungan dan/atau dari segi ekonomi[13]. Penerapan rencana tersebut dapat menghasilkan:

- Penurunan risiko dari fasilitas atau equipment yang diteliti.
- Peningkatan tingkat keselamatan, karena tetap mengikuti pada standar/kode internasional.
- Dapat menentukan equipment yang tidak memerlukan inspeksi ataupun tindakan mitigasi lainnya.
- Menghasilkan rencana inspeksi sesuai dengan risiko dari komponen tertentu yang efektif dari segi biaya.

2.5.2. Batasan dari RBI

Meskipun memiliki kelebihan yang menonjol, penerapan metode RBI tidak akan efektif apabila terdapat kekurangan seperti[13]:

- Data yang tidak akurat atau tidak lengkap
- Desain yang tidak memadai atau kesalahan pada pemasangan equipment.
- Pelaksanaan rencana yang tidak efektif.
- Tim atau personil yang kurang kompeten.

[13] API RP 580. 2009. *Risk-Based Inspection Technology*, *2nd edition*. Washington, D.C: API Publishing Services

Perlu diperhatikan bahwa RBI tidak dapat menghilangkan risiko. Namun penerapan RBI dapat mengatur risiko pada tingkat yang dapat diterima, tentunya dengan memprioritaskan komponen yang memiliki risiko lebih tinggi.

2.5.3. Hasil dari RBI

Hasil dari penerapan metode RBI adalah rencana inspeksi dari tiap komponen pada sistem/komponen yang dianalisa, dimana menjelaskan:

- Metode inspeksi yang dapat digunakan
- Interval waktu hingga inspeksi berikutnya
- Tindakan mitigasi lainnya seperti penggantian komponen, upgrade komponen, penggantian inhibitor korosi, dan tindakan lainnya sesuai dengan kondisi komponen.
- Penurunan risiko dari sebelum dan sesudah dilakukannya inspeksi atau mitigasi (jika ada).

2.6 Standar dan Reccomended Practices (RP)

Metode RBI dari definisi hingga perhitungannya dijelaskan secara rinci pada API RP 580 dan 581. Namun, kedua hal tersebut hanya diperuntukkan untuk hydrocarbon dan petrochemical, sehingga perlu penyesuaian standar untuk fluida geothermal atau sistem uap. Dalam kasus tersebut, dinilai cocok untuk menggunakan standar dan RP:

2.6.1. API RP 580 Risk-Based Inspection.

Reccomended Practices ini mengandung program persyaratan minimum untuk memenuhi syarat penetapkan interval inspeksi berdasarkan analisis Risk-Based Inspection (RBI) versus aturan, dan memberikan pedoman tambahan yang disarankan pada analisis risiko untuk mengembangkan rencana inspeksi yang efektif. Penggunaan metodologi berbasis risiko untuk perencanaan inspeksi tidak wajib; mereka opsional, mengikuti persyaratan dan batasan kode inspeksi lainnya[14].

Isu-isu pedoman RBI yang dibahas mencakup pengenalan konsep dan prinsip RBI untuk manajemen risiko, dan bagian-bagian detail yang menerangkan langkah-langkah dalam menerapkan prinsip-prinsip ini dalam kerangka proses RBI, termasuk:

- Memahami desain;
- Merencanakan penilaian RBI;
- Pengumpulan data dan informasi;
- Mengidentifikasi mekanisme kerusakan dan mode kegagalan;
- Menilai probabilitas kegagalan (POF);
- Menilai konsekuensi dari kegagalan (COF);
- Penentuan risiko, penilaian, dan manajemen;
- Manajemen risiko dengan kegiatan inspeksi dan pengendalian proses;
- Kegiatan mitigasi risiko lainnya;

- Peran, tanggung jawab, pelatihan, dan kualifikasi;
- Dokumentasi dan pencatatan.

2.6.2. API RP 581 Risk-Based Inspection Technology.

Metodologi RBI menyediakan prosedur kuantitatif untuk menetapkan program inspeksi menggunakan metode berbasis risiko untuk peralatan bertekanan tetap termasuk bejana tekan, perpipaan, tangki, alat pelepas tekanan (PRD), dan bundel heat exchanger. Perhitungan risiko dalam API 581 melibatkan penentuan Probability of Failure (POF) dan Consequence of Failure (COF). Kegagalan didefinisikan sebagai kehilangan kontainmen dari batas tekanan yang mengakibatkan kebocoran ke lingkungan di atmosfer komponen bertekanan. API 581 ini berisi metodologi untuk menghitung POF dan COF untuk dapat menentukan analisis risiko dan program perencanaan inspeksi untuk peralatan tertentu.[14]

2.7 Probability of Failure (PoF)

Dalam RBI probabilitas sebuah kegagalan dapat di rumuskan sebagai:

$$P_f\ (t) = gff.D_f\ (t).F_{MS} \quad \text{...(2.1)}$$

Dimana $P_f\ (t)$ adalah probabilitas kegagalan yang ditentukan oleh *gff* (generic failure frequency), $D_f\ (t)$ sebagai faktor kerusakan, dan faktor management sistem F_{MS}.

2.7.1. Generic Failure Frequency

Generic failure frequency merupakan sebuah nilai representatif dari data refining dan kegagalan dari tipe tipe komponen yang berbeda. GFF di gunakan sebagai frekuensi kegagalan sebelum terjadinya kerusakan yang di akibatkan oleh lingkungkan terhadap operasi sebuah komponen.

2.7.2. Management System Factor

Managenement system factor merupakan faktor dari pengaruh manajemen sistem terhadap integritas mekanik dari komponen. Faktor ini dipengaruhi probabilitas kerusakan yang terakumulasi pada waktu lama dan proporsional terhadap kualitas dari integritas program mekanik sebuah fasilitas.

$$FMS = 10^{(-0.02.pscore+1)} \text{.. (2.2)}$$

Dimana pscore adalah skor dari manajemen perusahaan.

2.7.3. Damage Mechanism

Merupakan faktor yang ditentukan dari detoriorasi (korosi, retak, dll.) yang proposional terhadap pemeliharaan. Pada API RP 581, terdapat 21 jenis damage factor:

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[14] API RP 581. 2016. *Risk-Based Inspection Technology, 3rd edition*. Washington, D.C: API Publishing Services

- Thinning Damage Factor
- Component Lining Damage Factor
- SCC Damage Factor – Caustic Cracking
- SCC Damage Factor – Amine Cracking
- SCC Damage Factor – Sulfide Stress Cracking
- SCC Damage Factor – HIC / SOHIC – H2S
- SCC Damage Factor – Alkaline Carbonate Cracking
- SCC Damage Factor – PTA Cracking
- SCC Damage Factor – CLSCC
- SCC Damage Factor – HSC-HF
- SCC Damage Factor – HIC / SOHIC – HF
- External Corrosion Damage Factor – Ferritic Component
- External CLSCC Damage Factor Austenitic Component
- CUI Damage Factor – Ferritic Component
- External CUI CLSCC Damage Factor – Austenitic Component
- HTHA Damage Factor
- Brittle Damage Factor
- Temper Embrittlement Damage Factor
- Embrittlement Damage Factor
- Sigma Phase Embrittlement Damage Factor
- Piping Mechanical Fatigue Damage Factor.[14]

Kedua puluh satu damage factor tersebut memiliki kriterianya masing-masing. Untuk mengawali perhitungan probability of failure pada komponen tertentu, dilakukan penyaringan damage factor agar dapat mengetahui kerusakan jenis apa saja yang terjadi di komponen tersebut. Penyaringan tersebut dapat dilakukan melalui data komponen serta pengamatan di lokasi.

Damage factor ditentukan dengan melakukan tabel screening dari API RP 581, sesuai dengan kondisi equipment terkait. Tabel 2.1 berikut adalah Screening criteria dari beberapa damage factor. Selanjutnya akan membahas mekanisme dan langkah perhitungannya.

Tabel 2.1 Damage factor screening criteria

No	Damage Factor	Screening Criteria	Yes/No
1.	Thining	All component should be checked for thining	Yes
2.	Component Lining	If the component has organic or inorganic lining, then the component should be evaluated for lining damage	No
3.	SCC Damage Factor-Caustic Cracking	If the component's material of construction is carbon or low alloy steel and the process environment contains caustic in any concentration, then the component should be evaluated for susceptibility to caustic cracking.	No

Table 2.1 – Lanjutan. Damage factor screening criteria

No	Damage Factor	Screening Criteria	Yes/No
4.	SCC Damage Factor-Amine Cracking	If the component's material of construction is carbon or low alloy steel and process environment contains acid gas treating amines (MEA, DEA, DIPA, MDEA, etc.) in any concentration, then the component should be evaluated for susceptibility to amine cracking.	No
5.	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 H_2S in any concentration, then the component should be evaluated to Sulfide Ctress Cracking (SCC).	Yes
6.	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 H_2S in any concentration, then the component should be evaluated to HIC/SOHIC-H_2S cracking.	Yes

2.7.3.1. Thinning Damage

Thinning – merupakan degradasi logam karena lingkungannya yang mengakibatkan penipisan ketebalan logam tersebut, dengan kata lain korosi. Ada beberapa mekanisme thinning yang dapat terjadi, dan masing-masing terjadi pada kondisi yang berbeda. Memahami mekanisme thinning yang terjadi sangatlah penting untuk mengetahui apakah thining terjadi secara local atau general, dan penentuan tindakan mitigasi kedepannya. Berikut adalah mekanisme thinning yang dapat terjadi sesuai dengan API RP 581 3rd Edition Part 2 – Annex 2.B.

- Korosi asam klorida (HCl)
  Mekanisme korosi thinning ini terjadi apabila pada proses terdapat HCl, air dan tingkat keasaman (pH) di bawah 7.0.
- Korosi asam sulfida/naftenat temperatur tinggi
  Mekanisme korosi thinning ini terjadi apabila pada prosesnya terdapat minyak dengan senyawa sulphur, dan beroperasi di atas 204^{o}C (400^{o}F).
- Korosi H_2S/H_2 termperatur tinggi
  Dapat terjadi apabila pada prosesnya terdapat H_2S dan hydrogen, serta beroperasi di atas 204^{o}C (400^{o}F).
- Korosi asam sulphur (H_2SO_4)
  Dapat terjadi apabila pada prosesnya terdapat H_2SO_4.
- Korosi asam hidroflourik (HF)
  Dapat terjadi apabila pada prosesnya terdapat HF.

- Korosi sour water
  Korosi sour water harus diperhitungkan apabila terdapat H_2S.
- Korosi amina
  Mekanisme thinning ini dapat terjadi apabila equipment terpapar gas amina untuk pengolah gas.
- Oksidasi temperatur tinggi
  Mekanisme ini dapat terjadi apabila terdapat oksigen dan beroperasi setidaknya 482^oC (900^oF).
- Korosi acid sour water
  Dapat terjadi apabila pada prosesnya mengandung klorida di bawah 50 ppm, H_2S, dan pH di bawah 7.0
- Cairan pendingin
  Jika equipment terintegrasi dengan cairan pendingin maka, korosi tipe ini harus diperhitungkan.
- Korosi tanah
  Mekanisme thinning ini dapat terjadi apabila equipment kontak dengan tanah (terkubur atau terkubur sebagian) dan materi equipment adalah carbon steel.
- Korosi karbon dioksida (CO_2)
  Korosi karena karbon dioksida dapat terjadi apabila materi equipment adalah carbon steel dengan kadar Cr <13%, dan terdapat air dengan H_2S.
- AST Bottom
  Mekanisme ini perlu diperhitungkan apabila bottom equipment berbentuk AST tank.

Masing-masing dari mekanisme thinning tersebut haruslah dicocokkan dengan kondisi equipment, agar mengetahui mekanisme thinning apa saja yang terjadi. Sedangkan perhitungan thinning, dijelaskan pada langkah-langkah berikut.

Langkah 1. Tentukan furnished thickness, t, dan usia komponen dari waktu instalasi.

Langkah 2. Tentukan corrosion rate untuk base material, Cr_{bm}, berdasarkan material konstruksi dan lingkungannya, serta cladding/overlay corrosion rate, Cr_{cm}.

Untuk menentukan corrosion rate di thinning damage factor, kita harus mempertimbangkan beberapa skenarion berdasarkan data yang tersedia dan kondisi dari equipment itu sendiri, seperti:

- Perhitungan corrosion rate berdasarkan RLA dari perusahaan
- Perhitungan corrosion rate berdasarkan API RP 581 Annex 2B. Corrosion rate ini merupakan gabungan corrosion rate dari mekanisme-mekanisme thinning yang terjadi pada komponen.

Langkah 3. Menentukan waktu operasi, age_{tk}, sejak inspeksi terakhir, t_{rdi}.

Langkah 4. Untuk cladding/weld overlay pressure vessel components, hitung usia untuk habisnya ketebalan di inspeksi terakhir (langkah 3) karena korosi, age_{rc}:

$$age_{rc} = \max\left[\left(\frac{t_{rdi} - tbm}{C_{r\,cm}}\right), 0.0\right] \quad (2.3)$$

Langkah 5. Determine the minimum thickness of the component's wall, t_{min}. Minimum thickness didapatkan dari designed pressure equipment, *allowable stress*, diameter dalam, *corrosion allowance dan joint efficiency*.[15]

Langkah 6. Tentukan parameter A_{rt} (age relating thickness).
Untuk komponen tanpa cladding/weld overlay menggunakan persamaan:

$$A_{rt} = \frac{Cr_{b,m} \cdot age_{tk}}{t_{rdi}} \quad (2.4)$$

Langkah 7. Hitung nilai flowstress, FS^{thin}.

$$FS^{Thin} = \frac{(YS+TS)}{2} \cdot E.1,1 \quad (2.5)$$

Langkah 8. Hitung parameter strength ratio, SR^{thin}.

$$SR_P^{Thin} = \frac{S.E}{FS^{Thin}} \cdot \frac{Max\,(t_{min}, t_c)}{FS^{Thin}} \quad (2.6)$$

Langkah 9. Tentukan jumlah dari inspeksi serta efektifitas dari inspeksi tersebut.
N_A^{Thin}, N_B^{Thin}, N_C^{Thin}, N_D^{Thin} didapat dari perusahaan dapat didefinisikan dari tabel berikut.

Tabel 2.2 Lingkup dari inspection effectiveness

Inspection effectiveness category	Ispection effectiveness description	Description
A	Highly effective	The inspection methods will correctly identify the true damage state in nearly every case (or 80-100% confidence)
B	Usually effective	The inspection methods will correctly identify the true damage state most of the time case (or 60-80% confidence)
C	Fairly effective	The inspection methods will correctly identify the true damage state about half of the time (or 40-60% confidence)
D	Poorly effective	The inspection methods will provide little information to correctly identify the true damage state (or 20-40% confidence)
E	Ineffective	The inspection method will provide no or almost no information that will correctly identify the true damage state and are considered ineffective for detecting the specific damage mechanism (less than 20% confidence)

[15] ASME Section VIII-Division 1. 1996. *ASME Boiler and Pressure Vessel Code, 3rd edition*. Washington, D.C: ASME Publishing Services

Langkah 10. Hitung factor inspection effectiveness , $I_1^{Thin}, I_2^{Thin}, I_3^{Thin}$, menggunakan persamaan berikut, dan prior probabilities, $Pr_{p1}^{Thin}, Pr_{p2}^{Thin}, Pr_{p3}^{Thin}$, dari Tabel 4.5 and 4.6 dari API RP 581 Part 2 of POF jumlah inspeksi, $N_A^{Thin}, N_B^{Thin}, N_C^{Thin}, N_D^{Thin}$, from the STEP 9.

$$I_1^{Thin} = Pr_{P1}^{Thin}(Co_{P1}^{ThinA})^{N_A^{Thin}}(Co_{P1}^{ThinB})^{N_B^{Thin}}(Co_{P1}^{ThinC})^{N_C^{Thin}}(Co_{P1}^{ThinD})^{N_D^{Thin}} \quad (2.7)$$

$$I_2^{Thin} = Pr_{P2}^{Thin}(Co_{P2}^{ThinA})^{N_A^{Thin}}(Co_{P2}^{ThinB})^{N_B^{Thin}}(Co_{P2}^{ThinC})^{N_C^{Thin}}(Co_{P2}^{ThinD})^{N_A^{Thin}} \quad (2.8)$$

$$I_3^{Thin} = Pr_{P3}^{Thin}(Co_{P3}^{ThinA})^{N_A^{Thin}}(Co_{P3}^{ThinB})^{N_B^{Thin}}(Co_{P3}^{ThinC})^{N_C^{Thin}}(Co_{P3}^{ThinD})^{N_A^{Thin}} \quad (2.9)$$

Untuk nilai Conditional probability didapatkan dari tabel berikut.

Tabel 2.3 Nilai conditional probability

Conditional probability of inspection	E	D	C	B	A
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

Langkah 11. Hitung Posterior Probability, $Po_{p1}^{Thin}, Po_{p2}^{Thin}, Po_{p3}^{Thin}$.

$$Po_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} \quad (2.10)$$

$$Po_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} \quad (2.11)$$

$$Po_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}} \quad (2.12)$$

Langkah 12. Hitung parameter, $ß_1^{Thin}, ß_2^{Thin}, ß_3^{Thin}$, dengan persamaan (2.13), (2.14), dan (2.15) dengan nilai $COV_{\Delta t} = 0.2$, $COV_{sf} = 0.2$, dan $COV_P = 0.05$.

$$ß_1^{Thin} = \frac{1-D_{S1} \cdot A_{rt}-SR_P^{Thin}}{\sqrt{D_{S1}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2+(1-D_{S1} \cdot A_{rt})^2 \cdot COV_{sf}^2+(SR_P^{Thin})^2 \cdot (COV_P)^2}} \quad (2.13)$$

$$ß_2^{Thin} = \frac{1-D_{S2} \cdot A_{rt}-SR_P^{Thin}}{\sqrt{D_{S2}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2+(1-D_{S2} \cdot A_{rt})^2 \cdot COV_{sf}^2+(SR_P^{Thin})^2 \cdot (COV_P)^2}} \quad (2.14)$$

$$ß_3^{Thin} = \frac{1-D_{S3} \cdot A_{rt}-SR_P^{Thin}}{\sqrt{D_{S3}^2 \cdot A_{rt}^2 \cdot COV_{\Delta t}^2+(1-D_{S3} \cdot A_{rt})^2 \cdot COV_{sf}^2+(SR_P^{Thin})^2 \cdot (COV_P)^2}} \quad (2.15)$$

Langkah 13. Untuk komponen tank bottom, tentukan base damage factor untuk thinning menggunakan Tabel 4.8 dari API RP 581 Part 2 dan perhitungan A_{rt} parameter dari langkah 6.

Langkah 14. Hitung base damage factor, D_{fB}^{Thin},

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi(-\beta_1^{Thin})\right)+\left(Po_{P2}^{Thin}\Phi(-\beta_2^{Thin})\right)+\left(Po_{P3}^{Thin}\Phi(-\beta_3^{Thin})\right)}{1.56E-0.4} \quad (2.16)$$

Langkah 15. Tentukan DF untuk thinning, D_f^{Thin}.

$$D_f^{Thin} = \text{Max}[(\frac{(D_{fb}^{Thin} \cdot F_{IP} \cdot F_{DL} \cdot F_{WD} \cdot F_{AM} \cdot F_{SM})}{F_{OM}}),0.1] \quad (2.17)$$

Langkah 16. Tentukan DF Total untuk thinning, D_{f-gov}^{Thin}.

Apabila adainternal liner damage factor,

$$D_{f-gov}^{Thin} = \min[D_f^{Thin}, D_f^{elin}] \quad (2.18)$$

Apabila tidak ada internal liner damage factor

$$D_{f-gov}^{Thin} = D_f^{Thin} \quad (2.19)$$

2.7.3.2. Stress Corrosion Cracking – Sulfide Stress Cracking Damage

Selanjutnya adalah mekanisme stress corrosion cracking (SCC). Stress corrosion cracking didefinisikan sebagai keretakan diakibatkan kombinasi tensile stress dan lingkungan yang korosif. Terdapat beberapa jenis SCC yang ada. Namun dengan mengacu ke tabel 2.1, pembahasan akan dipersempit pada sulfide stress cracking dan HIC/SOHIC – H_2S.

Sulfide stress cracking (SSC) didefinisikan sebagai keretakan diakibatkan kombinasi tensile stress dan lingkungan berair dan ber-H_2S. SSC adalah bentuk hydrogen stress cracking yang dihasilkan dari penyerapan hidrogen atom yang dihasilkan oleh proses korosi sulfida pada permukaan logam. SSC biasanya lebih mudah terjadi pada baja berkekuatan tinggi (high strength/hardness) dalam endapan las keras atau *heat affected zone* (HAZ) dari baja berkekuatan rendah[14]. Tingkat kerentanan terhadap SCC utamanya dipengaruhi oleh 2 parameter, yaitu tingkat kekerasan material, stress pada material. Semakin tinggi masing-masing kedua parameter tersebut, maka semakin rentan pula terhadap SCC. Pun kerentanan terhadap SCC juga dipengaruhi (bukan yang utama) oleh pH dan konsentrasi H_2S di air. Semakin jauh dari pH netral dan/atau semakin tinggi konsentrasi H_2S, maka akan semakin rentan terhadap SSC. Berikut adalah langkah-langkah perhitungan sulfide stress cracking damage factor.

Langkah 1. Tentukan environmental severity (potential level dari hydrogen flux) untuk cracking berdasarkan konten H_2S di air dan pH-nya. Penentuan dilakukan dengan data dari perusahaan dan tabel berikut.

Tabel 2.4 Environmental severity – SCC

pH of water	Environmental severity as a function of H_2S content of water			
	< 50 ppm	50 to 1000 ppm	1000 to 10000 ppm	>10000 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 H2S Concentrations greater than 1000ppm				

Langkah 2. Tentukan susceptibility untuk cracking dengan memperhatikan environmental severity di langkah 1, maksimum brinell hardness of weldments, dan kondisi PWHT komponen. Perlu diingat bahwa susceptibility yg tinggi harus digunakan apabila terdapat cracking.

Tabel 2.5 Susceptibility to SCC

Environmental Severity	Susceptibility to SCC as function of heat treatment					
	As-welded Max Brinnel Hardness			PWHT Max Brinnel Hardness		
	< 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

Langkah 3. Tentukan severity index, S_{VI} berdasarkan susceptibility.

Tabel 2.6 Severity Index

Susceptibility	Severity Index - S_{VI}
High	100
Medium	10
Low	1
None	0

Langkah 4. Tentukan waktu beroperasi, agetk, sejak inspeksi level A, B, atau C dilakukan dengan tidak adanya cracking atau cracking diperbaiki. Cracking terdeteksi tapi tidak diperbaiki harus dievaluasi dan rekomendasi inspeksi mendatang berdasarkan evaluasi FFS

Langkah 5. Tentukan jumlah inspeksi dan efektivitasnya mengacu pada section 8.6.2 di API RP 581 Part 2 untuk inspeksi terakhir pada waktu beroperasi. Gabungkan nilai tersebut untuk efektivitas yang lebih tinggi berdasarkan section 3.4.3 di API RP 581 Part 2

Langkah 6. Tentukan base damage factor untuk sulfide stress cracking, D_{fb}^{scc}, berdasarkan severity indeks, efektivitas inspeksi, dan jumlah inspeksi, mengacu pada tabel 6.3 di API RP 581 Part 2

Langkah 7. Tentukan damage factor berdasarkan waktu operasi sejak inspeksi terakhir (usia yang sama pada langkah 4).

$$D_f^{scc} = D_{fB}^{scc}.(Max[age, 1.0])^{1.1} \quad (2.20)$$

2.7.3.3. Stress Corrosion Cracking – HIC/SOHIC-H_2S

HIC/SOHIC – H_2S merupakan singkatan dari *hydrogen-induced cracking* dan *stress oriented hydrogen-induced cracking* karena pengaruh H_2S. HIC didefinisikan sebagai retakan internal bertahap yang menghubungkan hidrogen blister yang berdekatan pada bidang yang berbeda dalam logam, atau ke permukaan logam. HIC terjadi bukan karena stress eksternal, namun karena penumpukan tekanan internal dari hidrogen blister. Interaksi bidang dengan stress tinggi cenderung mengakibatkan keretakan yang menghubungkan hidrogen blister di bidang berbeda pada logam[14]. Kerentanan terhadap HIC utamanya dipengaruhi oleh kadar sulfur pada logam tersebut. Semakin tinggi kadarnya, maka semakin rentan. Pun kerentanan terhadap HIC juga dipengaruhi (bukan yang utama) oleh pH dan konsentrasi H_2S di air. Semakin jauh dari pH netral dan/atau semakin tinggi konsentrasi H_2S, maka akan semakin rentan terhadap HIC.

SOHIC didefinisikan sebagai susunan blister yang tergabung karena hydrogen-induced cracking yang sejajar dengan arah ketebalan baja sebagai hasil dari tensile stress yang terjadi secara lokal. SOHIC merupakan gabungan HIC yang umumnya terjadi di base material yang berdekatan dengan HAZ, area tertinggi dari stress karena penumpukan internal pressure dan residual stress dari pengelasan[14]. Sama halnya dengan HIC, kualitas dari logam (konten sulfur), serta konten H_2S mempengaruhi kerentanan terhadap SOHIC. Sebagai tambahan, pengurangan residual stress karena *post weld heat treatment* (PWHT) dapat mengurangi kerentanan terhadap SOHIC. Berikut adalah langkah-langkah perhitungan HIC/SOHIC-H_2S damage factor.

Langkah 1. Tentukan environmental severity (potential level dari hydrogen flux) untuk cracking berdasarkan konten H2S di air dan pH-nya. Gunakan tabel 2.4 untuk menyelesaikan langkah ini.

Langkah 2. Tentukan susceptibility untuk cracking dengan memperhatikan environmental severity di langkah 1, maksimum brinell hardness of weldments, dan kondisi PWHT komponen.

Tabel 2.7 Susceptibility to cracking

Enviromental severity	Susceptibility to Cracking as a Function of Steel Sulfur Content					
	High Sulfur Steel >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	Low	Low	Low	Low	Low	Low

Langkah 3. Tentukan severity index, S_{VI} berdasarkan susceptibility. Gunakan tabel 2.6 untuk langkah ini.

Langkah 4. Tentukan waktu beroperasi, agetk, sejak inspeksi level A, B, atau C dilakukan dengan tidak adanya cracking atau cracking diperbaiki. Cracking terdeteksi tapi tidak diperbaiki harus dievaluasi dan rekomendasi inspeksi mendatang berdasarkan evaluasi FFS.

Langkah 5. Tentukan jumlah inspeksi dan efektivitasnya mengacu pada section 8.6.2 di API RP 581 Part 2 untuk inspeksi terakhir pada waktu beroperasi. Gabungkan nilai tersebut untuk efektivitas yang lebih tinggi berdasarkan section 3.4.3 di API RP 581 Part 2.

Langkah 6. Tentukan base damage factor untuk sulfide stress cracking, $D_{fb}^{HIC/SOHIC-H_2S}$, berdasarkan severity indeks, efektivitas inspeksi, dan jumlah inspeksi, mengacu pada tabel 6.3-API RP 581 Part 2.

Langkah 7. Tentukan on-line adjustment factor F_{OM}.

Tabel 2.8 Faktor on-line adjustment

On-Line Monitoring Method	Adjustment Factors as a Function of On-line Monitoring - F_{om}
Key Process Variables	2
Hyrogen Probes	2
Key Process Variables & Hydrogen probes	4

Langkah 8. Tentukan damage factor berdasarkan waktu operasi sejak inspeksi terakhir (usia yang sama pada langkah 4).

$$D_f^{HIC/SOHIC-H_2S} = \frac{D_{fB}^{HIC/SOHIC-H_2S} .(Max[age, 1.0])^{1.1}}{F_{OM}} \quad (2.21)$$

Langkah 9. Total damage factor untuk stress corrosion cracking
Jika ada lebih dari 1 damage factor untuk stress corrosion cracking, maka nilai tersebut digabungkan dengan persamaan 2.22.

$$D_{f-gov}^{scc} = max\begin{bmatrix} D_f^{caustic}, D_f^{amine}, D_f^{scc}, D_f^{HIC/SOHIC-H_2S}, D_f^{ACSCC}, \\ D_f^{PASCC}, D_f^{CLSCC}, D_f^{HSC\_HF}, D_f^{HIC/SOHIC-HF} \end{bmatrix} \quad (2.22)$$

Total Damage Factor

Pada kasus damage mechanisms jamak, kombinasinya tertera di section 3.4.2 API RP 581 Part 2 3rd Edition. Jika ada lebih dari satu damage mechanisms, aturan berikut digunakan untuk menggabungkan DF. Total DF diberikan oleh persamaan (2.23) ketika damage eksternal dan / atau thinning diklasifikasikan sebagai lokal dan karenanya, tidak mungkin terjadi di lokasi yang sama.

$$D_{f-total} = max\left[D_{f-gov}^{thin}, D_{f-gov}^{extd}\right] + D_{f-gov}^{scc} + D_f^{htha} + D_{f-gov}^{brit} + D_f^{mfat} \quad (2.23)$$

Jika damage eksternal dan thinning terjadi secara general, maka damage kemungkinan terjadi di lokasi yang sama dan total DF diberikan oleh Persamaan (2.24).

$$D_{f-total} = D_{f-gov}^{thin} + D_{f-gov}^{extd} + D_{f-gov}^{scc} + D_{f}^{htha} + D_{f-gov}^{brit} + D_{f}^{mfat} \quad (2.24)$$

2.8 Consequence of Failures

Dapat disebut sebagai dampak apabila kegagalan pada komponen tersebut terjadi. Metodologi COF akan dilakukan untuk membantu dalam menetapkan peringkat equipment berdasarkan risiko dan juga dimaksudkan untuk digunakan untuk menetapkan prioritas untuk program inspeksi. Sesuai dengan API 581 RP, ada dua jenis level COF yaitu Level 1 dan Level 2 yang memiliki aplikasi karakteristik fluida yang berbeda satu sama lain. Metodologi COF Level 1 digunakan untuk daftar cairan berbahaya yang ditentukan. Metodologi COF Tingkat 2 dimaksudkan untuk lebih ketat dan dapat diterapkan pada kisaran yang lebih luas.

2.8.1. Kategori dari consequences

Terdapat beberapa kategori consequences yang dianalisa, sebagaimana dijelaskan sebagai berikut.[14]

- Flammable dan explosive consequences
  Flammable dan explosive consequence dihitung dengan menggunakan event tree untuk menentukan probabilitas dari berbagai hasil (cth. Kebakaran kolam, kebakaran kilat, ledakan awan uap), dikombinasikan dengan pemodelan komputer untuk menentukan besarnya konsekuensi. Area konsekuensi dapat ditentukan berdasarkan cedera personil yang serius dan kerusakan komponen akibat radiasi dan ledakan termal. Kerugian finansial ditentukan berdasarkan area yang terkena dampak rilis.
- Toxic consequences
  Toxic consequence dihitung dengan menggunakan pemodelan komputer untuk menentukan besarnya area konsekuensi sebagai akibat dari paparan berlebih kepada personel terhadap konsentrasi racun dalam uap. Jika cairan mudah terbakar dan beracun, probabilitas kejadian toksik mengasumsikan bahwa pelepasannya dinyalakan, konsekuensi toksik dapat diabaikan (mis. Racun terbakar oleh api). Kerugian finansial ditentukan berdasarkan area yang terkena dampak.
- Non-flammable, non-toxic consequences
  Non-flammable, non-toxic consequences dipertimbangkan karena masih dapat menimbulkan dampak serius. Konsekuensi dari percikan kimiawi dan luka bakar uap suhu tinggi ditentukan berdasarkan cedera serius pada personel. Ledakan fisik dan Ledakan Mendidih Cairan Uap (BLEVE) juga dapat menyebabkan cedera serius pada personil dan kerusakan komponen.
- Financial consequences
  Financial consequences termasuk kerugian diakibatkan gangguan bisnis dan biaya yang terkait dengan pelepasan ke lingkungan. Konsekuensi gangguan

bisnis diperkirakan sebagai fungsi dari hasil area konsekuensi yang mudah terbakar dan tidak mudah terbakar. Konsekuensi lingkungan ditentukan secara langsung dari massa yang tersedia untuk rilis atau dari laju rilis.

2.8.2. Perhitungan consquence of failures

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

Tabel 2.9 Consequence of failures analysis steps

Step	Description
1	Determine the released fluid and its properties, including the release phase.
2	Select a set of release hole sizes to determine the possible range of consequence in the risk calculation
3	Calculate the theoritical release rate
4	Estimate the total amount of fluid available for release
5	Determine the type of release, continuous or instantaneous, to determine the method used for modelling the dispersion and consequence
6	Estimate the impact of detection and isolation systems on release magnitude.
7	Determine the release rate and mass for the consequence analysis
8	Calculate flammable/explosive consequence
9	Calculate toxic consequence
10	Calculate non-flammable, non-toxic consequence
11	Determine the final probability weighted component damage and personnel injury consequence areas
12	Calculate financial consequence

Perlu diperhatikan bahwa analisa segi ekonomis tidak dilakukan, maka perhitungan konsekuensi yang berkaitan dengan segi ekonomis pun dilewat. Dalam perhitungan consequence area dari steam scrubber dan steam ejector (gas removal system) 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 tanpa memperhatikan segi ekonomis dijelaskan sebagai berikut[14]:

Langkah 1. Tentukan fluida yang dikeluarkan serta karakteristiknya.

1.1. Tentukan fluida representatif mengacu ke 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*".

Paragraf tersebut menjelaskan bahwa pada kasus fluida campuran, pemilihan fluida representatif disarankan fluida yang memiliki karakter *flammable* dan/atau *toxic* dimana diasumsikan memiliki nilai CoF lebih tinggi.

Tabel 2.10 Beberapa pilihan fluida representatif

H_2S	Type 0	Hydrogen Sulfide
Steam	Type 0	Steam
Water	Type 0	Water

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)

Nilai dari parameter tersebut tercantum di tabel 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.

Tabel 2.11 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

Langkah 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.

Tabel 2.12 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.

Nilai dari generic failure frequencies untuk tiap ukuran release hole ada di tabel berikut.

Tabel 2.13 Nilai gff untuk setiap 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

Langkah 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

$$W_n = \frac{Cd}{C2}\ x\ An \text{ x Ps} \sqrt{\left(\frac{k\ x\ MW\ x\ gc}{R\ x\ Ts}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}} \quad (2.25)$$

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

$$An = \frac{\pi dn^2}{4} \quad (2.26)$$

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

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.

Langkah 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,$massa_{comp}$,

Estimasi volume untuk tipe komponen tersedia di API RP 581, Part 3 – Annex 3.A.

$$Mass_{comp} = \rho \text{ x } V_{comp} \tag{2.27}$$

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.

$$\sum mass_{inv} = \sum_{i=1}^{n} mass_{comp,i} \tag{2.28}$$

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.

$$W_{max8} = \frac{Cd}{C2}\ x\ An \text{ x Ps} \sqrt{\left(\frac{k\ x\ MW\ x\ gc}{R\ x\ Ts}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}} \tag{2.29}$$

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.

$$Mass_{add,n} = 180\ .\ min[Wn\ , Wmax8] \tag{2.30}$$

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.

$$Mass_{avail,n} = min\ [\{Mass_{comp} + Mass_{add,n}\}, Mass_{inv}] \tag{2.31}$$

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

INSTANTANEOUS RELEASE

Instantaeous release atau pelepasan sesaat adalah pelepasan yang terjadi begitu cepat sehingga fluida menyebar sebagai satu awan atau kumpulan besar.

CONTINOUS RELEASE

Continous release atau pelepasan menerus adalah pelepasan 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

$$t_n = \frac{C3}{W_n} \tag{2.32}$$

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.

Langkah 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 berikut.

Tabel 2.14 Klasifikasi tipe system deteksi

Type of Detection System	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 envelop	B
Visual detection, cameras, or detectors with marginal coverage	C

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

Tabel 2.15 Klasifikasi tipe sistem isolasi

Type of Isolation System	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 suitabel location remote from the leak	B
Isolation dependent on manually operated valves	C

6.4. Menentukan faktor reduksi pelepasan, $fact_{di}$, tipe dari sistem isolasi dan deteksi 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 klasifikasi dari langkah 6.2 dan 6.3 dan tabel berikut.

Tabel 2.16 Durasi kebocoran berdasarkan sistem deteksi dan isolasi

Detection System Rating	Isolation System Rating	Maximum Leak Duration, ld_{max}
A	A	20 minutes for 1/4 inch leaks
		10 minutes for 1 inch leaks
		5 minutes for 4 inch leaks
A	B	30 minutes for 1/4 inch leaks
		20 minutes for 1 inch leaks
		10 minutes for 4 inch leaks
A	C	40 minutes for 1/4 inch leaks
		30 minutes for 1 inch leaks
		20 minutes for 4 inch leaks
B	A or B	40 minutes for 1/4 inch leaks
		30 minutes for 1 inch leaks
		20 minutes for 4 inch leaks

Table 2.16 - Lanjutan   Durasi kebocoran berdasarkan sistem deteksi dan isolasi

Detection System Rating	Isolation System Rating	Maximum Leak Duration, ld_{max}
B	C	1 hour for 1/4 inch leaks
		30 minutes for 1 inch leaks
		20 minutes for 4 inch leaks
C	A, B, or C	1 hour for 1/4 inch leaks
		40 minutes for 1 inch leaks
		20 minutes for 4 inch leaks

Langkah 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:

$$Rate_n = W_n (1 - fact_{di}) \quad (2.33)$$

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:

$$mass_n = min[\{rate_n . Id_n\}, mass_{avail,n}] \quad (2.34)$$

7.1. Hitung adjusted release rate, $rate_n$, menggunakan persamaan (2.33)

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

$$ldn = min . [\{\frac{Mass_{avail,n}}{Rate_n}\},\{60 . ld_{max,n}] \quad (2.35)$$

7.3. Hitung release mass, $mass_n$, untuk setiap ukuran release hole.
Untuk setiap ukuran release hole, hitung release mass, $mass_n$, menggunakan rumus 2.10 berdasarkan release rate, $rate_n$, durasi kebocoran, Id_n, dan, $mass_{avail,n}$.

Langkah 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 konsekuensi area, $fact_{mit}$, dari tabel berikut.

Tabel 2.17 Faktor reduksi mitigasi konsekuensi area

Mitigation System	Consequence Area Adjustment	$Fact_{mit}$
Inventory blowdown , couple with isolation system classification B or higher	Reduce consequence area by 25 %	0.25
Fire water deluge system and monitor	Reduce consequence area by 20%	0.2
Fire water monitor only	Reduce consequence area by 5%	0.05
Foam spray system	Reduce consequence area by 15%	0.15

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

$$eneff_4 = 4.log_{10}[C_4 \ . \ mass_n] - 15 \quad (2.36)$$

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), $CA^{AINL-CONT}$.

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

$$CA_{cmd,n}^{AINL-CONT} = \alpha(rate_n)^b \ . \ (1 - fact_{mit}) \quad (2.37)$$

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

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

$$CA_{cmd,n}^{AIL-CONT} = \alpha(rate_n)^b \ . \ (1 - fact_{mit}) \quad (2.38)$$

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

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

$$CA_{cmd,n}^{AINL-INST} = \alpha(mass_n)^b \ . \ \left(\frac{1 - fact_{mit}}{eneff_n}\right) \quad (2.39)$$

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

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

$$CA_{cmd,n}^{AIL-INST} = \alpha(mass_n)^b \cdot \left(\frac{1-fact_{mit}}{eneff_n}\right) \tag{2.40}$$

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

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

$$CA_{inj,n}^{AINL-CONT} = [\alpha.(rate_n^{AINL-CONT})^b].(1-fact_{mit}) \tag{2.41}$$

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

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

$$CA_{inj,n}^{AIL-CONT} = [\alpha.(rate_n^{AIL-CONT})^b].(1-fact_{mit}) \tag{2.42}$$

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

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

$$CA_{inj,n}^{AINL-INST} = [\alpha.(mass_n^{AINL-INST})^b].\left(\frac{1-fact_{mit}}{eneff_n}\right) \tag{2.43}$$

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

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

$$CA_{inj,n}^{AIL-INST} = [\alpha.(mass_n^{AIL-INST})^b].\left(\frac{1-fact_{mit}}{eneff_n}\right) \tag{2.44}$$

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

$$fact_n^{IC} = \min\left[\left\{\frac{rate_n}{C_5}\right\}, 1.0\right] \tag{2.45}$$

b. For instantaneous release type

For instantaneous releases, blending factor tidak dihitung. Karena definisi instantaneous release adalah satu keluaran besar, $rate_n$,, lebih besar (4356 kgs (10000 lbs.) dalam 3 menit), the blending factor sama dengan to 1.0.

$$fact_n^{IC} = 1.0 \quad (2.46)$$

8.13. Hitung AIT blending factor, $fact^{AIT}$, menggunakan persamaan (2.47), (2.48), or (2.49) as applicable.

$$fact^{AIT} = 0 \qquad \text{if } T_s + C_6 \leq AIT \quad (2.47)$$

$$fact^{AIT} = \frac{(T_s - AIT + C_6)}{2 \ x \ C_6} \qquad \text{if } T_s + C_6 > AIT > T_s - C_6 \quad (2.48)$$

$$fact^{AIT} = 1 \qquad \text{if } T_s - C_6 \geq AIT \quad (2.49)$$

8.14. Hitung continuous/instantaneous blended consequence area untuk komponen dan personil using equation (2.50) through (2.53) based on the consequence area that have been calculated in the previous steps.

$$CA_{cmd,n}^{AIL} = CA_{cmd,n}^{AIL-INST} x \, fact_n^{IC} + CA_{cmd,n}^{AIL-CONT} x \, (1 - fact_n^{IC}) \quad (2.50)$$

$$CA_{cmd,n}^{AINL} = CA_{cmd,n}^{AINL-INST} x \, fact_n^{IC} + CA_{cmd,n}^{AINL-CONT} x \, (1 - fact_n^{IC}) \quad (2.51)$$

$$CA_{inj,n}^{AIL} = CA_{inj,n}^{AIL-INST} x \, fact_n^{IC} + CA_{inj,n}^{AIL-CONT} x \, (1 - fact_n^{IC}) \quad (2.52)$$

$$CA_{inj,n}^{AINL} = CA_{inj,n}^{AINL-INST} x \, fact_n^{IC} + CA_{inj,n}^{AINL-CONT} x \, (1 - fact_n^{IC}) \quad (2.53)$$

8.15. Hitung AIT blended consequence areas untuk komponen menggunakan persamaan (2.54) dan (2.55).

$$CA_{cmd,n}^{flam} = CA_{cmd,n}^{AIL} \, x \, fact^{AIT} + CA_{cmd,n}^{AINL} x \, (1 - fact^{AIT}) \quad (2.54)$$

$$CA_{inj,n}^{flam} = CA_{inj,n}^{flam-AIL} \, x \, fact^{AIT} + CA_{inj,n}^{AINL} x \, (1 - fact^{AIT}) \quad (2.55)$$

8.16. Hitung consequence areas final untuk kerusakan komponen dan personil menggunakan persamaan (2.56) and (2.57).

$$CA_{cmd}^{flam} = \left(\frac{\sum gff_n \, . \, CA_{cmd,n}^{flam}}{gff_{total}} \right) \quad (2.56)$$

$$CA_{inj}^{flam} = \left(\frac{\sum gff_n \, . \, CA_{inj,n}^{flam}}{gff_{total}} \right) \quad (2.57)$$

Langkah 9. Hitung toxic consequence

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

$$ld_n^{tox} = \min \left(3000 \, , \, \left\{ \frac{mass_n}{W_n} \right\}, \, \{60. \, ld_{max,n}\} \right) \quad (2.58)$$

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 (2.59) and (2.60).

a. For continuous release type

$$rate_n^{tox} = mfrac^{tox}.W_n \quad (2.59)$$

b. For instantaneous release type

$$mass_n^{tox} = mfrac^{tox}.mass_n \quad (2.60)$$

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 (2.62) untuk continuous release dan (2.63) untuk instantaneous release type.

a. For continuous release type

$$CA_{inj,n}^{toxCONT} = e(Rate_n^{tox})\hat{}f \quad (2.61)$$

b. For instantaneous release type

$$CA_{inj,n}^{tox-INST} = e(Mass_n^{tox})\hat{}f \quad (2.62)$$

9.5. Jika ada komponen toxic tambahan di campuran fluida keluaran, langkah 9.2 hingga 9.4 harus diulang. Jika tidak ada, langkah 9.5 dapat dilewat.

9.6. Tentukan konsekuensi area toxic untuk injuri personil sesuai rumus (2.63)

$$CA_{inj}^{tox} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{tox}}{gff_{total}}\right) \quad (2.63)$$

Langkah 10. Hitung non-flammable, non-toxic consequence

Non-flammable dan non-toxic difokuskan terhadap uap, serta konten acid dan caustic. Uap terbentuk pada suhu 100^oC, namun pada jarak beberapa meter uap akan bercampur dengan udara dan menjadi lebih dingin. Untuk pendekatan ini, injury terjadi diatas suhu 60^oC.

10.1. Untuk setiap ukurang lubang keluaran, hitung non-flammable dan non-toxic consequence are menggunakan persamaan (2.64) and (2.65)

Untuk proses yang tidak mengandung acid dan caustic content, maka menghitung the stream non-flammable dan non-toxic menggunakan:

a. For continuous release type

$$CA_{inj,n}^{CONT} = (C_9.\text{Rate}_n) \quad (2.64)$$

b. For instantaneous release type

$$CA_{inj,n}^{INST} = (C_{10}.\ \text{Mass}_n)^{0.6384} \quad (2.65)$$

10.2. Untuk setiap ukuran lubang pelepasan, hitung faktor blending kontinyu / instan, $fact_{id}$, untuk steam menggunakan persamaan 2.66 berikut. Sedangkan untuk acid atau caustic, $fact_n^{IC} = 0$.

$$fact_n^{IC} = min\left[\left\{\frac{rate_n}{C_5}\right\}, 1.0\right] \quad (2.66)$$

10.3. Untuk setiap ukuran lubang keluaran, hitung consequence area untuk non-flammable dan non-toxic personel injury dari langkah 10.1 dan 10.2.

$$CA_{cmd,n}^{leak} = 0 \quad (2.67)$$

$$CA_{inj,n}^{leak} = CA_{inj,n}^{INST} . fact_n^{IC} + CA_{inj,n}^{CONT} . (1 - fact_n^{IC}) \quad (2.68)$$

10.4. Tentukan non-flammable, non-toxic consequence areas final untuk personnel injury menggunakan (2.69)

$$CA_{inj}^{nfnt} = \left(\frac{\sum gff_n \cdot CA_{inj,n}^{leak}}{gff_{total}}\right) \quad (2.69)$$

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

11.1. Hitung component damage consequence area final, CA_{cmd}, menggunakan persamaan (2.70)

$$CA_{cmd} = CA_{cmd}^{flam} \quad (2.70)$$

11.2. Hitung personnel injury consequence area final, CA_{inj}, menggunakan persamaan (2.71)

$$CA_{inj} = \max\left[CA_{inj}^{flam}, CA_{inj}^{tox}, CA_{inj}^{nfnt}\right] \quad (2.71)$$

11.3. Calculate the final consequence rea, CA, menggunakan persamaan (2.72)

$$CA = \max\left[CA_{cmd}, CA_{inj}\right] \quad (2.72)$$

2.9 Risiko

2.9.1. Definisi Risiko

Risiko didefinisikan sebagai kombinasi dari probabilitas suatu kejadian pada kurun waktu tertentu dan konsekuensinya (umumnya negatif) dari kejadian terkait[14]. Sebuah sistem terdiri dari beberapa atau banyak komponen, dimana masing-masing komponen memiliki risikonya masing-masing. Tentunya, karena komponen tersebut merupakan bagian dari sistem maka kegagalan pada komponen dapat berdampak pada sistem baik dari performa ataupun usianya. Maka probabilitas dari risiko komponen harus dipertahankan pada tingkat yang dapat diterima dengan cara melakukan testing ataupun inspeksi.

Secara matematika, risiko dapat didefinisikan sebagai:

$$Risk = P_{f(t)} . C_{f(t)} \quad \text{..........}(2.73)$$

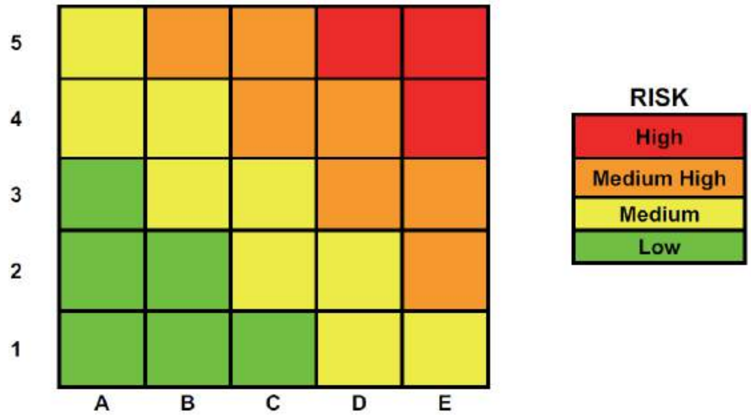
Dimana P_f *(t)* adalah probabilitas kegagalan, C_f *(t)* adalah konsekuensi dari kegagalannya. Dari persamaan tersebut dapat disimpulkan bahwa sebuah risk assessment yang efektif harus rasional, logis, terstruktur dan mengandung:

- Seberapa signifikan dampak dari risiko tersebut.
- Apakah risiko tersebut dapat diterima.

- Seberapa tinggi probabilitas risiko tersebut terjadi.

2.9.2. Matriks Risiko

Matriks risiko adalah cara untuk menentukan tingkat risiko dari komponen-komponen terkait. Merah menunjukkan risiko yang tinggi, jingga menunjukkan tingkat risiko yang menengah-tinggi, kuning menunjukkan bahwa risiko kegagalan komponen tersebut pada tingkat menengah, hijau menunjukkan risiko pada tingkat rendah. Contoh gambar matriks risiko ditunjukkan pada gambar 2.7 berikut.



Gambar 2.7 Matriks risiko[14]

Pada gambar 2.7, di sumbu horizontal adalah tingkatan dari consequence of failure atau damage factor, dan sumbu vertical adalah tingkatan dari probability of failure atau damage factor. Untuk pengklasifikasian nilai dapat dilihat pada tabel berikut yang merupakan kutipan dari tabel 4.1M di API RP 581, Part 1.

Tabel 2.18 Tingkatan nilai untuk matrisk risiko[15]

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) \leq$3.06E-04	$1 < D_{f-total} \leq 10$	B	9.29<CA≤92.9
3	3.06E-04 $< P_f(t, I_E) \leq$3.06E-03	$10 < D_{f-total} \leq 100$	C	92.9<CA≤929
4	3.06E-03 $< P_f(t, I_E) \leq$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

2.10 Inspection Plan

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 adalah[14]:

- Target Risiko – tingkat risiko minimum untuk mengadakan perencanaan inspeksi. Dapat berupa unit area (m^2/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. Untuk kegiatan inspeksi sendiri, ada 3 yaitu inspeksi internal, on-stream dan eksternal. Inspeksi internal adalah inspeksi 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[16].

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. Dalam hal thinning pun, untuk general dan local memiliki effectivenessnya masing-masing. Berikut adalah inspection effectiveness untuk local thinning, sulfide stress cracking, dan HIC/SOHIC – H_2S.

2.10.1. Local Thinning

Tabel berikut menjelaskan inspection effectiveness dari local thinning.

[16] API 510. 2006. *Pressure Vessel Inspection Code: In-Service Inspection, Rating, Repair, and Alteration, 9th edition*. Washington, D.C: API Publishing Services Code

Table 2.19 Inspection effectiveness untuk local thinning

Kategori Inspeski	Kategori	Inspeksi Intrusif	Inspeksi Non-Intrusif
A	Highly effective	Untuk area permukaan total: • 100% pemeriksaan visual. • 100% follow up di area local thinning.	Untuk total area yang dicurigai: Cakupan 100% dari CML menggunakan ultrasonic scanning atau profile radiography.
B	Usually effective	Untuk area permukaan total: • >75% pemeriksaan visual. • 100% follow up di area local thinning.	Untuk total area yang dicurigai: > cakupan 75% dari CML menggunakan ultrasonic scanning atau profile radiography.
C	Fairly effective	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.
D	Poorly effective	Untuk area permukaan total: • >20% pemeriksaan visual. • 100% follow up di area local thinning.	Untuk total area yang dicurigai: > cakupan 20% dari CML menggunakan ultrasonic scanning atau profile radiography.
E	Ineffective	Teknik inspeksi yang tidak efektif	Teknik inspeksi yang tidak efektif

Inspeksi intrusif diartikan sebagai inspeksi yang memerlukan masuk ke dalam equipment. Sedangkan non-intrusif diartikan sebaliknya.

2.10.2. Stress Corrosion Cracking

Tabel-tabel berikut menjelaskan inspection effectiveness dari beberapa stress corrosion cracking, difokuskan kepada sulfide stress cracking dan HIC/SOHIC-H_2S. Berikut adalah tabel inspection effectiveness untuk sulfide stress cracking.

Table 2.20 Inspection effectiveness untuk sulfide stress cracking

Kategori Inspeski	Kategori	Inspeksi Intrusive	Inspeksi Non-Intrusif
A	Highly effective	Untuk las / area las yang dipilih: 100% WFMT / ACFM dengan follow up terhadap seluruh indikasi relevan.	Untuk las / area las yang dipilih: 100% ultrasonic scanning secara otomatis atau manual.
B	Usually effective	Untuk las / area las yang dipilih: >75% WFMT / ACFM dengan follow up terhadap seluruh indikasi relevan.	Untuk las / area las yang dipilih: >75% ultrasonic scanning secara otomatis atau manual. **ATAU** >75% AE testing dengan follow up di seluruh indikasi relevan.
C	Fairly effective	Untuk las / area las yang dipilih: >35% WFMT / ACFM dengan follow up terhadap seluruh indikasi relevan.	Untuk las / area las yang dipilih: >35% ultrasonic scanning secara otomatis atau manual. **ATAU** >35% tes radiographic.
D	Poorly effective	Untuk las / area las yang dipilih: >10% WFMT / ACFM dengan follow up terhadap seluruh indikasi relevan.	Untuk las / area las yang dipilih: >35% ultrasonic scanning secara otomatis atau manual. **ATAU** >10% tes radiographic.
E	Ineffective	Teknik inspeksi yang tidak efektif	Teknik inspeksi yang tidak efektif

Sama halnya dengan tabel 2.19, intrusif diartikan sebagai inspeksi yang memerlukan inspeksi masuk ke dalam equipment. Inspeksi non-intrusif berarti inspeksi yang dapat dilaksanakan secara eksternal. Untuk tabel berikut adalah tabel 2.21 yang menunjukkan inspection effectiveness untuk HIC/SOHIC – H_2S.

Table 2.21 Inspection effectiveness untuk HIC/SOHIC – H_2S

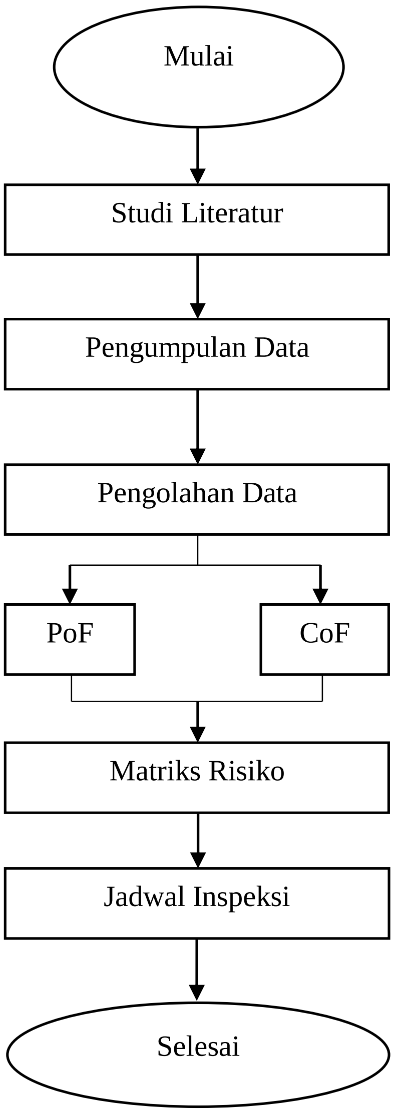
Kategori Inspeski	Kategori	Inspeksi Intrusif	Inspeksi Non-Intrusif
A	Highly effective	Untuk total area permukaan: • >95% A atau C scan dengan straight beam. • Diikuti dengan TOFD / Shear wave. • 100% visual.	Untuk total area permukaan: • >90% C scan dari logam dasar dengan UT tingkat lanjut. • Untuk area las dan HAZ – 100% shear wave dan TOFD. • HIC: 1 area 0.5 ft^2, C scan logam dasar dengan UT tingkat lanjut pada tiap plat dan heads
B	Usually effective	Untuk total area permukaan: • >75% A atau C scan dengan straight beam. • Diikuti dengan TOFD / Shear wave. • 100% visual.	Untuk total area permukaan: • >65% C scan dari logam dasar dengan UT tingkat lanjut. • HIC: 2 area 0.5 ft^2, C scan logam dasar dengan UT tingkat lanjut pada tiap plat dan heads
C	Fairly effective	Untuk total area permukaan: • >35% A atau C scan dengan straight beam. • Diikuti dengan TOFD / Shear wave. • 100% visual. **ATAU** • >50% WFMT / ACFM. • Follow up UT pada indikasi. • 100% Visual dari total area permukaan.	Untuk total area permukaan: • >35% C scan dari logam dasar dengan UT tingkat lanjut. • HIC: 1 area 0.5 ft^2, C scan logam dasar dengan UT tingkat lanjut pada tiap plat dan heads
D	Poorly effective	Untuk total area permukaan: • >10% A atau C scan dengan straight beam. • Diikuti dengan TOFD / Shear wave. • 100% visual. **ATAU** • >25% WFMT / ACFM. • Follow up UT pada indikasi. • 100% Visual dari total area permukaan.	Untuk total area permukaan: • >5% C scan dari logam dasar dengan UT tingkat lanjut. • HIC: 1 area 0.5 ft^2, C scan logam dasar dengan UT tingkat lanjut pada tiap plat dan heads
E	Ineffective	Teknik inspeksi yang tidak efektif	Teknik inspeksi yang tidak efektif

Sama halnya dengan tabel 2.19, intrusif diartikan sebagai inspeksi yang memerlukan inspeksi masuk ke dalam equipment. Inspeksi non-intrusif berarti inspeksi yang dilakukan di luar equipment.

BAB III
METODOLOGI PENELITIAN

3.1. Gambaran Umum

Bab III dalam tugas akhir ini berisi skema pengerjaan yang merupakan inti langkah pengerjaan yang diambil dalam melakukan perhitungan dan analisis risiko guna mendapatkan rencana inspeksi. Alur pengerjaan ditunjukkan oleh gambar 3.1 berikut.



Gambar 3.1 Flowchart metodologi penelitian

3.2. Mulai

Langkah pertama adalah mengidentifikasikan masalah yang akan diangkat dari penelitian. Inipun termasuk dari mengapa masalah tersebut bisa muncul dan apa dampak dari permasalahan tersebut.

3.3. Studi Literatur

Setelah memahami masalah penelitian yang diangkat. Selanjutnya adalah melakukan studi dari berbagai topik literatur untuk membantu pemahaman akan akar permasalahan dan metode penyelesaian yang digunakan. Studi literatur dilakukan dengan membaca, memahami dan merangkum dari sumber-sumber terpercaya seperti journal, handbook, laporan dan data perusahaan, tugas akhir dengan topik terkait, serta artikel-artikel yang dipublikasikan di internet. Selain dari itu, berdiskusi dengan dosen pembimbing, pihak perusahaan dapat membantu mendapatkan informasi tambahan. Berikut adalah beberapa ringkasan paper/journal yang dilakukan.

Tabel 3.1 Ringkasan literatur

Referensi	Hasil
Database perusahaan tentang scrubber vessel, steam ejector pada gas removal system dan inspeksi sebelumnya	Referensi dalam menyusun latar belakang, metodologi penelitian dan judul tugas akhir
Studi aplikasi *risk based inspection* pressure vessel pada penelitian sebelumnya	Referensi tambahan dalam menyusun latar belakang dan metodologi penelitian
Jurnal – jurnal internasional mengenai pembangkit listrik tenaga panas bumi	Referensi tambahan mengenai sistem dari pembangkit listrik tenaga panas bumi, serta karakteristik fluida panas bumi.
Guideline: • API 580 • API 581	Pedoman dalam menyusun langkah-langkah perhitungan *risk based inspection* dan penentuan perencanaan inspeksi
Diskusi dengan supervisor perusahaan	Diskusi mengenai sistem scrubber vessel dan gas removal system pada fasilitas perusahaan
Diskusi dengan dosen pembimbing	Analisa difokuskan di scrubber vessel, steam ejector pada gas removal system, karena cenderung mengalami korosi
Pustaka internet	Referensi tambahan untuk memahami pembangkit listrik tenaga panas bumi, scrubber vessel dan steam ejector

3.4. Pengumpulan Data

Pengumpulan data mengenai komponen penelitian dilakukan di Star Energy Geothermal Wayang Windu Unit 2, Jawa Barat. Data yang dikumpulkan dirangkum sebagai berikut:

- PID dan/atau PFD dari Wayang Windu Unit 2, khususnya untuk steam scrubber dan gas removal system.

- Data sheet mengenai steam scrubber dan steam ejector (gas removal system).
- Detail desain dari steam scrubber.
- Thickness inspection dari Steam Scrubber dan Steam ejector (gas removal system)
- Komposisi kimia dari fluida geothermal di lokasi serta pH-nya.

Data tersebut kemudian diproses untuk menentukan probabilitas dan konsekuensi kegagalan agar dapat menyusun perencanaan inspeksi sesuai dengan risiko dari komponen masing-masing.

3.5. Pengolahan Data

Data yang didapat kemudian diolah untuk mententukan probabilitas kegagalan (PoF) dan konsekuensi dari kegagalan (CoF) yang dibutuhkan untuk menentukan risiko. Probabilitas kegagalan didapatkan dari damage mechanism yang terjadi pada komponen, tipe komponen, dan nilai manajemen perusahaan. Sedangkan untuk konsekuensi kegagalan, hanya memperhitungkan konsekuensi area. Konsekuensi ekonomi tidak diperhitungkan.

3.7 Matriks Risiko

Nilai dari probabilitas kegagalan dan konsekuensi kegagalan digunakan untuk menentukan pada tingkat apa risiko komponen berada (low, medium, medium-high, high). Semakin tinggi risiko maka semakin tinggi prioritas untuk diinspeksi.

3.8 Jadwal Inspeksi

Perhitungan penentuan jadwal inspeksi ditentukan oleh target yang ingin dicapai oleh perusahaan. Rencana inspeksi berisi tentang kerusakan yang terjadi di komponen, risiko komponen, interval waktu hingga inspeksi berikutnya, dan rekomendasi inspeksi yang harus dilakukan.

3.9 Selesai

Tahap terakhir adalah pengambilan keputusan dari hasil inspeksi komparatif yang telah diterapkan pada perusahaan terkait. Pada langkah terakhir, kesimpulan akan diambil dari analisis tugas akhir ini. Pada tahap ini saran untuk perusahaan dicantumkan agar dapat menjadi bahan pertimbangan ke kebijakan selanjutnya.

Halaman sengaja dikosongkan

BAB IV
ANALISA DATA

4.1. Deskripsi Proses dan Data Steam Scrubber

Scrubber vessel berfungsi untuk menurunkan kelembaban dari uap yang melaluinya, sehingga dapat menghasilkan uap panas kering. Namun untuk pembangkit listrik tenaga panas bumi, scrubber juga berfungsi untuk menghilangkan mineral-mineral terlarut pada uap. Pada fasilitas Wayang Windu Unit 2 milik Star Energy Geothermal Ltd., scrubber vessel menerima uap dari separator vessel yang terdapat mineral-mineral dan cairan dalam jumlah kecil. Uap panas kering dari scrubber digunakan untuk menggerakkan turbin agar dapat menghasilkan listrik. Berikut adalah data steam Scrubber VS-81-009 pada Star Energy Geothermal Wayang Windu Unit 2.

Tabel 4.1 Steam scrubber general specification

GENERAL SPECIFICATION	
Tag Number	VS-81-009
Quantity	1
Service	Steam Scrubber
Serial No.	PV-GSB-099
Manufactured by	PT. Rekayasa Industri
Type of Pressure Vessel	Vertical
	Drum
Geometry Data	2:1 Ellipsodial
Code	ASME Section VIII Division 1 2015 Edition
Design Pressure	13.88 bar
Design Temperature	198°C
Operating Pressure	9.9°C
Operating Temperature	185.4°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

Untuk data P&ID dari VS-81-009 dapat dilihat di LAMPIRAN 1: DIAGRAM SCRUBBER.

4.2. Deskripsi Proses dan Data Gas Removal System

Gas removal system memiliki fungsi sebagai jalur pelepasan gas ke atmosfir. Uap panas hasil keluaran scrubber yang berlebih, serta uap (telah melewati turbin) yang tidak terkondensasi akan dilepas ke atmosfir melalui gas removal system. Gas removal system terdiri dari 4 equipment utama yaitu, 1^{st} stage steam ejector, inter condenser, 2^{nd} stage steam ejector, dan after condenser. Pada kasus ini, equipment yang diteliti adalah 1^{st} stage steam ejector (EJ-202).

Uap melewati keempat equipment tersebut, sebelum dilepas ke atmosfir. Uap panas berlebih dari scrubber dan uap yang tidak terkondensasi setelah melewati turbin, dialirkan menuju 1^{st} stage steam ejector. Steam ejector mengkonversi kondisi uap bertekanan tinggi dengan kecepatan rendah, menjadi bertekanan lebih rendah dengan kecepatan yang lebih tinggi. Uap tersebut kemudian dikondensasikan oleh inter condenser, kondensat kemudian dialirkan menuju *condensate injection well*, sedangkan uap yang tidak terkondensasi dialirkan menuju 2^{nd} stage steam ejector. Uap yang sudah melewati 2^{nd} stage ejector kemudian dikondensasikan kembali dengan after condenser. Kondensat hasil dari after condenser akan dialirkan menuju *condensate injection well*, sedangkan uap/gas yang tidak terkondensasi akan dilepas ke atmosfir. Berikut adalah data dari 1^{st} stage steam ejector.

Tabel 4.2 Steam ejector general specification

GENERAL SPECIFICATION	
Tag Number	EJ-202
Quantity	1
Service	1^{st} Stage Steam Ejector
Serial No.	-
Manufactured by	PT. Rekayasa Industri
Type of Pressure Vessel	Horizontal
	Drum
Code	ASME Section VIII Division 1 2015 Edition
Design Pressure	11 bar
Design Temperature	30°C
Operating Pressure	9.9°C
Operating Temperature	26.5°C
Vessel Volume	5.6609 m^3
Joint Efficiency (Head/Shell)	1
Corrosion Allowance	3.0 mm
	0.1181 inch
Year Built	2000
Material	SA 516 Gr. 70
Last Inspection	03 Juli 2014

Data P&ID dari gas removal system dapat dilihat di LAMPIRAN 2: DIAGRAM GAS REMOVAL SYSTEM.

4.3. Komposisi Fluida

Berikut adalah komposisi dari fluida geothermal yang terlibat.

Tabel 4.3 Komposisi kimia fluida

mmole/100 mole H2O							
CO_2	**H_2S**	**NH_3**	**N_2**	**CH_4**	**He**	**H_2**	**Ar**
239.871	7.3822	0.2297	24.557	0.4563	0.087	1.2557	0.029
Note: those values are average of the values sample taken on different date in September 2018.							

Fluida representatif adalah H_2S. Meskipun uap air dan CO_2 memiliki porsi yang lebih banyak, namun karena anjuran dari Annex 3.A API RP 581 Part 3 mengenai campuran fluida. Dipilihlah senyawa yang lebih berbahaya.

4.4. Steam Scrubber VS-81-009

4.4.1. Probability of Failure

Probability of failure didapatkan dari nilai damage factor, generic failure frequency dan factor management system dari perusahaan. Untuk damage factor screening criteria dari steam scrubber dapat dilihat di LAMPIRAN 3: DAMAGE FACTOR SCREENING QUESTION DARI STEAM SCUBBER. Damage factor yang sesuai dengan kondisi dari VS-81-009 adalah thinning, sulfide stress cracking, dan HIC/SOHIC – H_2S damage factor. Berikut adalah langkah – langkah perhitungannya.

- **Thinning**

Thinning – merupakan degradasi logam karena lingkungannya yang mengakibatkan penipisan ketebalan logam tersebut. Untuk mengetahui nilai damage factor thinning, memerlukan data laju korosi material. Data tersebut didapatkan dari inspeksi terakhir ataupun perhitungan lajur korosi berdasarkan mekanisme thinning pada Annex 2.B API RP 581. Thinning dapat terjadi karena beberapa mekanisme. Untuk kasus ini, mekanisme thinning yang sesuai dengan screening criteria corrosion rate API RP 581 adalah sour water corrosion, acid sour water corrosion, dan CO_2 corrosion. Sour water dan acid sour water corrosion terjadi karena adanya H_2S pada larutan yang pH nya di bawah 7,0. Sedangkan CO_2 corrosion terjadi karena adanya air serta CO_2 dan material konstruksi adalah carbon steel dengan kadar Cr < 13%. Untuk detail perhitungan dapat dilihat di LAMPIRAN 4A: PERHITUNGAN PROBABILITY OF FAILURE (POF) DARI STEAM SCRUBBER. Hasil perhitungan thinning menghasilkan nilai damage factor sebesar 0.241 untuk shell section dan head section dari scrubber VS-81-009.

- **Sulfide Stress Cracking**

  Sulfide stress cracking (SSC) didefinisikan sebagai keretakan diakibatkan kombinasi tensile stress dan lingkungan berair dan ber-H_2S. SSC adalah tipe *hydrogen stress cracking* yang dihasilkan dari penyerapan atom hidrogen yang dihasilkan oleh proses korosi sulfida pada permukaan logam. Kerentanan material terhadap sulfide stress cracking dapat diturunkan dengan perlakuan PWHT (*post weld heat treatment*) pada komponen. Untuk shell section dari scrubber tidak dilakukan PWHT, namun untuk head section ada riwayat perlakuan PWHT. Karena itu, ada perbedaan antara sulfide stress cracking damage factor shell (DF = 5.8651) dan head section (DF = 0).

- **HIC/SOHIC – H_2S**

  HIC/SOHIC – H_2S merupakan singkatan dari *hydrogen-induced cracking* dan *stress oriented hydrogen-induced cracking* karena pengaruh H_2S. HIC didefinisikan sebagai retakan internal bertahap yang menghubungkan hidrogen blister yang berdekatan pada bidang yang berbeda dalam logam, atau ke permukaan logam. HIC terjadi bukan karena stress eksternal, namun karena penumpukan tekanan internal dari hidrogen blister. Sedangkan SOHIC didefinisikan sebagai susunan blister yang tergabung karena hydrogen-induced cracking yang sejajar dengan arah ketebalan baja sebagai hasil dari tensile stress yang terjadi secara local.

  Kerentanan material terhadap HIC/SOHIC akan menurun seiring dengan lebih rendahnya konsentrasi sulfur pada baja, serta perlakuan PWHT pada komponen. Material konstruksi yang digunakan adalah SA 516 Gr. 70 dengan konten sulfur 0.03%. Komponen yang mengalami perlakuan PWHT hanya head section, sehingga menghasilkan damage factor 293.26 untuk shell section dan 29.33 untuk head section. Untuk detail perhitungan dapat dilihat di LAMPIRAN 4A: PERHITUNGAN PROBABILITY OF FAILURE (POF) DARI STEAM SCRUBBER.

- **Probability of Failure**

  Probability of failure merupakan kemungkinan terjadinya kegagalan pada komponen. Nilainya merupakan fungsi dari damage factor, generic failure frequency (gff) dan factor management system (fms). Nilai gff ditentukan berdasarkan tipe equipment (vessel) sebesar $3.06x10^{-5}$, nilai fms dapat diketahui dari screening terhadap manajemen perusahaan (dapat dilihat di LAMPIRAN 4B: FACTOR MANAGEMENT SYSTEM) sebesar 0.182, dan nilai damage factor merupakan gabungan dari ketiga damage factor tersebut. Menghasilkan DF = 293.5 untuk shell dan DF = 29.6 untuk head section. Sehingga dihasilkan nilai POF sebesar $1,64x10^{-3}$ untuk shell section dan $1,65x10^{-4}$ untuk head section. Untuk detail perhitungan dapat dilihat di LAMPIRAN 4A: PERHITUNGAN PROBABILITY OF FAILURE (POF) DARI STEAM SCRUBBER.

4.4.2. Consequence of Failure

Terdapat 11 langkah untuk menentukan Consequence of Area dari Steam Scrubber, yaitu:

Langkah 1. Tentukan fluida yang dikeluarkan serta karakteristiknya.

Fluida representatif adalah fluida dominan pada sistem yang dijadikan acuan perhitungan apabila terjadi kebocoran pada vessel. Umumnya, fluida representatif adalah senyawa dengan jumlah mol terbanyak pada fluida tersebut. Namun apabila pada campuran tersebut terdapat senyawa inert seperti CO_2 dan air, maka fluida representatif ditentukan berdasarkan dengan mengutamakan senyawa dengan dampak *flammable/toxic*, selain kedua senyawa tersebut. Pada Wayang Windu, fluida representatif adalah H_2S dimana fase H_2S saat vessel beroperasi dan keluar dari vessel adalah fase gas. Untuk detail perhitungan dapat dilihat di LAMPIRAN 5: PERHITUNGAN CONSEQUENCE OF FAILURE (COF) DARI STEAM SCRUBBER.

Langkah 2. Pilih ukuran lubang (release hole size) untuk menentukan rentang nilai konsekuensi di perhitungan.

Langkah kedua adalah menentukan ukuran lubang keluaran apabila terjadi kebocoran. Terdapat 4 ukuran lubang keluaran yaitu, *small, medium, large,* dan *rupture*. Tiap ukuran dihitung sebagai jenjang nilai konsekuensi yang dihasilkan. Hal tersebut berhubungan dengan seberapa besar laju keluaran fluida representatif (H_2S). Hasil ditunjukkan pada tabel 4.5 berikut.

Tabel 4.5 Ukuran lubang keluaran.

Release hole number	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

Dari beberapa jenjang nilai diameter ukuran lubang keluaran, diambil ukuran lubang keluaran untuk *small* sebesar 0,25 inch, *medium* 1 inch, *large* 4 inch, dan *rupture* 16 inch.

Langkah 3. Hitung theoretical release rate.

Theoritical release rate (W_n) dihitung tiap ukuran lubang keluaran untuk mendapatkan nilai laju massa keluaran H_2S di setiap ukuran lubang keluaran.

W_1 = 0.001927330 kg/s,
W_2 = 0.090034545 kg/s,
W_3 = 0.460167685 kg/s,
W_4 = 23.04312731 kg/s.

Semakin besar laju massa berarti semakin besar pula dampak yang dapat dihasilkan karena berhubungan dengan total massa H_2S yang dikeluarkan pada setiap waktunya.

Langkah 4. Estimasi total fluida yang dapat dikeluarkan.

Pada langkah ini total massa fluida diestimasi dari volume inventory equipment (volume inventory dapat dilihat di LAMPIRAN 1: DIAGRAM SCRUBBER). Estimasi nilai massa diambil berdasarkan asumsi porsi volume dari liquid dan gas untuk tipe equipment scrubber (knock-out drum) pada Annex 3.A API RP 581, yaitu 90% gas dan 10% liquid. Berikut adalah hasil perhitungannya.

$Mass_{inv}$ = 2005.6 kg.

Berikutnya adalah estimasi total massa inventori yang ditambahkan dengan inventori dari komponen-komponen tambahan yang dapat memberikan massa tambahan. Untuk massa tambahan sendiri, API 581 mengestimasi bahwa terdapat batasan massa, karena dalam 3 menit akan ada intervensi dari operator terhadap kebocoran. Total fluida yang dapat dikeluarkan di setiap lubang keluaran ($mass_{avail,n}$):

$mass_{avail,1}$ = 147.342 kg/s

$mass_{avail,2}$ = 163.201 kg/s

$mass_{avail,3}$ = 229.825 kg/s

$mass_{avail,4}$ = 1185.174 kg/s

Untuk detail perhitungan dapat dilihat di LAMPIRAN 5: PERHITUNGAN CONSEQUENCE OF FAILURE (COF) DARI STEAM SCRUBBER.

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

Kondisi keluaran dinyatakan *instantaneous* apabila dapat mengeluarkan massa 4536 kg dalam waktu kurang dari 180 detik. Perhitungan dilakukan untuk melihat durasi mengeluarkan massa 4536 kg fluida di tiap hole size.

t_1 = 2353511.295 s (*continuous*),

t_2 = 50380.66242 s (*continuous*),

t_3 = 9857.276267 s (*continuous*),

t_4 = 196.848281 s (*continuous*).

Hasil perhitungan menunjukkan bahwa tiap ukuran lubang mengeluarkan massa senilai 4536 kg dengan waktu lebih dari 180 detik.

Langkah 6. Dampak dari sistem deteksi dan isolasi.

Langkah 6 dilakukan untuk mengestimasi dampak dari sistem deteksi dan sistem isolasi terhadap keluaran. Pada perusahaan, sistem deteksinya berupa *visual detection, cameras or detectors with marginal coverage* yang terklasifikasikan sebagai kelas C. Sedangkan sistem isolasinya berupa *isolation dependent on manually operated valves* yang tergolong kelas C. Apabila keduanya tergolong kelas C, maka waktu maksimum kebocoran untuk tiap lubang keluaran adalah:

$Id_{max,1}$ = 1 hour,

$Id_{max,2}$ = 40 minutes,

$Id_{max,3}$ = 20 minutes,

$Id_{max,4}$ = 20 minutes.

Waktu maksimum kebocoran disini sudah termasuk waktu untuk mendeteksi kebocoran, waktu untuk menganalisa insiden dan menentukan tindakan korektif, serta waktu untuk melaksanakan tindakan korektif tersebut.

Langkah 7. Tentukan release rate dan mass untuk analisa consequence.

Untuk keluaran tipe continuous, keluaran digambarkan keluar stabil pada laju tertentu. Laju tersebut didapatkan dari nilai theoretical release rate pada langkah 3. Berikut adalah hasilnya:

$Rate_1$ = 0.001927333 kg/s
$Rate_2$ = 0.090034545 kg/s
$Rate_3$ = 0.460167685 kg/s
$Rate_4$ = 23.04312731 kg/s.

Selain *release rate*, *mass rate* juga harus dihitung sebagai pertimbangan untuk keluaran spontantaneous yang bersifat sementara. Berikut adalah hasilnya:

$Mass_1$ = 6.938398822 kg
$Mass_2$ = 163.201418 kg
$Mass_3$ = 229.8253833 kg
$Mass_4$ = 1185.174313 kg

Release rate dan mass rate digunakan untuk perhitungan konsekuensi di langkah-langkah selanjutnya.

Langkah 8. Hitung flammable/explosive consequence.

Menggunakan nilai release rate dan mass rate pada langkah 7, perhitungan langkah 8 dilakukan untuk menentukan consequence area bagi komponen dan personil dengan menggunakan persamaan 2.37 hingga 2.58. Pada persamaan-persamaan tersebut terdapat konstanta a dan b yang mana nilainya dapat ditentukan dari tabel 4.6 dan 4.7 berikut.

Table 4.6 Konstanta component damage flammable

Continuous Release Constant								Instantaneous Release Constant							
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	
α	b	α	b	α	b	α	b	α	b	α	b	α	b	α	b
6.6	1.0			38.1	0.89			22.6	0.63			53.7	0.61		

Auto ignition not likely berarti temperatur operasi berada di bawah temperatur auto ignition dari H_2S. Temperatur auto ignition H_2S adalah 500°C, sedangkan temperatur operasi adalah 185.4°C. Meskipun begitu, perhitungan untuk (CAIL) harus tetap dilakukan untuk blending factor dari nilai konsekuensi. Sama halnya dengan keluaran instan, meskipun keluarannya tipa kontinyu namun perhitungan instan tetap dilakukan sebagai pertimbangan adanya keluaran instan sementara dan untuk blending factor. Berikut adalah hasil dari konsekuensi flammability bagi komponen:

CA_{cmd}^{flam} = 7.81 m^2

Konsekuensi flammability bagi komponen apabila ada kebocoran, adalah seluas 7.81 m^2.

Sedangkan untuk konsekuensi flammability bagi personil, konstanta a dan b ditentukan dengan,

Table 4.7 Konstanta component damage flammable

Continuous Release Constant								**Instantaneous Release Constant**							
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**	
α	b	α	b	α	b	α	b	α	b	α	b	α	b	α	b
10.7	1.00			73	0.94			41.4	0.63			192	0.63		

Sama halnya dengan tabel 4.6 perhitungan untuk auto ignition likely, dan keluaran konstan tetap dilakukan sebagai blending factor dan pertimbangan adanya keluaran instan sementara. Berikut adalah hasil dari konsekuensi flammability bagi personil:

CA_{inj}^{flam} = 7.504 m^2

Konsekuensi flammability bagi komponen apabila ada kebocoran, adalah seluas 7.504 m^2.

Langkah 9. Hitung toxic consequence.

Pada komposisi fluida geothermal di fasilitas, ditemukan senyawa NH_3 dan H_2S pada fluida tersebut. Senyawa NH_3 hanya memberikan dampak toxic, sedangkan H_2S selain memberikan dampak toxic juga dampak flammability. Nilai konsekuensi toxicity merupakan fungsi dari release rate dan konsentrasi kedua senyawa tersebut pada larutan. Setelah dilakukan perhitungan didapatkan hasil konsekuensi toxicity senilai:

CA_{inj}^{tox} = 10.43 m^2

Langkah 10. Hitung non-flammable, non-toxic consequence.

Langkah ini terdiri atas 2 komponen, yaitu perhitungan untuk *steam* dan untuk *acids and caustics*. Pada fluida di fasilitas, tidak ada senyawa yang tergolong *acids and caustics*, namun terdapat uap. Perlu diingat bahwa untuk pendekatan nilai disini, injury terjadi pada uap diatas 60°C. Berikut adalah hasil yang didapat

CA_{inj}^{nfnt} = 0.0634 m^2

Konsekuensi non-flammable dan non-toxic apabila terjadi kebocoran adalah seluas 0.0634 m^2.

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

Untuk konsekuensi pada komponen, karena hanya ada flammability maka nilainya sama dengan konsekuensi flammability komponen.

CA_{cmd} = 7.81 m^2.

Sedangkan untuk dampak personil, terdapat beberapa konsekuensi yang mempengaruhi, yaitu konsekuensi flammability personil, toxicity, serta non-flammable dan non-toxic. Nilai ketiganya digabungkan, dan menghasilkan:

CA_{inj} = 10.43 m^2.

Total consequence area adalah nilai maksimum dari kedua nilai tersebut.

CA = 10.43 m^2

Untuk detail perhitungan dapat dilihat di LAMPIRAN 5: PERHITUNGAN CONSEQUENCE OF FAILURE (COF) DARI STEAM SCRUBBER.

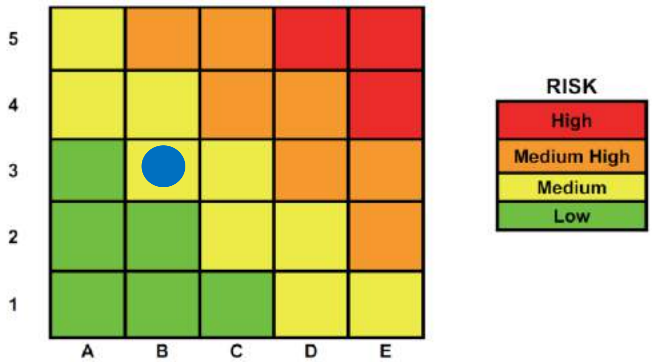
4.4.3. Perencanaan Inspeksi

Perencanaan inspeksi mengacu pada target yang diinginkan oleh perusahaan. Untuk kasus steam scrubber, perusahaan menetapkan target DF target sebesar 100. Karena itu, perencanaan inspeksi dilakukan untuk mencegah damage factor dari komponen melebihi 100. Ringkasan perhitungan dari shell steam scrubber dijelaskan pada tabel 4.8 berikut.

Tabel 4.8 Plotting risiko shell dari steam scrubber

Tanggal	Keterangan	DF	PoF	CoF	Risk (m^2/yr)
03/07/2014	Inspeksi terakhir	50.241	0.0002804	10.43 m^2	0.002924572
01/07/2019	RBI date	293.498	0.001638		0.01708434
01/07/2023	Plan date	492.328	0.0027493		0.028675199
Note: Inspection effectiveness: E					

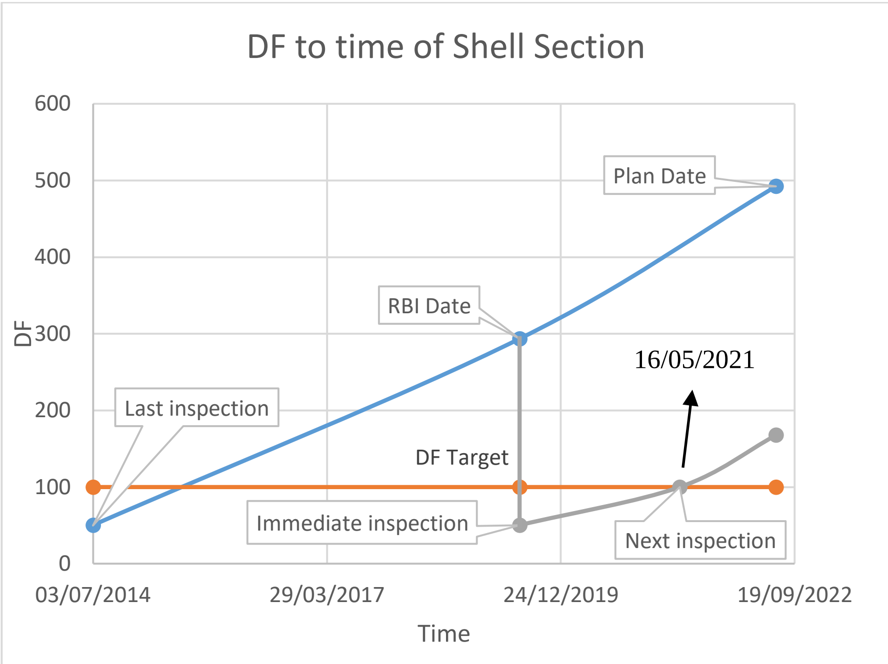
Dari data di tabel 4.8 apabila diplotkan ke dalam matriks risiko, maka risiko steam scrubber VS-81-009 pada saat RBI date berada pada kategori medium. Ditunjukkan pada gambar berikut.



Gambar 4.1 Risiko saat ini dari VS-81-009

Gambar 4.1 menunjukkan risiko saat RBI date dari steam scrubber VS-81-009. Sumbu vertikal dari matriks sendiri berdasarkan nilai damage factor, sedangkan sumbu horizontal merupakan consequence of failure. Untuk penempatan tingkatan nilai dari damage factor dan consequence of failure pada matriks, dapat mengacu pada tabel 2.18.

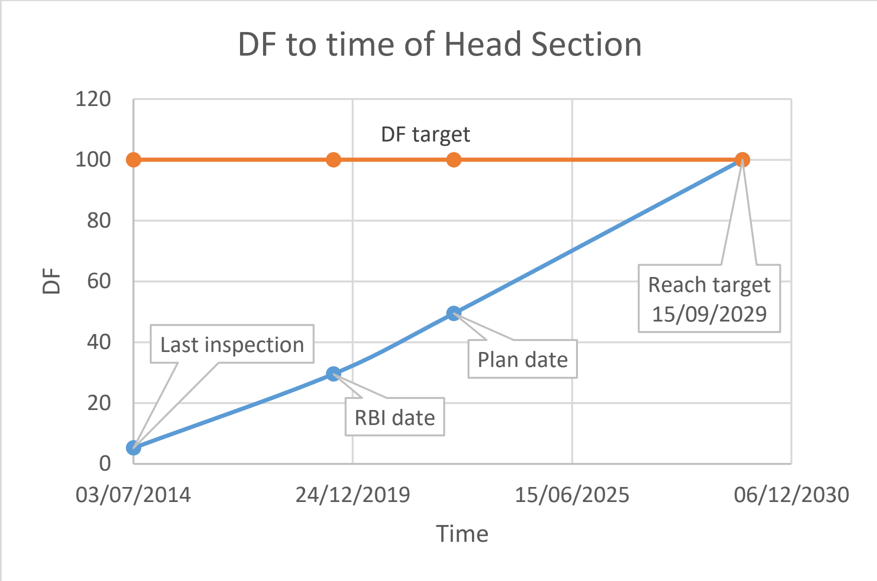
Untuk mendapat target inspection date, dilakukan dengan cara mensimulasi umur scrubber setelah melakukan RBI date hingga melebihi target damage factor. Gambar 4.2 berikut menunjukkan perbandingan antara damage factor dan waktu pada steam scrubber VS-81-009.



Gambar 4.2 Grafik DF to time dari shell steam scrubber

Garis biru pada gambar 4.2 adalah damage factor dari shell steam scrubber apabila tidak dilaksanakan inspeksi. Garis jingga adalah target damage factor. Sedangkan garis abu-abu adalah damage factor dari steam scrubber apabila dilakukan inspeksi sesegera mungkin. Karena pada RBI date, DF komponen sudah jauh melebihi target.

Dengan cara yang sama, dihasilkan pula tanggal inspeksi untuk head section yang dijelaskan pada gambar 4.3 berikut.



Gambar 4.3 Grafik DF to time dari head steam scrubber

Garis biru pada gambar 4.3 adalah damage factor dari head steam scrubber tiap waktu. Garis jingga adalah target damage factor. Damage factor dari head steam scrubber akan mencapai target pada 15 September 2029. DF dari head scrubber yang rendah dikarenakan adanya histori perlakuan PWHT pada komponen tersebut sehingga menjadi lebih tidak rentan terhadap sulfide stress cracking dan HIC/SOHIC – H_2S. Bertepatan dengan rekomendasi tanggal-tanggal tersebut, inspeksi yang disarankan ada pada tabel 4.9 berikut

Tabel 4.9 Rencana inspeksi steam scrubber

<table>
<tr><th>Damage factor</th><th>Efektivitas inspeksi</th><th>Kegiatan Inspeksi</th><th>Tanggal inspeksi shell</th><th>Tangal inspeksi head</th></tr>
<tr><td>Local Thinning</td><td>C (fairly effective)</td><td>Untuk total area:
> cakupan 50% dari CML menggunakan ultrasonic scanning atau profile radiography.</td><td rowspan="3">Sesegera mungkin, dan pada 16/05/ 2021</td><td rowspan="3">15/09/ 2029</td></tr>
<tr><td>Sulfide Stress Cracking</td><td>E (ineffective)</td><td>Laksanakan inspeksi</td></tr>
<tr><td>SIC/SOHIC – H_2S</td><td>E (ineffective)</td><td>Laksanakan inspeksi</td></tr>
</table>

Tabel 4.9 merupakan rekomendasi rencana inspeksi untuk VS-81-009. Pada dasarnya, rencana ini ditujukan untuk menurunkan DF agar nilainya di bawah 100 dengan cara meningkatkan efektivitas inspeksi dari 2 kali inspeksi tingkat E menjadi 2 kali inspeksi tingkat C.

4.5. Steam Ejector EJ-202 (Gas Removal System)

4.5.1. Probability of Failure

Probability of failure didapatkan dari nilai damage factor, generic failure frequency dan factor management system dari perusahaan. Untuk damage factor screening criteria dari steam ejector dapat dilihat di LAMPIRAN 6: DAMAGE FACTOR SCREENING QUESTION DARI STEAM EJECTOR (GAS REMOVAL SYSTEM). Damage factor yang sesuai dengan kondisi dari EJ-202 adalah thinning, sulfide stress cracking, dan HIC/SOHIC – H_2S damage factor. Berikut adalah langkah – langkah perhitungannya.

- **Thinning**

Thinning – merupakan degradasi logam karena lingkungannya yang mengakibatkan penipisan ketebalan logam tersebut. Untuk mengetahui nilai damage factor thinning, memerlukan data laju korosi material. Data tersebut didapatkan dari inspeksi terakhir ataupun perhitungan lajur korosi berdasarkan mekanisme thinning pada Annex 2.B API RP 581. Thinning dapat terjadi karena beberapa mekanisme. Untuk kasus ini, mekanisme thinning yang sesuai dengan screening criteria corrosion rate API RP 581 adalah sour water corrosion, acid sour water corrosion, dan CO_2 corrosion. Sour water dan acid sour water corrosion terjadi karena adanya H_2S pada larutan yang pH nya di bawah 7,0. Sedangkan CO_2 corrosion terjadi karena adanya air serta CO_2 dan material konstruksi adalah carbon steel dengan kadar Cr < 13%. Untuk detail perhitungan dapat dilihat di LAMPIRAN 7: PERHITUNGAN PROBABILITY OF FAILURE (POF) DARI STEAM EJECTOR (GAS REMOVAL SYSTEM). Hasil perhitungan thinning menghasilkan nilai damage factor sebesar 0.241 untuk steam ejector EJ-202.

- **Sulfide Stress Cracking**

Sulfide stress cracking (SSC) didefinisikan sebagai keretakan diakibatkan kombinasi tensile stress dan lingkungan berair dan ber-H_2S. SSC adalah tipe *hydrogen stress cracking* yang dihasilkan dari penyerapan atom hidrogen yang dihasilkan oleh proses korosi sulfida pada permukaan logam. Kerentanan material terhadap sulfide stress cracking dapat diturunkan dengan perlakuan PWHT (*post weld heat treatment*) pada komponen. Untuk steam ejector tidak dilakukan PWHT. Karena itu, nilai sulfide stress cracking damage factor dari EJ-202 adalah 5.8651.

- **HIC/SOHIC – H_2S**

HIC/SOHIC – H_2S merupakan singkatan dari *hydrogen-induced cracking* dan *stress oriented hydrogen-induced cracking* karena pengaruh H_2S. HIC didefinisikan sebagai retakan internal bertahap yang menghubungkan hidrogen blister yang berdekatan pada bidang yang berbeda dalam logam, atau ke permukaan logam. HIC terjadi bukan karena stress eksternal, namun karena penumpukan tekanan internal dari hidrogen blister. Sedangkan SOHIC didefinisikan sebagai susunan blister yang tergabung karena hydrogen-induced cracking yang sejajar dengan arah ketebalan baja sebagai hasil dari tensile stress yang terjadi secara local.

Kerentanan material terhadap HIC/SOHIC akan menurun seiring dengan lebih rendahnya konsentrasi sulfur pada baja, serta perlakuan PWHT pada komponen. Material konstruksi yang digunakan adalah SA 516 Gr. 70 dengan konten sulfur 0.03%. Komponen tidak mengalami perlakuan PWHT, sehingga menghasilkan damage factor 293.26. Untuk detail perhitungan dapat dilihat di LAMPIRAN 7: PERHITUNGAN PROBABILITY OF FAILURE (POF) DARI STEAM EJECTOR (GAS REMOVAL SYSTEM).

- **Probability of Failure**

Probability of failure merupakan kemungkinan terjadinya kegagalan pada komponen. Nilainya merupakan fungsi dari damage factor, generic failure frequency (gff) dan factor management system (fms). Nilai gff ditentukan berdasarkan tipe equipment (vessel) sebesar $3.06x10^{-5}$, nilai fms dapat diketahui dari screening terhadap manajemen perusahaan (dapat dilihat di LAMPIRAN 4B: FACTOR MANAGEMENT SYSTEM) sebesar 0.182, dan nilai damage factor merupakan gabungan dari ketiga damage factor tersebut, dan menghasilkan damage factor sebesar 293.5. Sehingga dihasilkan nilai POF sebesar $1,64x10^{-3}$. Untuk detail perhitungan dapat dilihat di LAMPIRAN 7: PERHITUNGAN PROBABILITY OF FAILURE (POF) DARI STEAM EJECTOR (GAS REMOVAL SYSTEM).

4.5.2. Consequence of Failure

Terdapat 11 langkah untuk menentukan Consequence of Area dari Steam Scrubber, yaitu:

Langkah 1. Tentukan fluida yang dikeluarkan serta karakteristiknya.

Fluida representatif adalah fluida dominan pada sistem yang dijadikan acuan perhitungan apabila terjadi kebocoran pada vessel. Umumnya, fluida representatif adalah senyawa dengan jumlah mol terbanyak pada fluida tersebut. Namun apabila pada campuran tersebut terdapat senyawa inert seperti CO_2 dan air, maka fluida representatif ditentukan berdasarkan dengan mengutamakan senyawa dengan dampak *flammable/toxic,* selain kedua senyawa tersebut. Pada Wayang Windu, fluida representatif adalah H_2S dimana fase H_2S saat vessel beroperasi dan keluar dari vessel adalah fase gas. Untuk detail perhitungan dapat dilihat di LAMPIRAN 8: PERHITUNGAN CONSEQUENCE OF FAILURE (COF) DARI STEAM EJECTOR (GAS REMOVAL SYSTEM).

Langkah 2. Pilih ukuran lubang (release hole size) untuk menentukan rentang nilai konsekuensi di perhitungan.

Langkah kedua adalah menentukan ukuran lubang keluaran apabila terjadi kebocoran. Terdapat 4 ukuran lubang keluaran yaitu, *small*, *medium*, *large*, dan *rupture*. Tiap ukuran dihitung sebagai jenjang nilai konsekuensi yang dihasilkan. Hal tersebut berhubungan dengan seberapa besar laju keluaran fluida representatif (H_2S). Hasil ditunjukkan pada tabel 4.5 di sub bab 4.4. Dari beberapa jenjang nilai diameter ukuran lubang keluaran, diambil ukuran lubang keluaran untuk *small* sebesar 0,25 inch, *medium* 1 inch, *large* 4 inch, dan *rupture* 16 inch.

Langkah 3. Hitung theoretical release rate.

Theoritical release rate (W_n) dihitung tiap ukuran lubang keluaran untuk mendapatkan nilai laju massa keluaran H_2S di setiap ukuran lubang keluaran.

W_1 = 0.00123069 kg/s,
W_2 = 0.019695984 kg/s,
W_3 = 0.315135739 kg/s,
W_4 = 5.040921366 kg/s.

Semakin besar laju massa berarti semakin besar pula dampak yang dapat dihasilkan karena berhubungan dengan total massa H_2S yang dikeluarkan pada setiap waktunya.

Langkah 4. Estimasi total fluida yang dapat dikeluarkan.

Pada langkah ini total massa fluida diestimasi dari volume inventory equipment (volume inventory dapat dilihat di LAMPIRAN 2: DIAGRAM STEAM EJECTOR). Estimasi nilai massa diambil berdasarkan asumsi porsi volume dari liquid dan gas untuk tipe equipment scrubber (knock-out drum) pada Annex 3.A API RP 581, yaitu 90% gas dan 10% liquid. Berikut adalah hasil perhitungannya.

$Mass_{inv}$ = 862.42 kg.

Berikutnya adalah estimasi total massa inventori yang ditambahkan dengan inventori dari komponen-komponen tambahan yang dapat memberikan massa tambahan. Untuk massa tambahan sendiri, API 581 mengestimasi bahwa terdapat batasan massa, karena dalam 3 menit akan ada intervensi dari operator terhadap kebocoran. Total fluida yang dapat dikeluarkan di setiap lubang keluaran ($mass_{avail,n}$):

$mass_{avail,1}$ = 63.432 kg/s
$mass_{avail,2}$ = 66.755 kg/s
$mass_{avail,3}$ = 119.934 kg/s
$mass_{avail,4}$ = 826.914 kg/s

Untuk detail perhitungan dapat dilihat di LAMPIRAN 8: PERHITUNGAN CONSEQUENCE OF FAILURE (COF) DARI STEAM EJECTOR (GAS REMOVAL SYSTEM).

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

Kondisi keluaran dinyatakan *instantaneous* apabila dapat mengeluarkan massa 4536 kg dalam waktu kurang dari 180 detik. Perhitungan dilakukan untuk melihat durasi mengeluarkan massa 4536 kg fluida di tiap hole size.

t_1 = 3685726.21 s (*continuous*),
t_2 = 230300.7593 s (*continuous*),
t_3 = 14393.79745 s (*continuous*),
t_4 = 899.8355005 s (*continuous*).

Hasil perhitungan menunjukkan bahwa tiap ukuran lubang mengeluarkan massa senilai 4536 kg dengan waktu lebih dari 180 detik.

Langkah 6. Dampak dari sistem deteksi dan isolasi.

Langkah 6 dilakukan untuk mengestimasi dampak dari sistem deteksi dan sistem isolasi terhadap keluaran. Pada perusahaan, sistem deteksinya berupa *visual detection, cameras or detectors with marginal coverage* yang terklasifikasikan sebagai kelas C. Sedangkan sistem isolasinya berupa *isolation dependent on manually operated valves* yang tergolong kelas C. Apabila keduanya tergolong kelas C, maka waktu maksimum kebocoran untuk tiap lubang keluaran adalah:

$Id_{max,1}$ = 1 hour,
$Id_{max,2}$ = 40 minutes,
$Id_{max,3}$ = 20 minutes,
$Id_{max,4}$ = 20 minutes.

Waktu maksimum kebocoran disini sudah termasuk waktu untuk mendeteksi kebocoran, waktu untuk menganalisa insiden dan menentukan tindakan korektif, serta waktu untuk melaksanakan tindakan korektif tersebut.

Langkah 7. Tentukan release rate dan mass untuk analisa consequence.

Untuk keluaran tipe continuous, keluaran digambarkan keluar stabil pada laju tertentu. Laju tersebut didapatkan dari nilai theoretical release rate pada langkah 3. Berikut adalah hasilnya:

$Rate_1$ = 0.001230694 kg/s
$Rate_2$ = 0.019695984 kg/s
$Rate_3$ = 0.315135739 kg/s
$Rate_4$ = 5.040921366 kg/s.

Selain *release rate*, *mass rate* juga harus dihitung sebagai pertimbangan untuk keluaran spontantaneous yang bersifat sementara. Berikut adalah hasilnya:

$Mass_1$ = 4.430497294 kg
$Mass_2$ = 47.27036088 kg
$Mass_3$ = 119.9344571 kg
$Mass_4$ = 826.9139004 kg

Release rate dan mass rate digunakan untuk perhitungan konsekuensi di langkah-langkah selanjutnya.

Langkah 8. Hitung flammable/explosive consequence.

Menggunakan nilai release rate dan mass rate pada langkah 7, perhitungan langkah 8 dilakukan untuk menentukan consequence area bagi komponen dan personil dengan menggunakan persamaan 2.37 hingga 2.58. Pada persamaan-persamaan tersebut terdapat konstanta a dan b yang mana nilainya dapat ditentukan dari tabel 4.6 dan 4.7 pada sub bab 4.4. Berikut adalah hasil dari konsekuensi flammability bagi komponen:

CA_{cmd}^{flam} = 2.07 m^2

Konsekuensi flammability bagi komponen apabila ada kebocoran, adalah seluas 2.07 m^2.

Meskipun temperatur auto ignition H_2S adalah 500°C, sedangkan temperatur operasi adalah 26,5°C, perhitungan untuk auto ignition dan konstan release harus tetap dilakukan untuk blending factor dan pertimbangan adanya keluaran instan sementara. Sama halnya dengan flammability komponen, perhitungan untuk auto ignition likely, dan keluaran konstan tetap melakukan perhitungan tersebut. Berikut adalah hasil dari konsekuensi flammability bagi personil:

CA_{inj}^{flam} = 2.342 m^2

Konsekuensi flammability bagi komponen apabila ada kebocoran, adalah seluas 2.342 m^2.

Langkah 9. Hitung toxic consequence.

Pada komposisi fluida geothermal di fasilitas, ditemukan senyawa NH_3 dan H_2S pada fluida tersebut. Senyawa NH_3 hanya memberikan dampak toxic, sedangkan H_2S selain memberikan dampak toxic juga dampak flammability. Nilai konsekuensi toxicity merupakan fungsi dari release rate dan konsentrasi kedua senyawa tersebut pada larutan. Setelah dilakukan perhitungan didapatkan hasil konsekuensi toxicity senilai:

CA_{inj}^{tox} = 1.72 m^2

Langkah 10. Hitung non-flammable, non-toxic consequence.

Langkah ini terdiri atas 2 komponen, yaitu perhitungan untuk *steam* dan untuk *acids and caustics*. Pada fluida di fasilitas, tidak ada senyawa yang tergolong *acids and caustics*, namun terdapat uap. Perlu diingat bahwa untuk pendekatan nilai disini, injury terjadi pada uap diatas 60°C. Namun karena suhu operasi steam ejector ada pada 26.5°C. Maka langkah ini dilewat.

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

Untuk konsekuensi pada komponen, karena hanya ada flammability maka nilainya sama dengan konsekuensi flammability komponen.

CA_{cmd} = 2.07 m^2.

Sedangkan untuk dampak personil, terdapat beberapa konsekuensi yang mempengaruhi, yaitu konsekuensi flammability personil, toxicity, serta non-flammable dan non-toxic. Nilai ketiganya digabungkan, dan menghasilkan:
CA_{inj} = 2.342 m^2.
Total consequence area adalah nilai maksimum dari kedua nilai tersebut.

CA = 2.342 m^2

Untuk detail perhitungan dapat dilihat di LAMPIRAN 8: PERHITUNGAN CONSEQUENCE OF FAILURE (COF) DARI STEAM EJECTOR (GAS REMOVAL SYSTEM).

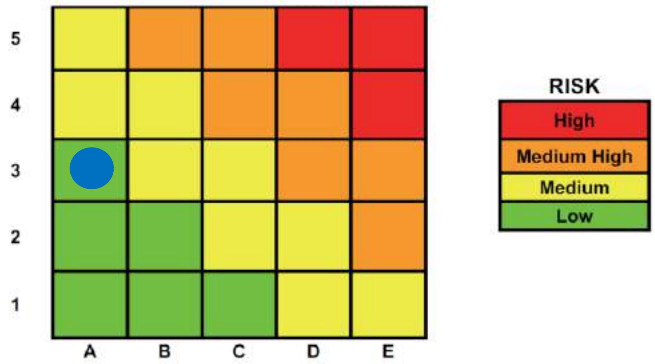
4.5.3. Perencanaan Inspeksi

Perencanaan inspeksi mengacu pada target yang diinginkan oleh perusahaan. Untuk kasus steam scrubber, perusahaan menetapkan target DF target sebesar 100. Karena itu, perencanaan inspeksi dilakukan untuk mencegah damage factor dari komponen melebihi 100. Ringkasan perhitungan dari steam ejector dijelaskan pada tabel 4.10 berikut.

Table 4.10 Plotting risiko shell dari steam ejector

Tanggal	Keterangan	DF	PoF	CoF	Risk (m^2/yr)
03/07/2014	Inspeksi terakhir	50.241	0.0002804	2.342 m^2	0.000656697
01/07/2019	RBI date	293.498	0.001638		0.003836196
01/07/2023	Plan date	492.328	0.0027493		0.006438861
Note: Inspection effectiveness: E					

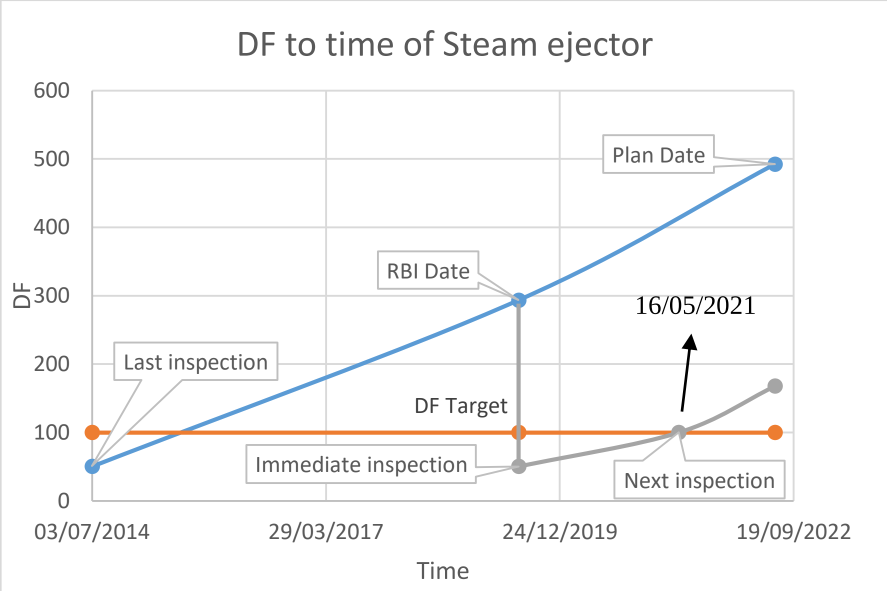
Dari data di tabel 4.10 apabila diplotkan ke dalam matriks risiko, maka risiko steam ejector EJ-202 pada saat RBI date berada pada kategori low. Ditunjukkan pada gambar berikut.



Gambar 4.4 . Risiko saat ini dari EJ-202

Gambar 4.4 menunjukkan risiko saat RBI date dari steam scrubber EJ-202. Sumbu vertikal dari matriks sendiri berdasarkan nilai damage factor, sedangkan sumbu horizontal merupakan consequence of failure. Untuk penempatan tingkatan nilai dari damage factor dan consequence of failure pada matriks, dapat mengacu pada tabel 2.18.

Untuk mendapat target inspection date, dilakukan dengan cara mensimulasi umur scrubber setelah melakukan RBI date hingga melebihi target damage factor. Gambar 4.2 berikut menunjukkan perbandingan antara damage factor dan waktu pada steam scrubber VS-81-009.



Gambar 4.5 Grafik DF to time dari shell steam scrubber

Garis biru pada gambar 4.2 adalah damage factor dari steam ejector apabila tidak dilaksanakan inspeksi. Garis jingga adalah target damage factor. Sedangkan garis abu-abu adalah damage factor dari steam scrubber apabila dilakukan inspeksi sesegera mungkin. Karena pada RBI date, DF equipment sudah jauh melebihi target. DF dari ejector yang tinggi dikarenakan tidak adanya histori perlakuan PWHT pada equipment tersebut sehingga menjadi lebih rentan terhadap sulfide stress cracking dan HIC/SOHIC – H_2S. Berikut adalah rekomendasi mengenai inspeksi steam ejector yang ditunjukkan oleh tabel 4.11

Tabel 4.11 Rencana inspeksi steam scrubber

Damage factor	Efektivitas inspeksi	Kegiatan Inspeksi	Tanggal inspeksi
Local Thinning	C (fairly effective)	Untuk total area: > cakupan 50% dari CML menggunakan ultrasonic scanning atau profile radiography.	Sesegera mungkin, dan pada 16/05/ 2021
Sulfide Stress Cracking	E (ineffective)	Laksanakan inspeksi	
SIC/SOHIC – H_2S	E (ineffective)	Laksanakan inspeksi	

BAB V
KESIMPULAN DAN SARAN

5.1. Kesimpulan

1. Berikut adalah nilai dari probability of failure, damage factor, dan consequence of failure dari steam scrubber dan steam ejector (gas removal system).

		RBI date		Plan date		CoF (m^2)
		DF	PoF	DF	PoF	
Scrubber	Shell	293.498	0.001638	492.328	0.0027493	10.43
	Head	29.5667	0.000163	49.4497	0.000274	10.43
Steam Ejector		293.498	0.001638	492.328	0.0027493	2.342

2. Terdapat penurunan yang tidak signifikan pada kategori risiko setelah inspeksi, dapat dilihat pada tabel berikut.

	Risiko tanpa dilaksanakan inspeksi		Inspeksi dilaksanakan
	Pada RBI date	Pada plan date	Pada inspection date
Steam Scrubber (VS-81-009)	4B	4B	3B
Steam Ejector (EJ-202)	3A	4A	3A

Warna kuning menandakan risiko berada pada tingkat medium, sedangkan hijau pada tingkat low.

3. Target dari perusahaan adalah damage factor = 100. Dengan rancangan tersebut, penulis menyarankan:

<table>
<tr><th>Damage factor</th><th>Efektivitas inspeksi</th><th>Kegiatan Inspeksi</th><th colspan="3">Tanggal Inspeksi</th></tr>
<tr><td>Local Thinning</td><td>C (fairly effective)</td><td>Untuk total area:
> cakupan 50% dari CML menggunakan ultrasonic scanning atau profile radiography.</td><td rowspan="3">Untuk Shell scrubber:

Sesegera mungkin, dan pada 16/05/ 2021</td><td rowspan="3">Untuk head scrubber:

15/09/ 2029</td><td rowspan="3">Untuk steam ejector:

Secepat nya, dan 16/05/ 2021</td></tr>
<tr><td>Sulfide Stress Cracking</td><td>E (ineffective)</td><td>Laksanakan inspeksi</td></tr>
<tr><td>SIC/SOHIC – H_2S</td><td>E (ineffective)</td><td>Laksanakan inspeksi</td></tr>
</table>

5.2. Saran

1. Sesegera mungkin melakukan inspeksi terhadap shell dari steam scrubber VS-81-009 dan steam ejector EJ-202, karena damage faktor komponen tersebut sudah jauh melebihi target.
2. Mengadakan inspeksi setiap 3 tahun sekali. Karena rentang waktu untuk steam scrubber dan steam ejector mencapai damage target adalah 3 tahun.
3. Inspeksi untuk head section dari steam scrubber dilaksanakan bersamaan dengan inspeksi shell section, 3 tahun sekali.

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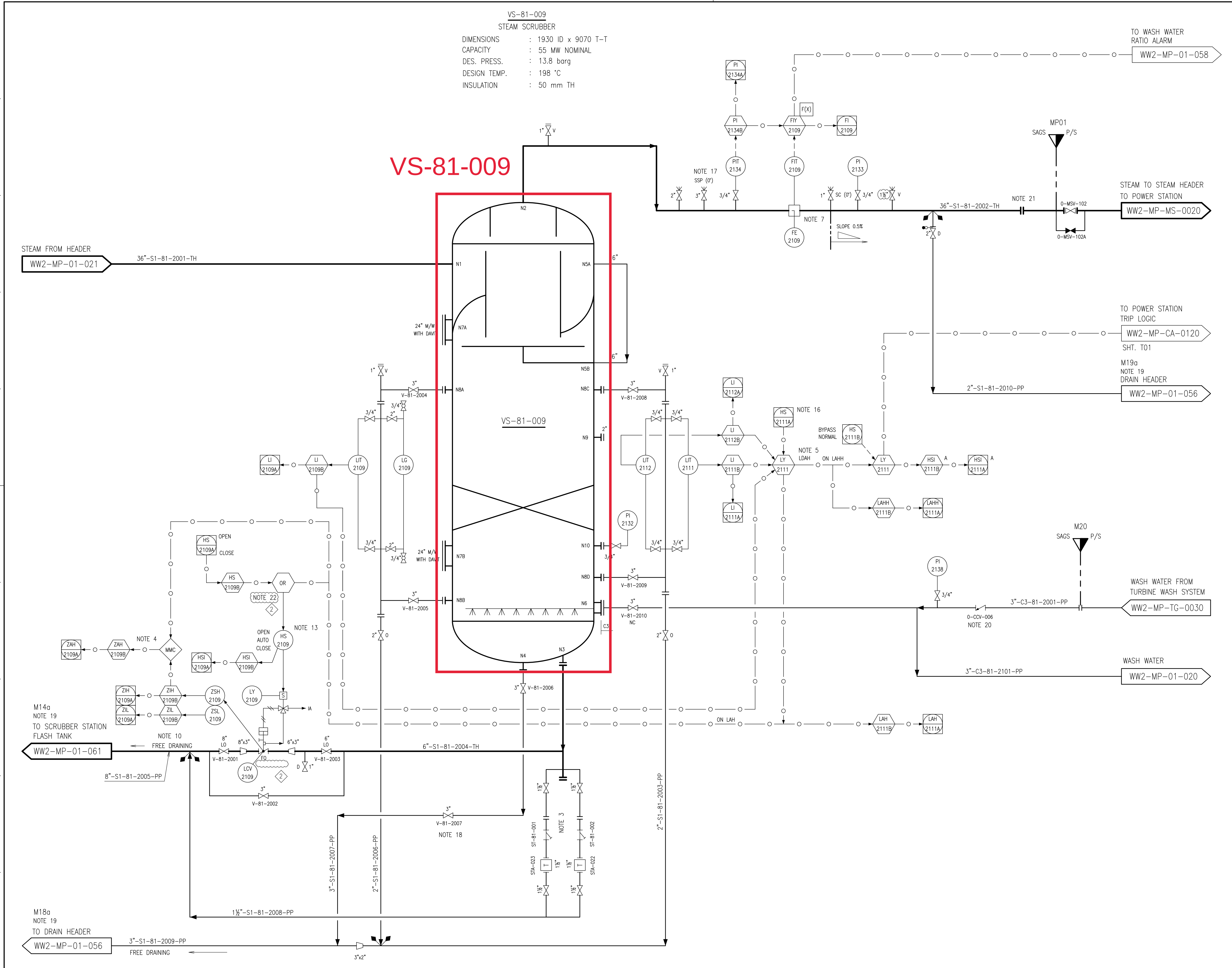
LAMPIRAN 1:

DIAGRAM SCRUBBER



NOTES :

1. PROVIDE VENTS AT ALL HIGHT POINTS AND DRAINS AT ALL LOW POINTS. ALL DRAINS RUN TO SCRUBBER PLANT DRAIN COLLECTION SYSTEM.
2. DELETED.
3. PROVIDE ACCESS FLANGES FOR CLEANOUT OF LINE.
4. IF HIGH LEVEL ON LIT TRIGERED AND LCV NOT FULLY OPEN WITHIN 15 SECONDS. ZAH SOUNDS.
5. 2 OUT OF 3 ALARM AND TRIP LOGIC FROM SCRUBBER LIT'S.
6. DELETED.
7. PROVIDE SUFFICIENT STRAIGHT LENGTH OF PIPE UPSTREAM AND DOWNSTREAM OF ANNUBAR (3D, 4D).
8. DELETED.
9. DELETED.
10. LCV LINE FREE DRAINS TO FLASH TANK.
11. DELETED.
12. DELETED.
13. IN AUTO LCV OPENS ON SCRUBBER LAH. VALVE MUST BE CLOSED MANUALLY VIA LOCAL OR REMOTE OPERATOR CONTROLS.
14. DELETED.
15. DELETED.
16. HS ALLOWS INDIVIDUAL LEVEL SIGNALS TO BE ISOLATED FROM ALARM/TRIP LOGIC AT LEAS ONE SIGNAL IS AVAILABLE AT ANY TIME.
17. VALVE ONLY FOR PROBE.
18. VALVE LOCATED OUTSIDE VESSEL SKIRT.
19. INTERFACE POINT AS TABLE 1.1 EXHIBIT AE SEC.1
20. CHECK VALVE IS SUPPLIED BY FES AND WILL BE INSTALLED BY REK.
21. REMOVABLE SPOOL.
22. AUTO STROKE IS APPLIED ON LCV (SEE DOCUMENT NO. WW2-IN-00-006). 2

REV.	DESCRIPTION	DATE	DRAWN	DSGN	CHKD	APVD	
2	AS BUILT	27/03/09	MB	AP	TZ	TR	JUN
1	AS BUILT	03/03/09	MB	AP	TZ	TR	JUN
0	AS BUILT	02/02/09	MB	AP	TZ	TR	JUN
F	REVISED AS MNL COMMENT	16/05/08	MB	AP	TZ	TR	JUN
E	REVISED AS MNL COMMENT	17/01/08	MB	ESR	TZ	TR	JUN
D	REVISED AS MNL COMMENT	02/01/08	MB	ESR	TZ	TR	JUN
C	REVISED AS MNL COMMENT	22/11/07	MB	AP	TZ	TR	JUN
B	REVISED AS MNL COMMENT	27/09/07	MB	AP	TZ	TR	JUN
A	REVISED AS MNL COMMENT	16/08/07	MB	AP	TZ	TR	JUN

REVISIONS

REV.	E	DATE	13/02/08	APPROVED	TR	JUN

ISSUED FOR CONSTRUCTION

Dwg Status: AS BUILT

Owner: MAGMA NUSANTARA LTD

PROJECT: WAYANG WINDU UNIT 2 GEOTHERMAL POWER PROJECT

Contract No.: 71510012-OS

Contractor: Sumitomo Corporation

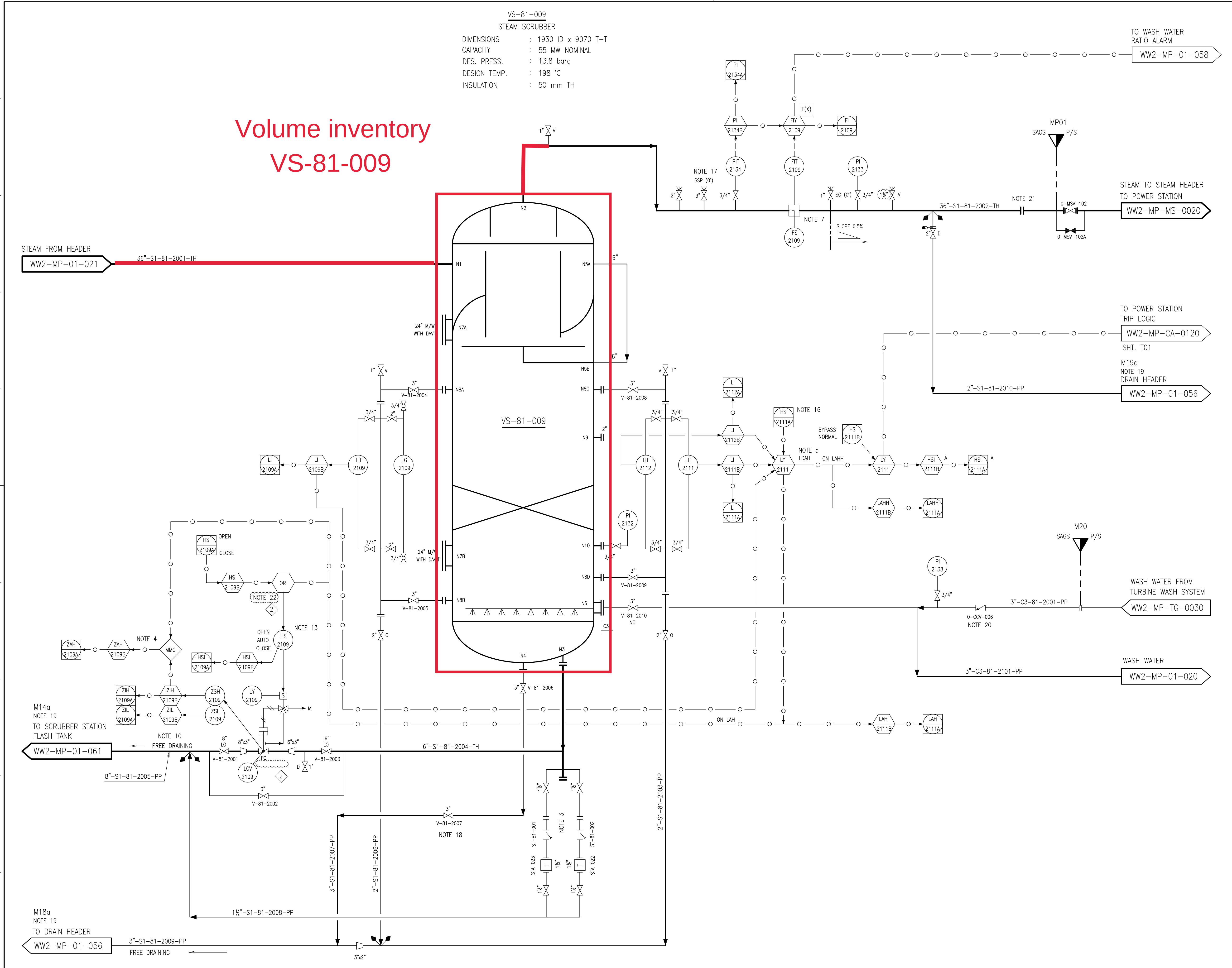
PT REKAYASA INDUSTRI
ENGINEERING & CONSTRUCTION

DWG TITLE: P & I DIAGRAM STEAM SCRUBBER VS-81-009 (AREA 81)

SCALE : N.T.S — REK'S JOB NO. : 07-1109

PROJECT: WW2 — Drawing No.: WW2-MP-01-019 — Revision: 2

FILE : WW2-MP-01-019-2



NOTES :

1. PROVIDE VENTS AT ALL HIGHT POINTS AND DRAINS AT ALL LOW POINTS. ALL DRAINS RUN TO SCRUBBER PLANT DRAIN COLLECTION SYSTEM.
2. DELETED.
3. PROVIDE ACCESS FLANGES FOR CLEANOUT OF LINE.
4. IF HIGH LEVEL ON LIT TRIGERED AND LCV NOT FULLY OPEN WITHIN 15 SECONDS. ZAH SOUNDS.
5. 2 OUT OF 3 ALARM AND TRIP LOGIC FROM SCRUBBER LIT'S.
6. DELETED.
7. PROVIDE SUFFICIENT STRAIGHT LENGTH OF PIPE UPSTREAM AND DOWNSTREAM OF ANNUBAR (3D, 4D).
8. DELETED.
9. DELETED.
10. LCV LINE FREE DRAINS TO FLASH TANK.
11. DELETED.
12. DELETED.
13. IN AUTO LCV OPENS ON SCRUBBER LAH. VALVE MUST BE CLOSED MANUALLY VIA LOCAL OR REMOTE OPERATOR CONTROLS.
14. DELETED.
15. DELETED.
16. HS ALLOWS INDIVIDUAL LEVEL SIGNALS TO BE ISOLATED FROM ALARM/TRIP LOGIC AT LEAS ONE SIGNAL IS AVAILABLE AT ANY TIME.
17. VALVE ONLY FOR PROBE.
18. VALVE LOCATED OUTSIDE VESSEL SKIRT.
19. INTERFACE POINT AS TABLE 1.1 EXHIBIT AE SEC.1
20. CHECK VALVE IS SUPPLIED BY FES AND WILL BE INSTALLED BY REK.
21. REMOVABLE SPOOL.
22. AUTO STROKE IS APPLIED ON LCV (SEE DOCUMENT NO. WW2-IN-00-006). 2

REV.	DESCRIPTION	DATE	DRAWN	DSGN	CHKD	APVD	
2	AS BUILT	27/03/09	MB	AP	TZ	TR	JUN
1	AS BUILT	03/03/09	MB	AP	TZ	TR	JUN
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A	REVISED AS MNL COMMENT	16/08/07	MB	AP	TZ	TR	JUN

REVISIONS

REV.	E	DATE	13/02/08	APPROVED	TR	JUN

ISSUED FOR CONSTRUCTION

Dwg Status
AS BUILT

Owner
MAGMA NUSANTARA LTD

PROJECT
WAYANG WINDU UNIT 2
GEOTHERMAL POWER PROJECT

Contract No.
71510012-OS

Contractor
Sumitomo Corporation

PT REKAYASA INDUSTRI
ENGINEERING & CONSTRUCTION

DWG TITLE
P & I DIAGRAM
STEAM SCRUBBER VS-81-009 (AREA 81)

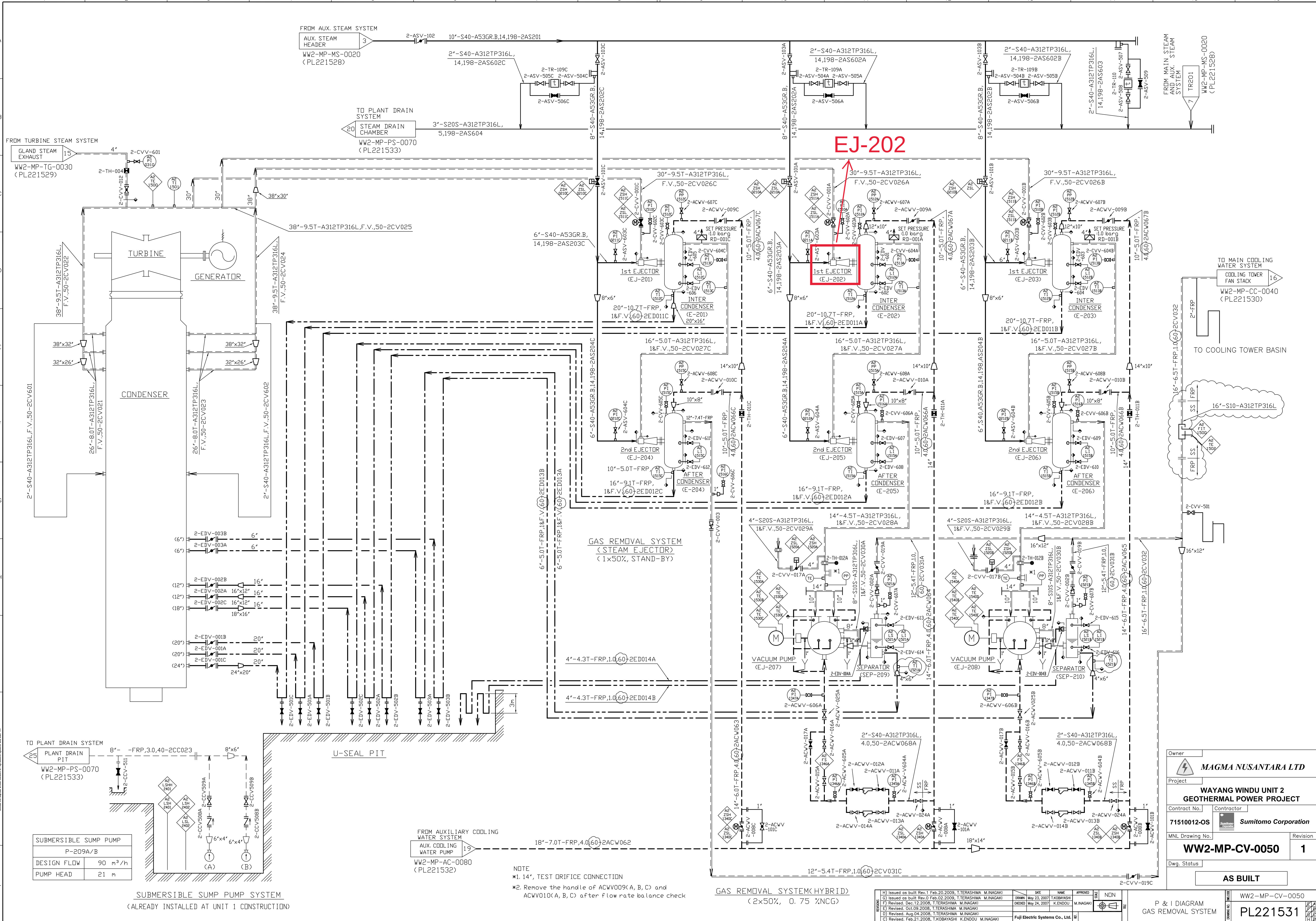
SCALE : N.T.S
REK'S JOB NO. : 07-1109

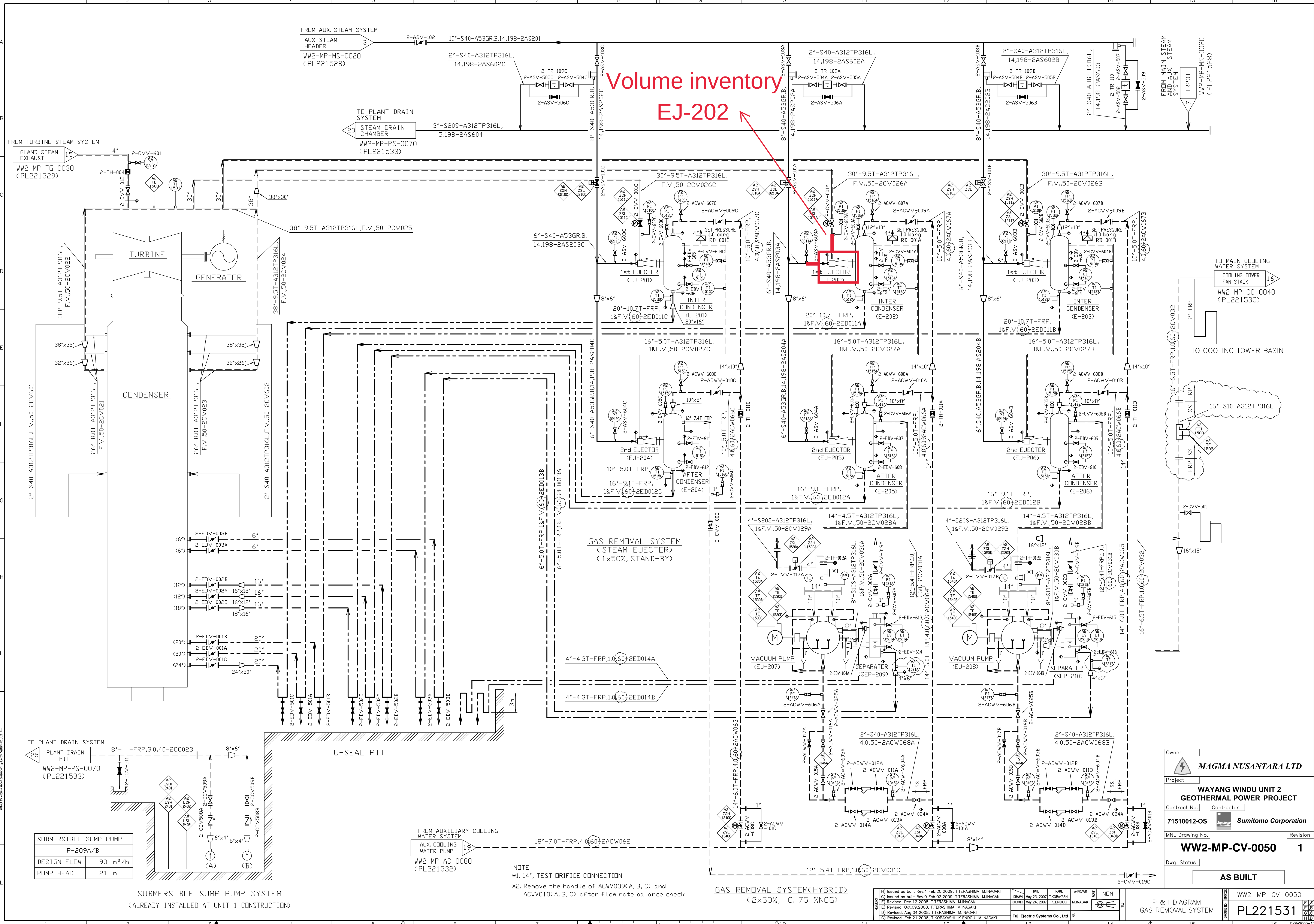
PROJECT: WW2
Drawing No.: WW2-MP-01-019
Revision: 2

FILE : WW2-MP-01-019-2

LAMPIRAN 2:

DIAGRAM GAS REMOVAL SYSTEM


EJ-202
FROM AUX. STEAM SYSTEM
AUX. STEAM HEADER
WW2-MP-MS-0020 (PL221528)
10"-S40-A53GR.B,14,198-2AS201
TO PLANT DRAIN SYSTEM
STEAM DRAIN CHAMBER
WW2-MP-PS-0070 (PL221533)
3"-S20S-A312TP316L, 5,198-2AS604
FROM TURBINE STEAM SYSTEM
GLAND STEAM EXHAUST
WW2-MP-TG-0030 (PL221529)
FROM MAIN STEAM AND AUX. STEAM SYSTEM
TR201
WW2-MP-MS-0020 (PL221528)
TURBINE
GENERATOR
CONDENSER
38"-9.5T-A312TP316L,F.V.,50-2CV025
1st EJECTOR (EJ-201)
1st EJECTOR (EJ-202)
1st EJECTOR (EJ-203)
INTER CONDENSER (E-201)
INTER CONDENSER (E-202)
INTER CONDENSER (E-203)
2nd EJECTOR (EJ-204)
2nd EJECTOR (EJ-205)
2nd EJECTOR (EJ-206)
AFTER CONDENSER (E-204)
AFTER CONDENSER (E-205)
AFTER CONDENSER (E-206)
SET PRESSURE 1.0 barg RD-001C
SET PRESSURE 1.0 barg RD-001A
SET PRESSURE 1.0 barg RD-001B
TO MAIN COOLING WATER SYSTEM
COOLING TOWER FAN STACK
WW2-MP-CC-0040 (PL221530)
TO COOLING TOWER BASIN
GAS REMOVAL SYSTEM (STEAM EJECTOR) (1x50%, STAND-BY)
VACUUM PUMP (EJ-207)
VACUUM PUMP (EJ-208)
SEPARATOR (SEP-209)
SEPARATOR (SEP-210)
U-SEAL PIT
TO PLANT DRAIN SYSTEM
PLANT DRAIN PIT
WW2-MP-PS-0070 (PL221533)
SUBMERSIBLE SUMP PUMP
P-209A/B
DESIGN FLOW 90 m³/h
PUMP HEAD 21 m
SUBMERSIBLE SUMP PUMP SYSTEM (ALREADY INSTALLED AT UNIT 1 CONSTRUCTION)
FROM AUXILIARY COOLING WATER SYSTEM
AUX. COOLING WATER PUMP
WW2-MP-AC-0080 (PL221532)
18"-7.0T-FRP,4.0,60-2ACW062
12"-5.4T-FRP,1.0,60-2CV031C
NOTE
*1. 14", TEST ORIFICE CONNECTION
*2. Remove the handle of ACWV009(A, B, C) and ACWV010(A, B, C) after flow rate balance check
GAS REMOVAL SYSTEM (HYBRID) (2x50%, 0.75 %NCG)
H) Issued as built Rev.1 Feb.20.2009, T.TERASHIMA M.INAGAKI
G) Issued as built Rev.0 Feb.02.2009, T.TERASHIMA M.INAGAKI
F) Revised. Dec.12.2008, T.TERASHIMA M.INAGAKI
E) Revised. Oct.09.2008, T.TERASHIMA M.INAGAKI
D) Revised. Aug.04.2008, T.TERASHIMA M.INAGAKI
C) Revised. Feb.21.2008, T.KOBAYASHI K.ENDOU M.INAGAKI
DRAWN May 23, 2007 T.KOBAYASHI
CHECKED May 24, 2007 K.ENDOU M.INAGAKI
Fuji Electric Systems Co., Ltd.
NON
P & I DIAGRAM GAS REMOVAL SYSTEM
WW2-MP-CV-0050
PL221531
Owner
MAGMA NUSANTARA LTD
Project
WAYANG WINDU UNIT 2 GEOTHERMAL POWER PROJECT
Contract No. 71510012-OS
Contractor Sumitomo Corporation
MNL Drawing No. WW2-MP-CV-0050
Revision 1
Dwg. Status AS BUILT


Volume inventory
EJ-202
FROM AUX. STEAM SYSTEM
AUX. STEAM HEADER
WW2-MP-MS-0020 (PL221528)
TO PLANT DRAIN SYSTEM
STEAM DRAIN CHAMBER
WW2-MP-PS-0070 (PL221533)
FROM TURBINE STEAM SYSTEM
GLAND STEAM EXHAUST
WW2-MP-TG-0030 (PL221529)
TURBINE
GENERATOR
CONDENSER
1st EJECTOR (EJ-201)
1st EJECTOR (EJ-202)
1st EJECTOR (EJ-203)
INTER CONDENSER (E-201)
INTER CONDENSER (E-202)
INTER CONDENSER (E-203)
2nd EJECTOR (EJ-204)
2nd EJECTOR (EJ-205)
2nd EJECTOR (EJ-206)
AFTER CONDENSER (E-204)
AFTER CONDENSER (E-205)
AFTER CONDENSER (E-206)
SET PRESSURE 1.0 barg RD-001C
SET PRESSURE 1.0 barg RD-001A
SET PRESSURE 1.0 barg RD-001B
GAS REMOVAL SYSTEM (STEAM EJECTOR) (1x50%, STAND-BY)
VACUUM PUMP (EJ-207)
VACUUM PUMP (EJ-208)
SEPARATOR (SEP-209)
SEPARATOR (SEP-210)
GAS REMOVAL SYSTEM(HYBRID) (2x50%, 0.75 %NCG)
TO MAIN COOLING WATER SYSTEM
COOLING TOWER FAN STACK
WW2-MP-CC-0040 (PL221530)
TO COOLING TOWER BASIN
FROM MAIN STEAM AND AUX. STEAM SYSTEM
WW2-MP-MS-0020 (PL221528)
U-SEAL PIT
TO PLANT DRAIN SYSTEM
PLANT DRAIN PIT
WW2-MP-PS-0070 (PL221533)
SUBMERSIBLE SUMP PUMP
P-209A/B
DESIGN FLOW 90 m³/h
PUMP HEAD 21 m
SUBMERSIBLE SUMP PUMP SYSTEM
(ALREADY INSTALLED AT UNIT 1 CONSTRUCTION)
FROM AUXILIARY COOLING WATER SYSTEM
AUX. COOLING WATER PUMP
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NOTE
*1. 14", TEST ORIFICE CONNECTION
*2. Remove the handle of ACWV009(A, B, C) and ACWV010(A, B, C) after flow rate balance check
MAGMA NUSANTARA LTD
WAYANG WINDU UNIT 2 GEOTHERMAL POWER PROJECT
Contract No. 71510012-OS
Sumitomo Corporation
MNL Drawing No. WW2-MP-CV-0050
Revision 1
AS BUILT
H) Issued as built Rev.1 Feb.20.2009, T.TERASHIMA M.INAGAKI
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F) Revised. Dec.12.2008, T.TERASHIMA M.INAGAKI
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C) Revised. Feb.21.2008, T.KOBAYASHI K.ENDOU M.INAGAKI
Fuji Electric Systems Co., Ltd.
P & I DIAGRAM
GAS REMOVAL SYSTEM
WW2-MP-CV-0050
PL221531

LAMPIRAN 3:

DAMAGE FACTOR SCREENING QUESTION DARI STEAM SCUBBER

DAMAGE FACTOR SCREENING QUESTION

DETERMINATION OF PROBABILITY OF FAILURE

API 581 PART 2

I. DAMAGE FACTOR

Damage Factor(s) provides a screening tool to determine inspection priorities and optimize inspection. The basic function of the DF is to statistically evaluate the amount of damage that may be present as a function of time in service and the effectiveness of an inspection activity. DFs are calculated based on the 3 different techniques as mentioned below, but are not intended to reflect the actual POF for the purposes of reliability analysis. DFs reflect a relative level of concern about the component based on the stated assumptions in each of the applicable sectiion of the document.

a. Structural reliability modes

b. Statistical models based on generic data

c. Expert judgement

Table of Damage Factor Screening Questions

No	Damage Factor	Screening Criteria	Yes/No
1.	Thining	All component should be checked for thining	Yes
2.	Component Lining	If the component has organic or inorganic lining, then the component should be evaluated for lining damage	No
3.	SCC Damage Factor-Caustic Cracking	If the component's material of construction is carbon or low alloy steel and the process environment contains caustic in any concentration, then the component should be evaluated for susceptibility to caustic cracking.	No
4.	SCC Damage Factor-Amine Cracking	If the component's material of construction is carbon or low alloy steel and process environment contains acid gas treating amines (MEA, DEA, DIPA, MDEA, etc.) in any concentration, then the component should be evaluated for susceptibility to amine cracking.	No
5.	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 H_2S in any concentration, then the component should be evaluated to Sulfide Ctress Cracking (SCC).	Yes
6.	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 H_2S in any concentration, then the component should be evaluated to HIC/SOHIC-H_2S cracking.	Yes

<table>
<tr><th>No</th><th>Damage Factor</th><th colspan="3">Screening Criteria</th><th>Yes/No</th></tr>
<tr><td rowspan="3">7.</td><td rowspan="3">SCC Damage Factor-Carbonate Stress Corrosion Cracking</td><td colspan="3">If the component’s material of construction is carbon or low alloy steel and the process environment contains sour water at pH > 7.5 in any concentration, then the component should be evaluated for susceptibility to carbonate cracking.</td><td>No</td></tr>
<tr><td colspan="3">There is no data for Balance Heat Material.</td><td>No</td></tr>
<tr><td colspan="3">Another trigger would be changes in FCCU feed sulfurr and nitrogen contents particularly when feed changes have reduced sulfur (low sulfur feeds or hydroprocessed feeds) or increased nitrogen.</td><td>No</td></tr>
<tr><td>8.</td><td>SCC Damage Factor-Polythionic Acid Stress Corrosion Cracking</td><td colspan="3">If the component's material of construction is an austenitic stainless steel or nickel based alloys and the components is exposed to sulfur bearing compunds, then the component should be evaluated for susceptibility to PASCC.</td><td>No</td></tr>
<tr><td rowspan="4">9.</td><td rowspan="4">SCC Damage Factor-Chloride Stress Corrosion Cracking</td><td colspan="3">If <u>ALL</u> of the following are true, then the component should evaluated for suscepibility to CLSCC cracking:</td><td rowspan="4">No</td></tr>
<tr><td>a.</td><td>The component's material of construction is an austenitic stainless</td><td>N</td></tr>
<tr><td>b.</td><td>The component is exposed or potentially exposed to chlorides and water also considering upsets and hydrotest water remaining in component, and cooling tower drift (consider both under insulation and</td><td>Y</td></tr>
<tr><td>c.</td><td>The operating temperature is above 38^{o}C (100^{o}F)</td><td>Y</td></tr>
<tr><td>10.</td><td>SCC Damage Factor-Hydrogen Stress Cracking-HF</td><td colspan="3">If the component's material of construction is ccarbon or low alloy steel and the component is exposed too hydrofluoric acid in any concentration, then the component should be evaluated for susceptibility to HSC-HF.</td><td>No</td></tr>
<tr><td>11.</td><td>SCC Damage Factor HIC/SOHIC-HF</td><td colspan="3">If the component's material of construction is ccarbon or low alloy steel and the component is exposed too hydrofluoric acid in any concentration, then the component should be evaluated for susceptibility to HIC/SOHIC-HF.</td><td>No</td></tr>
</table>

No	Damage Factor	Screening Criteria			Yes/No
12.	External Corrosion Damage Factor-Ferritic component	If the component is un-insulated and subject to any of the following , then the component should be evaluated for external damage from corrosion.			No
		a.	Areas exposed to mist overspray from cooling towers.	N	
		b.	Areas exposed to steam vents	N	
		c.	Areas exposed to deluge system	N	
		d.	Areas subject to process spills, ingress of moisture, or acid vapors.	N	
		e.	Carbon steel system, operatinng between -12^{o}C and 177^{o}C (10^{o}F and 350^{o}F). External corrosion is particulartly aggressive where operating temperatures cause frequent or continuous condensation and re-evaporation of atmospheric moisture. (Operating Temperature is 185.4 ^{o}C.	N	
		f.	Systems that do not operating in normally temperature between -12^o and 177^{o}C (10^{o}F and 350^{o}F) but cool or heat into this range intermitterntly or are subjected to frequent outages.	N	
		g.	Systems with deteoriated coating and/or wrappings.	N	
		h.	Cold service equipment consistently operating below the atmospheric dew point.	N	
		i.	Un-insulated nozzles or other prostrusions components of insulated equipment in cold service conditions.	N	

No	Damage Factor	Screening Criteria			Yes/No
13.	Corrosion Under Insulation Damage Factor-Ferritic Commponent	Specific locations and/or systems as stated below are highly suspect and should be considered during inspection program development. Examples the areas include, but are not limited to, the following:			No
		a.	Penetrations 1. All penetrations or breaches in the insulation jacketing systems, such as dead legs (vents, drains, and other similar items), hangers and other supports, valves and fittings, bolted-on pipe shoes, ladders, and platforms. 2. Steam tracer tubing penetrations. 3. Termination of insulation at flanges and other components. 4. Poorly designed insulation support rings. 5. Stiffener rings	N	
		b.	Damaged Insulation Areas 1. Damaged or missing insulation jacketing. 2. Termination of insulation in a vertical pipe or piece of equipment. 3. Caulking that has hardened, has separated, or is missing. 4. Bulges, staining of the jacketing system or missing bands (bulges may indicate corrosion product build-up). 5. Low points in systems that have a known breach in the insulation system, including low points in long unsupported piping runs. 6. Carbon or low alloy steel flanges, bolting, and other components under insulation in high alloy piping.	N	
14.	External Chloride Stress Corrosion Cracking Damage Factor-Austenitic Component	If <u>**ALL**</u> of the following are true, then the component should evaluated for suscepibility to CLSCC:			No
		a.	The component's material of construction is an austenitic stainless	N	
		b.	The component external surface is exposed to chloride containing fluids, mists, or solids.	N	
		c.	The operating temperature is between 50^{o}C and 150^{o}C (120^{o}F and 300^{o}F) , or the system heats or cools into this range intermittently.	N	

No	Damage Factor	Screening Criteria			Yes/No
15.	External Chloride Stress Corrosion Cracking Under Insulation Damage Factor-Austenitic Component	If **ALL** of the following are true, then the component should be evaluated for susceptibiity to CUI CLSCC:			No
		a.	The component's material of construction is an austenitic stainless	N	
		b.	The component is insulated	Y	
		c.	The component external surface is exposed to chloride containing fluids, mists, or solids.	N	
		d.	The operating temperature is between 50^{o}C and 150^{o}C (120^{o}F and 300^{o}F) , or the system heats or cools into this range intermittently.	N	
16.	High Temperature Hydrogen Attack Damage Factor	If **ALL** of the following are true, then the component should be evaluated for susceptibiity to HTHA:			No
		a.	The material is carbon steel, C-$^{1}/_{2}$Mo, or a CrMo low alloy steel (such as $^{1}/_{2}$Cr-$^{1}/_{2}$Mo, 1Cr-$^{1}/_{2}$Mo, $1^{1}/_{4}$Cr-^{1}/2Mo, $2^{1}/_{4}$Cr-1Mo, 3Cr-1Mo, 5Cr-1Mo, 7Cr-1Mo, 9Cr-1Mo).	N	
		b.	The operating temperature is greater than 177^{o}C (350^{o}F).	Y	
		c.	The operating hydrogen partial presssure is greater than 0.345 Mpa (50 psia).	N	
17.	Brittle Fracture Damage Factor	If **BOTH** of the following are true, then the component should be evaluated for susceptibility to brittle fracture:			
		a.	The material is carbon steel or low alloy steel (see Table 20.1).	Y	
		b.	If Minimum Design Metal Temperature (MDMT), T_{MDMT}, or Minimum Allowable Metal Temperature (MAT), T_{MAT}, is unknown, or the component is known to operate at below MDMT or MAT under normal or upset conditions.	N	

No	Damage Factor	Screening Criteria			Yes/No
18.	Low Alloy Steel Embrittlement Damage Factor	If **<u>ALL</u>** of the following are true, then the component should be evaluated for susceptibility to low alloy steel embrittlement:			No
		a.	The material is 1Cr--0.5Mo, 1.25Cr-0.5Mo, or 3Cr-1Mo low alloy steel.	N	
		b.	The operating temperature is between 343^{o}C and 577^{o}C (650^{o}F and 1070^{o}F).	N	
19.	885^{o}F Embrittlement Damage Factor	If **<u>BOTH</u>** of the following are true, then the component should be evaluated for susceptibiity to 885^{o}F embrittlemet:			No
		a.	The material is high chromium (>12% Cr) ferritic steel	N	
		b.	The operating temperature is between 371^{o}C and 566^{o}C (700^{o}F and 1050^{o}F).	N	
20.	Sigma Phase Embrittlement Damage Factor	If **<u>BOTH</u>** of the following are true, then the component should be evaluated for susceptibiity to sigma phase embrittlemet:			No
		a.	The component's material of construction is an austenitic stainless steel.	N	
		b.	The operating temperature is between 593^{o}C and 927^{o}C (1100^{o}F and 1700^{o}F).	N	
21.	Piping Mechanical Fatigue Damage Factor	If **<u>BOTH</u>** of the following are true, then the component should be evaluated for susceptibiity to mechanical fatigue:			No
		a.	The component is pipe	N	
		b.	There have been past fatigue failure in this piping system or there is visible/audibble shaking in this piping system or there is a source of cyclic vibration within approximately 15.24 meters (50 feet) and connected to the piping (directly or indirectly via structure). Shaking and source of shaking can be continuous or intermittent. Transient conditions often cause intermittent virbration.	N	

LAMPIRAN 4A:

PERHITUNGAN PROBABILITY OF FAILURE (POF) DARI STEAM SCRUBBER

THINNING DAMAGE FACTOR CALCULATION

1. RLA DATA

REQUIRED DATA

The basic component data required for analysis is given in Table 4.1. Component types and geometry data are shown in Tables 4.2 and 4.3, respectively. The data required for determination of the thinning DF is provided in Table 4.4.

Table 4.1. Basic Component Data Required for Analysis

Basic Data	Value	Unit	Comments
Start Date	01/05/2000		The date the component was placed in service.
Thickness	20.05	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	198	^oC	The design temperature, shell side and tube side for heat exchanger.
Design Pressure	1388	Kpa	The design pressure, shell side and tubbe side for heat exchanger.
Operating Tempearture	185.4	^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	990	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 1 2007 Edition		The designing of the component containing the component.
Equipment Type	Steam Scrubber		The type of equipment.
Component Type	Filter		The type of component.
Geometry Data	2:1 Ellipsoidal		Component geometry data depending on the type of component.
Material Specification	SA 516 Gr. 70		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	262000	Kpa	The design yield strength of the material based on material specification.
Tensile Strength	485000	Kpa	The design tensile strength of the material based on material specification.
Weld Joint Efficiency	1.00		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	=	0.7894	inch	
	=	20.050	mm	(It is assumed on 13 February 2008)
age	=	11	years	

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 4.14		
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 185.4°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?	N	No
		2.	Is the operating temperature > 204°C (400°F)?	N	
			The operating temperature is 185.4°C.		

5.	Hydrifluoric Corrosion	1.	Does the process contain HF?	N	No
6.	Sour Water Corrsion	1.	Is free water with H_2S present? H_2S concentration is 0.015%	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)? The operating temperature is 185.4^{o}C.	N	No
		2.	Is the oxygen present?	N	
9.	Acid Sour Water Corrosion	1.	Is free water with H_2S present and pH < 7.0? Actual relatively pH is 4.13	Y	Yes
		2.	Does the proocess contain < 50 ppm chlorides? Contains 0,12 ppm of chlorides	Y	
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?	Y	
12.	CO_2 Corrosion	1.	Is the free water with CO_2 present (including consideration for dew point condensation)?	Y	Yes
		2.	Is the material of construction carbon steel or < 13% Cr? Low alloy steel with 0,3% Cr	Y	
13.	AST Bottom	1.	Is the equipment item an AST tank bottom?	N	No

1. Corrosion Rate (Cr) from the RLA data

Cr Shell =	0.005236 inch/year	Cr Head =	0.001181 inch/year
=	0.133000 mm/year	=	0.030000 mm/year

2.a. Corrosion Rate (Cr) based on the Annex 2B alkaline sour water

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

Table 2.B.7.1-Alkaline Sour Water Corrosion – Basic Data Required for Analysis

Basic Data	Comments
NH_4HS concentration (wt%)	Determine the NH4HS 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 H2S and NH3 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)
Stream 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.

From chemical composition report company, known that:

wt% H_2S	= 0.0074	wt% NH_3	= 0.0002297
		2 wt% NH_3	= 0.0004594

So wt% H2S > 2 x (wt% NH3), the wt% NH4HS can be calculated by:

wt% NH4HS = 3.0 x (wt% H_2S)

wt% NH4HS = 0.0222

Table 2.B.7.1-Alkaline Sour Water Corrosion – Baseline Corrosion Rates for Carbon Steel (mpy)

NH4HS (wt%)	Velocity (m/s)				
	3.05	4.57	6.1	7.62	9.14
2	0.08	0.1	0.13	0.2	0.28
5	0.15	0.23	0.3	0.38	0.46
10	0.51	0.69	0.89	1.09	1.27
15	1.14	1.78	2.54	3.81	5.08

1.	for pH2S < 345 kPa, Adjusted CR = max $\left[\left\{\left(\frac{Baseline\ CR}{173}\right).(pH2S\ -345)+Baseline\ CR\right\},0\right]$
2.	for pH2S ≥ 345 kPa, Adjusted CR = max $\left[\left\{\left(\frac{Baseline\ CR}{276}\right).(pH2S\ -345)+Baseline\ CR\right\},0\right]$

mole% of H2S in gas phase = 0.0074 % pH2S = 0.0731 kPa
Baseline CR = 0.08 mm/year

Adjusted alkaline sour water corrosion rate : 0.000 mm/year

2.b. Corrosion Rate (Cr) based on the Annex 2B acid sour water

The steps required to determine the corrosion rate are shown in Figure 2.B.10.1. If the pH is less than 4.5, then the corrosion rate shall be calculated using paragraph 2.B.2. If the pH is greater than 7, then the corrosion rate is calculated using paragraph 2.B.7. Otherwise, the corrosion rate of carbon steel exposed to acid sour water is computed using Equation (2.B.1)

CR = $CR_{ph}.F_O F_V$

The base corrosion rate, C_{pH} , of carbon steel exposed to acid sour water as a function of pH is provided in Table 2.B.10.2. The modification factor for the corrosion rate as a function of the oxygen content factor, F_O , is provided in Table 2.B.10.3. The corrosion rate also varies with fluid velocity. The modification factor for fluid velocity is given by the following equations.

Fv = 1 *when velocity < 1.83 m/s*
Fv = 0.82 . Velocity -0.5 *when 1,83 m/s ≤ velocity ≤ 6,1 m/s*
Fv = 5 *when velocity > 6,1 m/s*

Table 2.B.10.2M – Acid Sour Water Corrosion Estimated Corrosion Rates for Carbon and Low Alloy Steel (mm/y) – CRpH

pH	Temperature (°C)			
	38	52	79	93
4.75	0.03	0.08	0.13	0.18
5.25	0.02	0.05	0.08	0.1
5.75	0.01	0.04	0.05	0.08
6.25	0.01	0.03	0.04	0.05
6.75	0.01	0.01	0.02	0.03

Table 2.B.10.3 – Acid Sour Water Corrosion – Basic Data Required for Analysis

Oxygen content	Adjustment factor - F_O
Not significant (≤ 50 pbb)	1.0
High (> 50 pbb)	2.0

CR_{pH} = 0.18 Fv = 1.000 F_O = 1.0

So, CR = 0.18000

Acid sour water corrosion rate is : 0.1800 mm/year

2.c. Corrosion Rate (Cr) based on the Annex 2B CO_2 Corrosion Calculation

CR = $CR_B . \min[F_{glycol}, F_{inhib}]$

Base Corrosion Rate

$CR_B = f(T,pH) . f_{CO2}^{0.62} . (\frac{S}{19})^{0.146+0.0324\, fco2}$

Where ;

CR_B = Base corrosion rate (mm/y)

f(T,pH) = Temperature-pH function tabulated in Table 2.B.13.2

f_{CO2} = CO_2 fugacity

S = Shear stress yo calculate the flow velocity (Pa)

a. Determine the calculated pH

$pH = 2.5907 + 0.8668. log_{10}[T] - 0.49 log_{10}[p_{CO2}]..$

T = 185.4 °C

= 365.72 °F

= 458.4 K

mole% of CO2 in dry gas = 85.72 %

P_{CO2} = 848.63 kPa

= 123.08 psi

= 8.4863 bar

$pH = 2.5907 + 0.8668. log_{10}[T] - 0.49 log_{10}[p_{CO2}]$

= 3.839503074

b. Determine the CO_2 fugacity

$log_{10}[f_{CO2}] = log_{10}[p_{CO2}] + \min[250, p_{CO2}].(0.0031 - \frac{1.4}{T+273})$

$log_{10}[f_{CO2}] = log_{10}[8.4863] + \min[250, 8.4863].(0.0031 - \frac{1.4}{185.4+273})$

= 0.8909

c. Determine the flow velocity

To determine the flow velocity, the API 581 reffers to the NORSOK M-506. and both of the Recommended Practice use the fluid flow shear stress, S, to model the effect of flow velocity n the base corrosion rate.

$$S = \frac{f.\rho m.um^2}{2}$$

In the calculation for the corrosion rate, the shear stress need not exceed 150 Pa.

Where;

f = Friction factor

ρ_m = Mixture mass density kg/m^3

= 5.8 kg/m^3

u_m = Mixture flow velocity m/s

= 1.8 m/s

$$f = 0.001375\ [\ 1+ (20000(\frac{e}{D}) + (\frac{10^6}{Re})^{0.33}]$$

$\frac{\varepsilon}{D}$ = Relative roughness of the material

0.1

Based on the Table below that for the Carbon Steel (SA 516 GR 70) material of construction which is assumed as slighly corroded is approximately ranging from 0.5-1.5.

Material	Absolute Roughness (mm)
Copper, Lead, Brass, Aluminum (new)	0.001 - 0.002
PVC and Plastic Pipes	0.0015 - 0.007
Flexible Rubber Tubing - Smooth	0.006-0.07
Stainless Steel	0.0015
Steel Commercial Pipe	0.045 - 0.09
Weld Steel	0.045
Carbon Steel (New)	0.02-0.05
Carbon Steel (Slightly Corroded)	0.05-0.15
Carbon Steel (Moderately Corroded)	0.15-1
Carbon Steel (Badly Corroded)	1-3
Asphalted Cast Iron	0.1-1
New Cast Iron	0.25 - 0.8
Worn Cast Iron	0.8 - 1.5
Rusty Cast Iron	1.5 - 2.5
Galvanized Iron	0.025-0.15
Wood Stave	0.18-0.91
Wood Stave, used	0.25-1
Smoothed Cement	0.3
Ordinary Concrete	0.3 - 1
Concrete – Rough, Form Marks	0.8-3

Source by:
https://www.nuclear-power.net/nuclear-engineering/fluid-dynamics/major-head-loss-friction-loss/relative-roughness-of-pipe/

$$Re = \frac{D.\rho m.um}{\mu m}$$

Re = Reynolds number

D = Diameter

= 1930 mm

= 1.93 m

μm = Viscosity of the mixture cp

= 0.4 Cp

= 0.0004 Pa s

$$Re = \frac{D.\rho m.um}{\mu m}$$

= 57569.143

$$f = 0.001375\ [\ 1 + (20000(\frac{e}{D}) + (\frac{10^6}{Re})^{0.33}]$$

= 0.008

After the value of relative roughness, Reynolds number, and the friction factor have been determines. Then, the value of the flow velocity can be calculated.

$$S = \frac{f.\rho m.um^2}{2}$$

= 0.0764152 Pa

Those calculated pH, CO_2 fugacity, and also flow velocity have been known. So, the value of Base Corrosion Rate (Cr_{base}) can be determined.

$$CR_B = f(T,pH)\ .\ f_{CO2}^{\ 0.62}\ .\ (\frac{S}{19})^{0.146+0.0324\ fco2}$$

Where;

f(T,pH) = Temperature-pH function tabulated in Table 2.B.13.2

= 3.62

Cr_{base} = 2.4788978 mpy

= 0.062964 mm/y

Because there is no any mixture for glycol and the other inhibitors inside the Steam Scrubber, then, Cr is equal to Cr_{base}. The glycol or inhibitor is placed in another equipment not being process in the Steam Scrubber itself.

Where;

CR = $CR_B.\min[F_{glycol}, F_{inhib}]$

<u>CR</u> = Cr_{base}

= 0.062964 mm/y

<u>Calculated corrosion rate =</u> 0.1800 mm/year

STEP 3 Determine the time in service, age_{tk}, since the last known inspection, t_{rdi}.

- Shell t_{rdi} = 0.7659 inch
  = 19.45 mm
- Head t_{rdi} = 18.51 mm

Last inspection is on: 03/07/2014
RBI Date is on: 01/07/2019
Planned Date is on: 01/07/2022

age_{tk} = 4.994 years (Last inspection was held on July 2014)

age_{PD} = 7.995 years Inspection is held every 4 years

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:

$$age_{rc} = \max\left[\left(\frac{t_{rdi} - tbm}{C_{r\,cm}}\right), 0.0\right]$$

Because the steam scrubber is not cladding/weld overlay. Then, the equation above does not need to be considered.

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}.

$$t_{min} = \frac{PR_C}{S\,E - 0.6P}$$

$$R_C = \frac{D_i + 2CA}{2}$$

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Where,

Rc : Inside radius in the corroded condition (mm)
P : Designed Pressure (psig)
S : Allowable stress (psig)
E : Joint efficiency
Di : Inside diameter (mm)
CA : Corrosion allowance

$$R_C = \frac{1930 + 2(3)}{2}$$

Rc = 968 mm

$$t_{min} = \frac{201.31\,x\,929}{17500\,x1 - 0.6(201.31)}$$

t_{min} = 0.4415 inch
= 11.213 mm

STEP 6 Determine the A_{rt} Parameter

For component without clading/weld overlay then use the equation following.

$$A_{rt} = \frac{Cr_{b,m}.age_{tk}}{t_{rdi}}$$

Where,

- $Cr_{b.m}$: Corrosion base material
- age_{tk} : Component in-service time since the last inspection
- t_{rdi} : Furnished thickness since last inspection

Shell A_{rt} on RBI Date:

$$A_{rt} = \frac{Cr_{b,m}.age_{tk}}{t_{rdi}}$$
= 0.0462076 **(Annex 2B)**

$$A_{rt} = \frac{Cr_{b,m}.age_{tk}}{t_{rdi}}$$
= 0.0341423 **(RLA data)**

Head A_{rt} on RBI Date:

$$A_{rt} = \frac{Cr_{b,m}.age_{tk}}{t_{rdi}}$$
= 0.0485625 **(Annex 2B)**

$$A_{rt} = \frac{Cr_{b,m}.age_{tk}}{t_{rdi}}$$
= 0.0080937 **(RLA data)**

Shell A_{rt} on Plan Date:

$$A_{rt} = \frac{Cr_{b,m}.age_{tk}}{t_{rdi}}$$
= 0.0739727 **(Annex 2B)**

$$A_{rt} = \frac{Cr_{b,m}.age_{tk}}{t_{rdi}}$$
= 0.0546576 **(RLA data)**

Head A_{rt} on Plan Date:

$$A_{rt} = \frac{Cr_{b,m}.age_{tk}}{t_{rdi}}$$
= 0.0777425 **(Annex 2B)**

$$A_{rt} = \frac{Cr_{b,m}.age_{tk}}{t_{rdi}}$$
= 0.0129571 **(RLA data)**

STEP 7 Calculate the Flow Stress, FS^{Thin}, using E from STEP 5 and equation below.

$$FS^{Thin} = \frac{(YS+TS)}{2}.\ E.1,1$$

Where;

YS	=	262000 KPa	https://www.sidastico.com/en/steels-for-high-temperature-compartments-steels-for-pressurised-compartments/sa516-gr-70-mechanical-properties/
TS	=	485000 KPa	
E	=	1	

$$FS^{Thin} = \frac{(YS+TS)}{2}. E.1,1$$

$$= \quad 410850$$

STEP 8 Calculate the strength ratio parameter, SR_P^{Thin} using the appropriate equation.

$$SR_P^{Thin} = \frac{S.E}{FS^{Thin}} . \frac{Max\ (t_{min}, t_c)}{t_{rdi}}$$

Where;

t_c = is the minimum structural thickness of the component base material

= 0.4414505 inch

= 11.212843 mm

$$SR_P^{Thin} = \frac{S.E}{FS^{Thin}} . \frac{Max\ (t_{min}, t_c)}{t_{rdi}} \qquad SR_P^{Thin} = \frac{S.E}{FS^{Thin}} . \frac{Max\ (t_{min}, t_c)}{t_{rdi}}$$

= 0.1692761 **(Shell)** = 0.1779030 **(Head)**

STEP 9 Determine the number of inspections for each of the correspondesing inspection effectiveness, $N_A^{Thin}, N_B^{Thin}, N_C^{Thin}, N_D^{Thin}$ 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, $I_1^{Thin}, I_2^{Thin}, I_3^{Thin}$ using equation 61 below, prior probabilities, $Pr_{p1}^{Thin}, Pr_{p2}^{Thin}$ and Pr_{p3}^{Thin} Table 4.5. The Conditional Probabilities (for each inspection effectiveness level), , from Table 4.6, and the number of inspection, N_A^{Thin} $N_B^{Thin}, N_C^{Thin}, N_D^{Thin}$, in each effectiveness level from STEP 9.

$$I_1^{Thin} = Pr_{P1}^{Thin} (Co_{P1}^{ThinA})^{N_A^{Thin}} (Co_{P1}^{ThinB})^{N_B^{Thin}} (Co_{P1}^{ThinC})^{N_C^{Thin}} (Co_{P1}^{ThinD})^{N_D^{Thin}}$$

$$I_2^{Thin} = Pr_{P2}^{Thin} (Co_{P2}^{ThinA})^{N_A^{Thin}} (Co_{P2}^{ThinB})^{N_B^{Thin}} (Co_{P2}^{ThinC})^{N_C^{Thin}} (Co_{P2}^{ThinD})^{N_D^{Thin}}$$

$$I_3^{Thin} = Pr_{P3}^{Thin} (Co_{P3}^{ThinA})^{N_A^{Thin}} (Co_{P3}^{ThinB})^{N_B^{Thin}} (Co_{P3}^{ThinC})^{N_C^{Thin}} (Co_{P3}^{ThinD})^{N_D^{Thin}}$$

Table 4.5 - Prior Probability for Thinning Corrosion Rate

Damage State	Low Confidence Data	Medium Confidence	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

$$I_1^{Thin} = Pr_{P1}^{Thin}(Co_{P1}^{ThinA})^{N_A^{Thin}}(Co_{P1}^{ThinB})^{N_B^{Thin}}(Co_{P1}^{ThinC})^{N_C^{Thin}}(Co_{P1}^{ThinD})^{N_D^{Thin}}$$

= 0.50

$$I_2^{Thin} = Pr_{P2}^{Thin}(Co_{P2}^{ThinA})^{N_A^{Thin}}(Co_{P2}^{ThinB})^{N_B^{Thin}}(Co_{P2}^{ThinC})^{N_C^{Thin}}(Co_{P2}^{ThinD})^{N_D^{Thin}}$$

= 0.30

$$I_3^{Thin} = Pr_{P3}^{Thin}(Co_{P3}^{ThinA})^{N_A^{Thin}}(Co_{P3}^{ThinB})^{N_B^{Thin}}(Co_{P3}^{ThinC})^{N_C^{Thin}}(Co_{P3}^{ThinD})^{N_D^{Thin}}$$

= 0.20

STEP 11 Calculate the Posteroir Probability, Po_{p1}^{Thin}, Po_{p2}^{Thin} and Po_{p3}^{Thin}, using equations:

$$Po_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

= 0.5

$$Po_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

= 0.3

$$Po_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

= 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.

$$ß_1^{Thin} = \frac{1-D_{S1}.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S1}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S1}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$ß_2^{Thin} = \frac{1-D_{S2}.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S2}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S2}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

$$ß_3^{Thin} = \frac{1-D_{S3}.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S3}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S3}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

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

RBI DATE:

BASED ON CORROSION RATE FROM RLA DATA

Shell section:

$ß_1^{Thin}$ = 4.1172

$ß_2^{Thin}$ = 4.0765

$ß_3^{Thin}$ = 3.9657

Head section:

$ß_1^{Thin}$ = 4.0990

$ß_2^{Thin}$ = 4.0911

$ß_3^{Thin}$ = 4.0741

BASED ON CORROSION RATE FROM ANNEX 2B

Shell section:

$ß_1^{Thin}$ = 4.1038

$ß_2^{Thin}$ = 4.0422

$ß_3^{Thin}$ = 3.8587

Head section:

$ß_1^{Thin}$ = 4.0554

$ß_2^{Thin}$ = 3.987

$ß_3^{Thin}$ = 3.7821

PLANNED DATE:

BASED ON CORROSION RATE FROM RLA DATA

Shell section:

$ß_1^{Thin}$ = 4.0938

$ß_2^{Thin}$ = 4.0151

$ß_3^{Thin}$ = 3.7668

Head section:

$ß_1^{Thin}$ = 4.0943

$ß_2^{Thin}$ = 4.0811

$ß_3^{Thin}$ = 4.0514

BASED ON CORROSION RATE FROM ANNEX 2B

Shell section:

$ß_1^{Thin}$ = 4.0688

$ß_2^{Thin}$ = 3.9429

$ß_3^{Thin}$ = 3.496

Head section:

$ß_1^{Thin}$ = 4.0166

$ß_2^{Thin}$ = 3.8763

$ß_3^{Thin}$ = 3.3748

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, then this step of calculation can be skipped.

STEP 14 For all components (excluding tank bottoms covered in STEP 13), calculate the base damage factor, . D_{fB}^{Thin}

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi(-\beta_1^{Thin})\right)+\left(Po_{P2}^{Thin}\Phi(-\beta_2^{Thin})\right)+\left(Po_{P3}^{Thin}\Phi(-\beta_3^{Thin})\right)}{1.56E-0.4}$$

RBI DATE:

<u>BASED ON CORROSION RATE FROM RLA DATA</u>

Shell section: D_{fb}^{Thin} = 0.2410104

Head section: D_{fb}^{Thin} = 0.2410119

<u>BASED ON CORROSION RATE FROM ANNEX 2B</u>

Shell section: D_{fb}^{Thin} = 0.2410067

Head section: D_{fb}^{Thin} = 0.2410012

PLANNED DATE:

<u>BASED ON CORROSION RATE FROM RLA DATA</u>

Shell section: D_{fb}^{Thin} = 0.2410025

Head section: D_{fb}^{Thin} = 0.2410113

<u>BASED ON CORROSION RATE FROM ANNEX 2B</u>

Shell section: D_{fb}^{Thin} = 0.24098

Head section: D_{fb}^{Thin} = 0.2409586

STEP 15 Determine the DF for thinning, D_f^{Thin} using equation equation below.

$$D_f^{Thin} = \text{Max}[(\frac{(D_{fb}^{Thin} . F_{IP} . F_{DL} .F_{WD}.F_{AM} .F_{SM})}{F_{OM}}),0.1]$$

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

RBI DATE:

BASED ON CORROSION RATE FROM RLA DATA

D_f^{Thin} = Max[$(\frac{(D_{fb}^{Thin}.}{F_{OM}})$,0.1]

Shell section:

D_f^{Thin} = 0.2410104

Head section:

D_f^{Thin} = 0.2410104

BASED ON CORROSION RATE FROM ANNEX 2B

Shell section:

D_f^{Thin} = 0.2410067

Head section:

D_f^{Thin} = 0.2410067

PLANNED DATE:

BASED ON CORROSION RATE FROM RLA DATA

Shell section:

D_f^{Thin} = 0.2410025

Head section:

D_f^{Thin} = 0.2410025

BASED ON CORROSION RATE FROM ANNEX 2B

Shell section:

D_f^{Thin} = 0.2409800

Head section:

D_f^{Thin} = 0.2409800

DAMAGE FACTOR FOR THINNING

The governing thinning DF is determined based on the presence of an internal liner using equation below.

D_{f-gov}^{Thin} = min[D_f^{Thin}, D_f^{elin}] When internal liner is present

$D_{f-gov}^{Thin} = D_f^{Thin}$ When internal liner is not present

According to above calculaton, there is no any presence of liner, then, we can consider to use the second governing thinning DF calculation.

$$D_{f-gov}^{Thin} = D_f^{Thin}$$

RBI DATE:

Based on RLA Data

Shell section:

D_{f-gov}^{Thin} = 0.2410104

Head section:

D_{f-gov}^{Thin} = 0.2410104

Based on Corrosion Rate from Annex 2B

Shell section:

D_{f-gov}^{Thin} = 0.2410067

Head section:

D_{f-gov}^{Thin} = 0.2410067

PLANNED DATE:

Based on RLA Data

Shell section:

D_{f-gov}^{Thin} = 0.2410025

Head section:

D_{f-gov}^{Thin} = 0.2410025

Based on Corrosion Rate from Annex 2B

Shell section:

D_{f-gov}^{Thin} = 0.2409800

Head section:

D_{f-gov}^{Thin} = 0.2409800

TYPE OF THINNING

The type of thinning (wheter it is local or general) can be determined from table 2.B.1.2 from API RP 581 3rd Edition Part 2 - Annex 2.B, as follow:

Table 2.B.1.2 Type of Thinning

Thinning Mechanism	Condition	Type of Thinning
Hydrochloric Acid (HCl) Corrosion	—	Local
High Temperature Sulfidic/Naphthenic Acid Corrosion	TAN ≤ 0.5	General
	TAN > 0.5	Local
High Temperature H_2S/H_2 Corrosion	—	General
Sulfuric Acid (H_2SO_4) Corrosion	Low Velocity ≤ 0.61 m/s (2 ft/s) for carbon steel, ≤ 1.22 m/s (4 ft/s) for SS, and ≤ 1.83 m/s (6 ft/s) for higher alloys	General
	High Velocity ≥ 0.61 m/s (2 ft/s) for carbon steel, ≥ 1.22 m/s (4 ft/s) for SS, and ≥ 1.83 m/s (6 ft/s) for higher alloys	Local
Hydrofluoric Acid (HF) Corrosion	—	Local
Sour Water Corrosion	Low Velocity: ≤ 6.1 m/s (20 ft/s)	General
	High Velocity: > 6.1 m/s (20 ft/s)	Local
Amine Corrosion	Low Velocity < 1.5 m/s (5 ft/s) rich amine < 6.1 m/s (20 ft/s) lean amine	General
	High Velocity > 1.5 m/s (5 ft/s) rich amine > 6.1 m/s (20 ft/s) lean amine	Local
High Temperature Oxidation	—	General
Acid Sour Water Corrosion	< 1.83 m/s (6 ft/s) ≥ 1.83 m/s (6 ft/s)	General Local
Cooling Water Corrosion	≤ 0.91 m/s (3 ft/s) 0.91-2.74 m/s (3-9 ft/s) > 2.74 m/s (9 ft/s)	Local General Local
Soil Side Corrosion	—	Local
CO_2 Corrosion	—	Local
AST Bottom	Product Side Soil Side	Local Local

From the data, the the velocity of fluid is 1.8 m/s

And the thinning mechanisms are sour water, acid sour water, and CO_2 corrosion.

If both general and localized thinning mechanisms are possible, then the type of thinning should be designated as localized. The type of thinning designated will be used to determine the effectiveness of inspection performed.

So, the thinning damage is designated as <u>localized</u>

SCC DAMAGE FACTOR - SULFIDE STRESS CRACKING CALCULATION

REQUIRED DATA

The basic component data required for analysis is given in Table 4.1 and the specific data required for determination of the sulfide stress cracking DF is provided in Table 8.1.

STEP 1 Determine the environmental severity (potential level of hydrogen flux) for cracking based on the H_2S content of the water and its pH using Table 8.2.

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				

pH: 4.14 H_2S concentration: 73.8 ppm

Based on table 8.2 the environmental severity: **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 Brinnell hardness of weldments, and knowledge of whether the component was subject to PWHT. Note that a HIGH susceptibility should be used if cracking is confirmed to be present.

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.						

Max Brinnell Hardness: TS (psi) = 500 x HB

HB = 140.69

Shell subjects to PWHT: No Head subjects to PWHT: Yes

Shell susceptibility to SSC as a Function of Heat Treatment: **Low**

Head susceptibility to SSC as a Function of Heat Treatment: **Not**

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

Severity Index (S_{VI}) of Shell = 1 Severity Index (S_{VI}) of Head = 0

STEP 4 Determine the time in-service, age_{tk} , 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.

age_{PD} =	7.99452 years	Last inspection is on:	03/07/2014
		RBI Date is on:	01/07/2019
age_{tk} =	4.99384 years	Planned Date is on:	01/07/2022

STEP 5

Determine the number of inspections, and the corresponding inspection effectiveness category using Section 8.6.2 for past inspections performed during the in service time. Combine the inspections to the highest effectiveness performed using Section 3.4.3.

Inspections are ranked according to their expected effectiveness at detecting SSC. Examples of inspection activities that are both intrusive (requires entry into the equipment) and non-intrusive (can be performed externally), are provided in Annex 2.C, Table 2.C.9.6 (Section 8.6.2 API RP 3rd Edition Part 2)

Table 2.C.9.6 – LoIE Example for SSC

Inspection Category	Inspection Effectiveness Category	Intrusive Inspection Example[1,2]	Non-intrusive Inspection Example[1,2]
A	Highly Effective	For the total weld area: 100% WFMT/ACFM with UT follow-up of relevant indications.	For the total weld area: 100% automated or manual ultrasonic scanning.
B	Usually Effective	For selected welds / weld area: >75% WFMT/ACFM with UT follow-up of all relevant indications.	For selected welds / weld area: >75% automated or manual ultrasonic scanning OR AE testing with 100% follow-up of relevant indications.
C	Fairly Effective	For selected welds / weld area: >35% WFMT/ACFM with UT follow-up of all relevant indications.	For selected welds / weld area: >35% automated or manual ultrasonic scanning OR >35% radiographic testing.
D	Poorly Effective	For selected welds / weld area: >10% WFMT/ACFM with UT follow-up of all relevant indications or	For selected welds / weld area: >10% automated or manual ultrasonic scanning **OR** >10% radiographic testing.
E	Ineffective	Ineffective inspection technique/plan was utilized	Ineffective inspection technique/plan was utilized

Notes:
1. Inspection quality is high.
2. Suspect Area shall be considered the Total Surface Area unless defined by knowledgeable individual (subject matter expert).

If multiple inspections have been performed, equivalent relationships are used for SCC, External Damage (external chloride stress corrosion cracking, external chloride stress corrosion cracking under insulation) and HTHA. Inspections of different grades (A, B, C and D) are approximated as equivalent inspection effectiveness in accordance with the following relationships (Section 3.4.3 API RP 3rd Edition Part 2):

a) 2 Usually Effective (B) Inspections = 1 Highly Effective (A) Inspection, or 2B = 1A

b) 2 Fairly Effective (C) Inspections = 1 Usually Effective (B) inspection, or 2C = 1B

c) 2 Poorly Effective (D) Inspections = 1 Fairly Effective (C) inspection, or 2D = 1C

Note:

1. Equivalent inspection valuesare not used for Thinning and External Corrosion DF calculations.
2. The equivalent higher inspection rules shall not be applied to No Inspections (E).

Number of inspections: 2 Effectiveness category: Ineffective (E)

Inspection effectiveness: **E**

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

Number of inspection = 2 Effectiveness = E

Base damage factor (D_{fb}^{scc}):

For shell section: 1 For head section: 0

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 below. 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.

$$D_f^{scc} = D_{fB}^{scc}.(Max[age, 1.0])^{1.1}$$

RBI DATE:

Shell section:

$$D_f^{scc} = 1.(Max[5,1.0])^{1.1}$$

D_f^{scc} = 5.8651

Head section:

$$D_f^{scc} = 0.(Max[5,1.0])^{1.1}$$

D_f^{scc} = 0.0000

PLANNED DATE:

Shell section:

$$D_f^{scc} = 1.(Max[8,1.0])^{1.1}$$

D_f^{scc} = 9.8417

Head section:

$$D_f^{scc} = 0.(Max[8,1.0])^{1.1}$$

D_f^{scc} = 0.0000

SCC DAMAGE FACTOR - HIC/SOHIC - H_2S

REQUIRED DATA

The basic component data required for analysis is given in Table 4.1 and the specific data required for determination of the HIC/SOHIC-H_2S cracking DF is provided in Table 9.1

STEP 1 Determine the environmental severity (potential level of hydrogen flux) for cracking based on the H_2S content of the water and its pH using Table 9.2. Note that a HIGH environmental severity should be used if cracking is confirmed to be present.

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				

pH: 4.14 H2S concentration: 73.8 ppm

Based on table 9.2 the environmental 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 sulfur content of the carbon steel, product form 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 % https://www.azom.com/article.aspx?ArticleID=4787

Environmental severity: Moderate

Post Weld Heat Treatment (PWHT) for Shell section: No

Post Weld Heat Treatment (PWHT) for Head section: Yes

Shell section susceptibility for Cracking: **High**

Head section susceptibility for Cracking: **Medium**

STEP 3 Based on the susceptibility in STEP 2, determine the severity index, SVI , from 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

Severity Index (S_{VI}) for shell section = 100

Severity Index (S_{VI}) for head section = 10

STEP 4 Determine the time in-service, age , since the last Level A, B or C inspection was performed 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.

age_{PD}	=	7.9945	year	Last inspection is on:	03/07/2014
				RBI Date is on:	01/07/2019
age_{tk}	=	4.9938	year	Planned Date is on:	01/07/2022

STEP 5

Determine the number of inspections, and the corresponding inspection effectiveness category using Section 9.6.2 for past inspections performed during the in service time. Combine the inspections to the highest effectiveness performed using Section 3.4.3.

Inspections are ranked according to their expected effectiveness at detecting SSC. Examples of inspection activities that are both intrusive (requires entry into the equipment) and non-intrusive (can be performed externally), are provided in Annex 2.C, Table 2.C.9.6 (Section 8.6.2 API RP 3rd Edition Part 2)

Table 2.C.9.6 – LoIE Example for SSC

Inspection Category	Inspection Effectiveness Category	Intrusive Inspection Example[1,2]	Non-intrusive Inspection Example[1,2]
A	Highly Effective	For the total weld area: 100% WFMT/ACFM with UT follow-up of relevant indications.	For the total weld area: 100% automated or manual ultrasonic scanning.
B	Usually Effective	For selected welds / weld area: >75% WFMT/ACFM with UT follow-up of all relevant indications.	For selected welds / weld area: >75% automated or manual ultrasonic scanning OR AE testing with 100% follow-up of relevant indications.
C	Fairly Effective	For selected welds / weld area: >35% WFMT/ACFM with UT follow-up of all relevant indications.	For selected welds / weld area: >35% automated or manual ultrasonic scanning OR >35% radiographic testing.
D	Poorly Effective	For selected welds / weld area: >10% WFMT/ACFM with UT follow-up of all relevant indications or	For selected welds / weld area: >10% automated or manual ultrasonic scanning **OR** >10% radiographic testing.
E	Ineffective	Ineffective inspection technique/plan was utilized	Ineffective inspection technique/plan was utilized

Notes:
1. Inspection quality is high.
2. Suspect Area shall be considered the Total Surface Area unless defined by knowledgeable individual (subject matter expert).

If multiple inspections have been performed, equivalent relationships are used for SCC, External Damage (external chloride stress corrosion cracking, external chloride stress corrosion cracking under insulation) and HTHA. Inspections of different grades (A, B, C and D) are approximated as equivalent inspection effectiveness in accordance with the following relationships (Section 3.4.3 API RP 3rd Edition Part 2):

a) 2 Usually Effective (B) Inspections = 1 Highly Effective (A) Inspection, or 2B = 1A

b) 2 Fairly Effective (C) Inspections = 1 Usually Effective (B) inspection, or 2C = 1B

c) 2 Poorly Effective (D) Inspections = 1 Fairly Effective (C) inspection, or 2D = 1C

Note:

1. Equivalent inspection valuesare not used for Thinning and External Corrosion DF calculations.
2. The equivalent higher inspection rules shall not be applied to No Inspections (E).

Number of inspections: 2 Effectiveness category: Ineffective (E)
Inspection effectiveness: **E**

STEP 6 Determine the base DF for HIC/SOHIC-H_2S cracking, $D_{fB}^{HIC/SOHIC-H_2S}$, using Table 6.3 based on the number of, and the highest inspection effectiveness determined in STEP 5, and the severity index, 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

S_{VI} = 100 Number of inspection = 2 Effectiveness = E

Base damage factor ($D_{fB}^{HIC/SOHIC-H_2S}$) for shell section: **100**
Base damage factor ($D_{fB}^{HIC/SOHIC-H_2S}$) for head section: **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.	

On-Line monitoring adjustment factor (F_{OM}): 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 below. 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

$$D_f^{HIC/SOHIC-H_2S} = \frac{D_{fB}^{HIC/SOHIC-H_2S}.(Max[age, 1.0])^{1.1}}{F_{OM}}$$

RBI DATE:

Shell section:

$D_{fB}^{HIC/SOHIC-H_2S}$ = 293.257

Head section:

$D_{fB}^{HIC/SOHIC-H_2S}$ = 29.326

PLANNED DATE:

Shell section:

$D_{fB}^{HIC/SOHIC-H_2S}$ = 492.087

Head section:

$D_{fB}^{HIC/SOHIC-H_2S}$ = 49.209

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 as follow.

$$D_{f-gov}^{scc} = max\left[\begin{matrix} D_f^{caustic}, D_f^{amine}, D_f^{scc}, D_f^{HIC/SOHIC-H_2S}, D_f^{ACSCC}, \\ D_f^{PASCC}, D_f^{CLSCC}, D_f^{HSC\_HF}, D_f^{HIC/SOHIC-HF} \end{matrix}\right]$$

RBI DATE:

D_{f-gov}^{scc} = 293.257 (Shell)
D_{f-gov}^{scc} = 29.3257 (Head)

PLANNED DATE:

D_{f-gov}^{scc} = 492.09 (Shell)
D_{f-gov}^{scc} = 49.209 (Head)

PROBABILITY OF FAILURE

The probability of failure can be calculated using the equation of;

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

Where,

pf (t)	=	The PoF as a function of time
gff	=	General failure frequency
Fms	=	Management system factor
Df (t)	=	Total damage factor

DETERMINING DAMAGE FACTOR (Df)

In the case of multiple damage mechanisms, the combination of those damage mechanims is explained in section 3.4.2 API RP 581 Part 2 3rd Edition. Total DF, $D_{f-total}$ - If more than one damage mechanism is present, the following rules are used to combine the DFs. The total DF is given by Equation (2.2) when the external and/or thinning damage are classified as local and therefore, unlikely to occur at the same location.

$$D_{f-total} = max\left[D_{f-gov}^{thin}, D_{f-gov}^{extd}\right] + D_{f-gov}^{scc} + D_{f}^{htha} + D_{f-gov}^{brit} + D_{f}^{mfat}$$

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).

$$D_{f-total} = D_{f-gov}^{thin} + D_{f-gov}^{extd} + D_{f-gov}^{scc} + D_{f}^{htha} + D_{f-gov}^{brit} + D_{f}^{mfat}$$

Note that the summation of DFs can be less than or equal to 1.0. This means that the component can have a POF less than the generic failure frequency.

Acccording to the observation and last inspection to Steam Scrubber equipment is categorized as local thinning and also it does not likely occur at the same location. So, we used equation correlated to local thinning.

RBI DATE:

Based on RLA Data

Shell section:

$D_{f-total}$ = 293.4978

Head section:

$D_{f-total}$ = 29.566689

Based on Corrosion Rate from Annex 2B

Shell section:

$D_{f-total}$ = 293.4978

Head section:

$D_{f-total}$ = 29.566686

PLANNED DATE:

Based on RLA Data

Shell section:

$D_{f\text{-}total}$ = 492.328

Head section:

$D_{f\text{-}total}$ = 49.449703

Based on Corrosion Rate from Annex 2B

Shell section:

$D_{f\text{-}total}$ = 492.32798

Head section:

$D_{f\text{-}total}$ = 49.44968

DETERMINING GENERAL FAILURE FREQUENCY (gff)

To determine the value of gff, we can use the recommended list from table 3.1 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

gff : 3.06.E-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

For details of management system factor screening, stated in LAMPIRAN 4B: MANAGEMENT SYSTEM FACTOR

Management system factor score according from the survey, the score is

fms = 869.5

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

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 = 0.1823896

CALCULATING PROBABILITY OF FAILURE

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

RBI DATE:

Based on Corrosion Rate from RLA Data

- ***Pf (t) = 3,06,E−0,5 . 0,18 . 293,5***
  Pf (t) = 1.64E-03 (Shell)
- ***Pf (t) = 3,06,E−0,5 . 0,18 . 29,6***
  Pf (t) = 1.65E-04 (Head)

Based on Corrosion Rate from Annex 2B

- ***Pf (t) = 3,06,E−0,5 . 0,18 . 293,5***
  Pf (t) = 1.64.E-03 (Shell)
- ***Pf (t) = 3,06,E−0,5 . 0,18 . 29,6***
  Pf (t) = 1.65.E-04 (Head)

PLANNED DATE:

Based on Corrosion Rate from RLA Data

- ***Pf (t) = 3,06,E−0,5 . 0,18 . 492,3***
  Pf (t) = 2.75E-03 (Shell)
- ***Pf (t) = 3,06,E−0,5 . 0,18 . 49,4***
  Pf (t) = 2.76E-04 (Head)

Based on Corrosion Rate from Annex 2B

- ***Pf (t) = 3,06,E−0,5 . 0,18 . 492,3***
  Pf (t) = 2.75.E-03 (Shell)
- ***Pf (t) = 3,06,E−0,5 . 0,18 . 49,4***
  Pf (t) = 2.76.E-04 (Head)

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LAMPIRAN 4B:

FACTOR MANAGEMENT SYSTEM

Section	Area	Score
2.A.1	Leadership and Administration	68
2.A.2	Process Safety Information	67
2.A.3	Process Hazard Analysis	80
2.A.4	Management of Change	68
2.A.5	Operating Procedures	57
2.A.6	Safe Work Practices	78
2.A.7	Training	85
2.A.8	Mechanical Integrity	96.5
2.A.9	Pre-Startup Safety Review	60
2.A.10	Emergency Response	61
2.A.11	Incident Investigation	71
2.A.12	Contractors	45
2.A.13	Management Systems Assessments	33
	Total	869.5

pscore	86.95
Management Factor	0.1824

Table 2.A.1 – Leadership and Administration

	Questions	Possible Score	Actual Score
1	Does the organization at the corporate or local level have a general policy statement reflecting management's commitment to Process Safety Management, and emphasizing safety and loss control issues?	10	10
2	Is the general policy statement:		
	a. Contained in manuals?	2	2
	b. Posted in various locations?	2	2
	c. Included as a part of all rule booklets?	2	2
	d. Referred to in all major training programs?	2	2
	e. Used in other ways? (Describe)	2	2
3	Are responsibilities for process safety and health issues clearly defined in every manager's job description?	10	10
4	Are annual objectives in the area of process safety and health issues established for all management personnel, and are they then included as an important consideration in their regular annual appraisals?	15	15
5	What percentage of the total management team has participated in a formal training course or outside conference or seminar on Process Safety Management over the last three years?	% x 10	8
6	Is there a site Safety Committee, or equivalent?	5	5
	a. Does the committee make-up represent a diagonal slice of the organization?	5	5
	b. Does the committee meet regularly and document that appropriate recommendations are implemented?	5	5
Total Points		**70**	**68**

Table 2.A.2 – Process Safety Information

	Questions	Possible Score	Actual Score
	Are Material Safety Data Sheets (MSDS) available for all chemical substances used or handled in each unit?	5	5
	a. Is the maximum on-site inventory of each of these chemicals listed?	2	2
	b. Is this information available to operations and maintenance personnel and any appropriate contract personnel in the unit?	2	2
1	c. Are the hazardous effects, if any, of inadvertent mixing of the various materials on site clearly stated in the Standard Operating Procedures and emphasized in operator training programs?	2	2
2	Are quality control procedures in place and practiced to ensure that all identified materials meet specifications when received and used?	10	5
	Is up-to-date written information readily available in the unit that:		
	a. Summarizes the process chemistry?	3	3
	b. Lists the safe upper and lower limits for such items as temperatures, pressures, flows and compositions?	3	3
3	c. States the safety-related consequences of deviations from these limits?	3	3
4	Is a block flow diagram or simplified process flow diagram available to aid in the operator's understanding of the process?	5	5
5	Are P&IDs available for all units at the site?	10	10
6	Does documentation show all equipment in the unit is designed and constructed in compliance with all applicable codes, standards, and generally accepted good engineering practices?	8	8
	Has all existing equipment been identified that was designed and constructed in accordance with codes, standards, or practices that are no longer in general use?	4	2
7	Has it been documented that the design, maintenance, inspection and testing of such equipment will allow it to be operated in a safe manner?	4	0
	Have written records been compiled for each piece of equipment in the process, and do they include all of the following?		
	a. Materials of construction	1	1
	b. Design codes and standards employed	1	1
	c. Electrical classification	1	1
	d. Relief system design and design basis	1	1
	e. Ventilation system design	1	1
8	f. Safety systems, including interlocks, detection and suppression systems	1	1
9	Are procedures in place to ensure that each individual with responsibility for managing the process has a working knowledge of the process safety information appropriate to his or her responsibilities?	5	3
10	Is a documented compilation of all the above Process Safety Information maintained at the facility as a reference? The individual elements of the Information may exist in various forms and locations, but the compilation should confirm the existence and location of each element.	8	8
	Total Points	**80**	**67**

Table 2.A.3 – Process Hazard Analysis

	Questions	Possible Score	Actual Score
1	What percentage of all process units that handle hazardous chemicals at the facility have had a formal Process Hazard Analysis (PHA) within the last five years?	% x 10	0
2	Has a priority order been established for conducting future PHAs?	5	0
	Does the basis for the prioritization address the following factors?:		
	a. The quantity of toxic, flammable, or explosive material at the site	1	0
	b. The level of toxicity or reactivity of the materials	1	0
	c. The number of people in the immediate proximity of the facility, including both onsite and offsite locations	1	0
	d. Process complexity	1	0
	e. Severe operating conditions or conditions that can cause corrosion or erosion	1	0
3	Do the PHAs conducted to date address:		
	a. The hazards of the process?	2	2
	b. A review of previous incident/accident reports from the unit being analyzed to identify any previous incidents that had a potential for catastrophic consequences?	2	2
	c. Engineering and administrative controls applicable to the hazards and their interrelationships?	2	2
	d. Consequences of failure of engineering and administrative controls?	2	2
	e. Facilities siting?	2	2
	f. Human factors?	2	2
	g. A qualitative evaluation of the possible safety and health effects of failure	2	2
4	Based on the most recent PHA conducted:		
	a. Was the team leader experienced in the technique being employed?	3	3
	b. Had the team leader received formal training in the method being employed?	3	3
	c. Was at least one member of the team an expert on the process being analyzed?	3	3
	d. Were all appropriate disciplines represented on the team or brought in as required during the analysis?	3	3
	e. Was at least one member of the team a person who did not participate in the original design of the facility?	3	3
5	Is a formal system in place to promptly address the findings and recommendations of a Process Hazard Analysis to ensure that the recommendations are resolved in a timely manner and that the resolution is documented?	8	8
	a. If so, are timetables established for implementation?	3	3
	b. Does the system require that decisions concerning recommendations in PHAs and the status of implementation be communicated to all operations, maintenance and other personnel who may be affected?	3	3
6	Is the methodology used in past PHAs and/or planned future PHAs appropriate for the complexity of the process?	10	10
7	Are the PHAs being led by an individual who has been trained in the methods being used?	12	12
8	Based on the most recent PHAs conducted, are the average rates of analysis appropriate for the complexity of the systems being analyzed? (Typically, 2–4 P&IDs of average complexity will be analyzed per day.)	10	10
9	After the process hazards have been identified, are the likelihood and consequences of the failure scenarios assessed using either qualitative or quantitative techniques?	5	5
	Total Points	**100**	**80**

Table 2.A.4 – Management of Change

	Questions	Possible Score	Actual Score
	Does the facility have a written Management of Change procedure that must be followed whenever new facilities are added or changes are made to a process?	9	5
1	Are authorization procedures clearly stated and at an appropriate level?	5	5
	Do the following types of "changes" invoke the Management of Change procedure?		
	a. Physical changes to the facility, other than replacement in kind (expansions, equipment modifications, instrument or alarm system revisions, etc.).	4	4
	b. Changes in process chemicals (feedstocks, catalysts, solvents, etc.).	4	4
	c. Changes in process conditions (operating temperatures, pressures, production rates, etc.).	4	0
2	d. Significant changes in operating procedures (startup or shutdown sequences, unit staffing level or assignments, etc.).	4	0
	Is there a clear understanding at the facility of what constitutes a "temporary change?"	5	5
	a. Does Management of Change handle temporary changes as well as permanent changes?	4	4
3	b. Are items that are installed as "temporary" tracked to ensure that they are either removed after a reasonable period of time or reclassified as permanent?	5	5
	Do the Management of Change procedures specifically require the following actions whenever a change is made to a process?		
	a. Require an appropriate Process Hazard Analysis for the unit.	3	3
	b. Update all affected operating procedures.	3	3
	c. Update all affected maintenance programs and inspection schedules.	3	3
	d. Modify P&IDs, statement of operating limits, Material Safety Data Sheets, and any other process safety information affected.	3	3
	e. Notify all process and maintenance employees who work in the area of the change, and provide training as required.	3	3
	f. Notify all contractors affected by the change.	3	3
4	g. Review the effect of the proposed change on all separate but interrelated upstream and downstream facilities.	3	3
5	When changes are made in the process or operating procedures, are there written procedures requiring that the impact of these changes on the equipment and materials of construction be reviewed to determine whether they will cause any increased rate of deterioration or failure, or will result in different failure mechanisms in the process equipment?	10	10
6	When the equipment or materials of construction are changed through replacement or maintenance items, is there a system in place to formally review any metallurgical change to ensure that the new material is suitable for the process?	5	5
	Total Points	**80**	**68**

Table 2.A.5 – Operating Procedures

	Questions	Possible Score	Actual Score
	Are written operating procedures available to operations and maintenance personnel in all units?	10	10
1	Do the operating procedures clearly define the position of the person or persons responsible for operation of each applicable area?	5	5
	Are the following operating considerations covered in all Standard Operating Procedures (SOPs)?		
	a. Initial startup	2	2
	b. Normal (as well as emergency) operation	2	2
	c. Normal shutdown	2	2
	d. Emergency shutdown	2	2
	e. Is the position of the person or persons who may initiate these procedures defined?	2	2
	f. Steps required to correct or avoid deviation from operating limits and consequences of the deviation	2	2
	g. Startup following a turnaround	2	2
2	h. Safety systems and their functions	2	2
	Are the following safety and health considerations covered in all SOPs for the chemicals used in the process?		
	a. Properties of, and hazards presented by, the chemicals	3	3
	b. Precautions necessary to prevent exposure, including controls and personal protective equipment	4	4
3	c. Control measures to be taken if physical contact occurs	3	3
4	Are the SOPs in the facility written in a clear and concise style to ensure effective comprehension and promote compliance of the users?	10	8
5	Are there adequate procedures for handover/transfer of information between shifts?	10	5
	How frequently are operating procedures formally reviewed to ensure they reflect current operating practices and updated as required? (Choose one)		3
	At least annually, or as changes occur	11	
	Each two years	6	
	Only when major process changes occur	3	
6	No schedule has been established	0	
	How often is an unbiased evaluation made of the level of compliance with written operating procedures? (Choose one)		0
	Every 6 months	8	
	Yearly	4	
	Each 3 years	2	
7	Not Done	0	
	Total Points	**80**	**57**

Table 2.A.6 – Safe Work Practices

	Questions	Possible Score	Actual Score
	Have safe work practices been developed and implemented for employees and contractors to provide for the control of hazards during operation or maintenance, including:		
	a. Hot work	2	2
	b. Line breaking procedures	2	2
	c. Lockout/tagout	2	2
	d. Confined space entry	2	2
	e. Opening process equipment or piping	2	2
	f. Entrance into a facility by maintenance, contract, laboratory, or other support personnel	2	2
	g. Vehicle entry	2	2
	h. Crane lifts	2	2
	i. Handling of particularly hazardous materials (toxic, radioactive, etc.)	2	2
1	j. Inspection or maintenance of in-service equipment	2	2
2	Do all the safe work practices listed in Question 1 require a work authorization form or permit prior to initiating the activity?	10	10
	If so, do the permit procedures include the following features?		
	a. Forms that adequately cover the subject area	1	1
	b. Clear instructions denoting the number of copies issued and who receives each copy	1	1
	c. Authority required for issuance	1	1
	d. Sign-off procedure at completion of work	1	1
3	e. Procedure for extension or reissue after shift change	1	1
4	Is formal training provided to persons issuing each of the above permits?	10	10
5	Are the affected employees trained in the above permit and procedure requirements?	10	10
	How often is an independent evaluation made (e.g., by Safety Department or similar group), with results communicated to appropriate management, to determine the extent of compliance with requirements for work permits and specialized procedures for major units within the organization? (Choose one)		2
	Every 3 months	7	
	Every 6 months	4	
	Yearly	2	
6	Not done	0	
	Is a procedure in place that requires that all work permit procedures and work rules be formally reviewed at least every three years and updated as required?	10	10
7	Do records indicate that these reviews are being conducted on a timely basis?	5	3
	Have surveys been conducted to determine whether working environments are consistent with ergonomic standards?	4	4
8	Either no deficiencies were found in the above survey, or if they were, are they being corrected?	4	4
	Total Points	**80**	**78**

Table 2.A.7 – Training

	Questions	Possible Score	Actual Score
1	Is there a written procedure that defines the general training in site-wide safety procedures, work practices, etc., that a newly hired employee will receive?	10	10
2	Is there a written procedure that defines the amount and content of site-specific training, in addition to the general training provided in Question 1, that an employee newly assigned to an operations position will receive prior to assuming his duties?	10	10
	Does the procedure described in Question 2 require that the training include the following?		
	a. An overview of the process and its specific safety and health hazards	3	3
	b. Training in all operating procedures	3	1
	c. Training on site-emergency procedures	3	3
	d. Emphasis on safety-related issues such as work permits, importance of interlocks and other safety systems, etc.	3	3
	e. Safe work practices	3	3
3	f. Appropriate basic skills	3	3
	At the completion of formal training of operations personnel, what method is used to verify that the employee understands the information presented? (Choose one)		7
	Performance test followed by documented observation	10	
	Performance test only	7	
	Opinion of instructor	3	
4	No verification	0	
	How often are operations employees given formal refresher training? (Choose one)		5
	At least once every three years	10	
	Only when major process changes occur	5	
5	Never	0	
	What is the average amount of training given to each operations employee per year, averaged over all grades? (Choose one)		7
	15 days/year or more	10	
	11 to 14 days/year	7	
	7 to 10 days/year	5	
	3 to 6 days/year	3	
6	Less than 3 days/year	0	
	Has a systematic approach (e.g., employee surveys, task analysis, etc.) been used to identify the training needs of all employees at the facility, including the training programs referred to in Questions 1 and 2?	4	4
	a. Have training programs been established for the identified needs?	4	4
7	b. Are training needs reviewed and updated periodically?	4	4
	Are the following features incorporated in the plant's formal training programs?		
	a. Qualifications for trainers have been established and are documented for each trainer.	5	3
	b. Written lesson plans are used that have been reviewed and approved to ensure complete coverage of the topic.	5	5
	c. Training aids and simulators are used where appropriate to permit "hands-on" training.	5	5
8	d. Records are maintained for each trainee showing the date of training and means used to verify that training was understood.	5	5
Total Points		**100**	**85**

Table 2.A.8 – Mechanical Integrity

	Questions	Possible Score	Actual Score
	Has a written inspection plan for the process unit been developed that includes the following elements:		
	a. All equipment needing inspection has been identified?	2	1
	b. The responsibilities to conduct the inspections have been assigned?	2	2
	c. Inspection frequencies have been established?	2	2
	d. The inspection methods and locations have been specified?	2	2
1	e. Inspection reporting requirements have been defined?	2	2
	Does the inspection plan referred to in Question 1 include a formal, external visual inspection program for all process units?	2	2
	a. Are all the following factors considered in the visual inspection program: the condition of the outside of equipment, insulation, painting/coatings, supports and attachments, and identifying mechanical damage, corrosion, vibration, leakage or improper components or repairs?	1	1
	b. Based on the inspection plan referred to in Question 1, do all pressure vessels in the unit receive such a visual external inspection at least every 5 years?	2	2
2	c. Based on this inspection plan, do all on-site piping systems that handle volatile, flammable products, toxins, acids and caustics, and other similar materials receive a visual external inspection at least every 5 years?	2	2
3	Based on the inspection plan, do all pressure vessels in the unit receive an internal or detailed inspection using appropriate nondestructive examination procedures at least every 10 years?	5	3
	Has each item of process equipment been reviewed by appropriate personnel to identify the probable causes of deterioration or failure?	5	3
	a. Has this information been used to establish the inspection methods, locations, and frequencies and the preventive maintenance programs?	1	0
4	b. Have defect limits been established, based on fitness for service considerations?	1	0.5
	Is a formal program for thickness measurements of piping as well as vessels being used?	3	3
	a. When the locations for thickness measurements are chosen,		
	1. Is the likelihood and consequence of failure a major factor?	1	0
	2. Is localized corrosion and erosion a consideration?	1	0
	b. Are thickness measurement locations clearly marked on inspection drawings and on the vessel or piping system to allow repetitive measurements at precisely the same locations?	2	2
	c. Are thickness surveys up to date?	2	2
5	d. Are the results used to predict remaining life and adjust future inspection frequency?	2	2

	Has the maximum allowable working pressure (MAWP) been established for all piping systems, using applicable codes and current operating conditions?	3	3
6	Are the MAWP calculations updated after each thickness measurement, using the latest wall thickness and corrosion rate?	2	2
7	Is there a written procedure that requires an appropriate level of review and authorization prior to any changes in inspection frequencies or methods and testing procedures?	5	5
	Have adequate inspection checklists been developed and are they being used?	3	1
8	Are they periodically reviewed and updated as equipment or processes change?	2	0
	Are all inspections, tests and repairs performed on the process equipment being promptly documented?	3	3
	Does the documentation include all of the following information?:	3	2
	a. The date of the inspection		
	b. The name of the person who performed the inspection		
	c. Identification of the equipment inspected		
	d. A description of the inspection or testing		
	e. The results of the inspection		
	f. All recommendations resulting from the inspection		
9	g. A date and description of all maintenance performed		
	Is there a written procedure requiring that all process equipment deficiencies identified during an inspection be corrected in a safe and timely manner and are they tracked and followed up to assure completion?	5	5
	a. Is a system used to help determine priorities for action?	1	0
10	b. If defects are noted, are decisions to continue to operate the equipment based on sound engineering assessments of fitness for service?	2	1
	Is there a complete, up-to-date, central file for all inspection program information and reports?	3	3
11	Is this file information available to everyone who works with the process?	2	1
12	Have all employees involved in maintaining and inspecting the process equipment been trained in an overview of the process and its hazards?	5	2
	Have all employees involved in maintaining and inspecting the process equipment been trained in all procedures applicable to their job tasks to ensure that they can perform the job tasks in a safe and effective manner?	3	1
13	At completion of the training described above, are formal methods used to verify that the employee understands what he was trained on?	2	0
14	Are inspectors certified for performance in accordance with applicable industry codes and standards (e.g., API 510, 570 and 653)?	5	5
15	Are training programs conducted for contractors' employees where special skills or techniques unique to the unit or plant are required for these employees to perform the job safely?	5	5
	Has a schedule been established for the inspection or testing of all pressure relief valves in the unit?	3	3
	a. Is the schedule being met?	1	1
	b. Are all inspections and repairs fully documented?	1	1

16	c. Are all repairs made by personnel fully trained and experienced in relief valve maintenance?	1	1
	Does the preventive maintenance program used at the facility meet the following criteria?		
	a. All safety-critical items and other key equipment, such as electrical switchgear and rotating equipment, are specifically addressed.	1	1
	b. Check lists and inspection sheets are being used.	1	1
	c. Work is being completed on time.	1	1
	d. The program is continuously modified based on inspection feedback.	1	1
17	e. Repairs are identified, tracked and completed as a result of the PM program	1	1
	Does the facility have a quality assurance program for construction and maintenance to ensure that:		
	a. Proper materials of construction are used?	1	1
	b. Fabrication and inspection procedures are proper?	1	1
	c. Equipment is maintained in compliance with codes and standards?	1	1
	d. Flanges are properly assembled and tightened?	1	1
18	e. Replacement and maintenance materials are properly specified, inspected and stored?	1	1
	Is there a permanent and progressive record for all pressure vessels that includes all of the following?	5	5
	a. Manufacturers' data reports and other pertinent data records		
	b. Vessel identification numbers		
	c. Relief valve information		
19	d. Results of all inspections, repairs, alterations, or re-ratings that have occurred to date		
20	Are systems in place, such as written requirements, with supervisor sign off, sufficient to ensure that all design repair and alteration done on any pressure vessel or piping system be done in accordance with the code to which the item was built, or in-service repair and inspection code?	5	5
	Total Points	**120**	**96.5**

Table 2.A.9 – Pre-Startup Safety Review

	Questions	Possible Score	Actual Score
1	Does company policy require a formal Process Hazard Analysis at the conception and/or design stages of all new development, construction, and major modification projects?	10	10
2	Is there a written procedure requiring that all of the following items have been accomplished before the startup of new or significantly modified facilities?	10	10
	a. Written operating procedures have been issued.		
	b. Training has been completed for all personnel involved in the process.		
	c. Adequate maintenance, inspection, safety and emergency procedures are in place.		
	d. Any recommendations resulting from the formal PHA have been completed.		
3	Is there a written procedure requiring that all equipment be inspected prior to startup to confirm that it has been installed in accordance with the design specifications and manufacturer's recommendations?	10	10
	a. Does the procedure require formal inspection reports at each appropriate stage of fabrication and construction?	5	5
	b. Does the procedure define the corrective action and follow-up needed when deficiencies are found?	5	5
4	In the pre-startup safety review, is it required that physical checks be made to confirm:		
	a. Leak tightness of all mechanical equipment prior to the introduction of highly hazardous chemicals to the process?	5	5
	b. Proper operation of all control equipment prior to startup?	5	5
	c. Proper installation and operation of all safety equipment (relief valves, interlocks, leak detection equipment, etc.)?	5	5
5	Is there a requirement to formally document the completion of the items in Questions 1, 2, 3, and 4 prior to startup, with a copy of the certification going to facility management?	5	5
	Total Points	**60**	**60**

Table 2.A.10 – Emergency Response

	Questions	Possible Score	Actual Score
1	Does the facility have an emergency plan in writing to address all probable emergencies?	10	10
	Is there a requirement to formally review and update the emergency plan on a specified schedule?	5	5
	a. Does the facility's Management of Change procedure include a requirement to consider possible impact on the facility emergency plan?	2	1
2	b. Are the results of all new or updated PHA's reviewed to determine whether any newly identified hazards will necessitate a change in the facility emergency plan?	2	0
	Does the emergency plan include at least the following?		
	a. Procedures to designate one individual as Coordinator in an emergency situation, with a clear statement of his or her responsibilities.	2	2
	b. Emergency escape procedures and emergency escape route assignments.	2	2
	c. Procedures to be followed by employees who remain to perform critical plant operations before they evacuate.	2	2
	d. Procedures to account for all employees after emergency evacuation has been completed.	2	2
	e. Rescue and medical duties for those employees who are to perform them.	2	2
	f. Preferred means of reporting fires and other emergencies.	2	2
	g. Procedures for control of hazardous materials.	2	2
	h. A search and rescue plan.	2	2
3	i. An all-clear and re-entry procedure.	2	2
	Has an emergency control center been designated for the facility?	5	5
	Does it have the following minimum resources?		
	a. Emergency power source	2	2
	b. Adequate communication facilities	2	2
4	c. Copies of P&IDs, SOPs, MSDS, Plot Plans, and other critical safety information for all process units at the facility	2	2
	Have persons been designated who can be contacted for further information or explanation of duties under the emergency plan?	5	5
5	Is this list of names posted in all appropriate locations (control rooms, security office, emergency control center, etc.)?	2	1
6	Are regular drills conducted to evaluate and reinforce the emergency plan?	10	10
Total Points		**65**	**61**

Table 2.A.11 – Incident Investigation

	Questions	Possible Score	Actual Score
	Is there a written incident/accident investigation procedure that includes both accidents and near misses?	10	10
1	Does the procedure require that findings and recommendations of investigations be addressed and resolved promptly?	5	5
	Does the procedure require that the investigation team include:		
	a. A member trained in accident investigation techniques?	3	3
2	b. The line supervisor or someone equally familiar with the process?	3	3
	Indicate whether the investigation procedure requires an investigation of the following items by the immediate supervisor with the results recorded on a standard form:		
	a. Fire and explosions	2	2
	b. Property losses at or above an established cost base	2	2
	c. All non-disabling injuries and occupational illnesses	2	2
	d. Hazardous substance discharge	2	2
3	e. Other accidents/incidents (near-misses)	2	2
	Is there a standard form for accident/incident investigation that includes the following information?		
	a. Date of incident	2	2
	b. Date investigation began	2	2
	c. Description of the incident	2	2
	d. Underlying causes of the incident	2	2
	e. Evaluation of the potential severity and probable frequency of recurrence	2	2
4	f. Recommendations to prevent recurrence	2	2
5	Based on a review of plant records, to what degree does it appear that the established incident investigation procedures are being followed?	5	4
6	If the incident/accident involved a failure of a component or piece of equipment, are appropriate inspection or engineering people required to be involved in a failure analysis to identify the conditions or practices that caused the failure?	10	10
7	Are incident investigation reports reviewed with all affected personnel whose job tasks are relevant to the incident findings, including contract employees, where applicable?	5	5
8	During the last 12-month period, have any incident or accident reports or report conclusions been transmitted to other sites that operate similar facilities within the company?	6	6
9	Do the procedures for incident reporting and/or process hazard analysis require that the findings from all applicable incident reports be reviewed and incorporated into future PHAs?	6	3
Total Points		**75**	**71**

Table 2.A.12 – Contractors

	Questions	Possible Score	Actual Score
1	Do contractor selection procedures include the following prior to awarding the contract?		
	a. A review of the contractor’s existing safety and health programs	3	3
	b. A review of the contractor’s previous loss experience data	3	3
	c. A review of the documentation of the experience and skills necessary to reasonably expect the contractor to perform the work safely and efficiently	3	3
2	Before the start of work, is the contract employer advised in writing of:		
	a. All known potential hazards of the process and of the contractor's work?	2	2
	b. Plant safe-work practices?	2	2
	c. Entry/access controls?	2	2
	d. All applicable provisions of the emergency response plan?	2	2
3	Are pre-job meetings held with contractors to review the scope of contract work activity plus the company's requirements for safety, quality assurance, and performance?	9	9
4	Are periodic assessments performed to ensure that the contract employer is providing to his or her employees the training, instruction, monitoring, etc., required to ensure the contract employees abide by all facility safe-work practices?	9	9
5	Are all contractors who perform maintenance or repair, turnaround, major renovation or specialty work covered by all the procedures addressed in this section?	10	10
Total Points		**45**	**45**

Table 2.A.13 – Management Systems Assessments

	Questions	Possible Score	Actual Score
1	How often is a formal written assessment conducted of the facility's Process Safety Management system? (Choose one)		7
	Every year	10	
	Every three years	7	
	Not done	0	
2	Has an action plan been developed to meet program needs as indicated by the last assessment?	10	6
3	Based on the most recent assessment, did the assessment team include people with the following skills:		
	a. Formal training in assessment techniques?	5	5
	b. In-depth knowledge of the process being assessed?	5	5
4	Based on a review of the most recent assessment, was the breadth and depth of the assessment appropriate for the facility?	10	10
Total Points		**40**	**33**

LAMPIRAN 5:

PERHITUNGAN CONSEQUENCE OF FAILURE (COF) DARI STEAM SCRUBBER

PART 1 : DETERMINE THE RELEASE FLUID AND ITS PROPERTIES, INCLUDING T RELEASE PHASE

1.1 REPRESENTATIVE FLUIDS

A representative fluid that most closely matches the fluid contained pressurized system being evaluated is selected from the representative fluids table shown in Table 4.1 API 581 Part 3 of COF.

1.2 FLUID PROPERTIES

The required fluid properties estimated for each representattive fluids are provided in the Table 4.2 API 581 Part 3 of COF and are dependent on the stored phase of the fluid below:

A). Stored Liquid

1. Normal Boiling Point (NBP)
2. Density (ρt)
3. Auto-iIgnition Temperature (AIT)

B). Stored Vapor or Gas

1. Normal Boiling Point (NBP)
2. Morcular Weight (MW)
3. Ideal Gas Specific Heat Capacity (k)
4. Constant Pressure Specific Heat (Cp)
5. Auto-iIgnition Temperature (AIT)

1.3 RELEASE PHASE

The dispersion characteristics of fluids and probability of consequence outcomes (events) after release are strongly dependent on the phase (gas, liquid, or two-phase) of the fluid after it is released into the environment. Guidelines for determining the phase of the released fluid can be seen on Table 4.3 API 581 Part 3 of COF. For this, the release phase is gas/vapor.

STEP 1.1 Select the representative fluid group from Table 4.1 Annex 3.A

Gas in Steam (%)					
H_2O	**Total gas content**	**CO_2**	**H_2S**	**NH_3**	**Rsd**
99.343	0.657016748	0.610713	0.014271	0.000324	0.036059
Note: those values are average of the values sample taken on different date in September 2018.					

mmole/100 mole H2O							
CO_2	**H_2S**	**NH_3**	**N_2**	**CH_4**	**He**	**H_2**	**Ar**
239.871	7.38218	0.22971	24.5565	0.4563	0.08704	1.2557	0.02902
Note: those values are average of the values sample taken on different date in September 2018.							

The representative fluid is **water steam** but for fluid mixture, there are some other considerations of representative fluid in API RP 581 - Annex 3.A section 3.A.3.1.2 Choice of Representative Fluids of Mixtures stated in the following paragraph.

If a mixture contains inert materials such as CO2 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.

Table 4.1 – List of Representative Fluids Available for Level 1 Consequence Analysis

Representative Fluid	Fluid TYPE (see Section 4.1.5)	Examples of Applicable Materials
H_2	TYPE 0	Hydrogen
H_2S	TYPE 0	Hydrogen Sulfide
HF	TYPE 0	Hydrogen Fluoride
water	TYPE 0	Water
steam	TYPE 0	Steam
Acid	TYPE 0	Acid, Caustic

The representative fluid is H_2S

STEP 1.2 Determine the stored fluid phase

The Steam Scrubber of Star Energy Geothermal Wayang Windu Unit 2 is vapor stored fluid phase.

STEP 1.3 Determine the stored fluid properties

For a stored vapor or gas fluid, the properties are dependent on these parameters such as:

1). Molecular Weight (MW), kg/kg-mol (lb/lb-mol)

The stored vapor Molecular Weight (MW) can be estimated from Table 4.2

MW = 34.00 (kg/kg-mol)

2). Auto-Ignition Temperature, K

The stored liquid Auto-Ignition Temperature (AIT) can be estimated from Table 4.2 of API 581 Part 3 of COF.

AIT = 500 (^oC)

AIT = 773.15 (K)

3). Ideal gas specific heat ratio, k

Cp_A = 31.9 J/kmol-K

Cp_B = 1.44E-03 J/kmol-K

Cp_C = 2.43E-05 J/kmol-K

Cp_D = -1.18E-08 J/kmol-K

T = 185.4 °C

T = 365.72 °F

T = 458.55 K

R = 8.314 J/kg-mol-K

$$Cp = A + BT + CT^2 + DT^3$$

$= 3.34x10^4 + (2.68x10^4 \times 458.55) + (2.61x10^3 \times 458.55)^2 + (8.9x10^3 \times 458.55)^3$

= 3.26E+01 J/kmol-K

$$k = \frac{Cp}{Cp - R}$$ ……………………………………………… (equation 2)

$$= \frac{8.29x10^{22}}{8.29x10^{22} - 8.314}$$

= 1.342896

STEP 1.4 Determine the steady state phase of the fluid after release to the atmosphere

Determining the ateady state phase of the fluid after release to the atmosphere can be adopted from the Table 4.3 API 581 Part 3 of COF shown below:

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^{o}F, then model as a liquid
Liquid	Liquid	Model as liquid

SUMMARY of STEP 1:

1 According the data of Company chemical analysis, the major fluids are water steam and H2S which has the percentage of 99.316% and 0.0155% of all.

2 The fluid stored in the pressure vessel (Steam Scrubber) is assumed as gas, because the gaseous constituent is dominant.

3 Fluid properties id based on the STEP 1.3 which has been adjusted by using Table 4.2 in API RP 581 Part 3 of COF

MW	=	34.00	(kg/kg-mol)
AIT	=	773.15	(K)
T	=	458.55	(K)
Cp	=	3.3E+01	(J/kmol-K)
k	=	1.3429	

4 The steady state phase after release to the atmoshpere is gaseous type.

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PART 2: SELECT A SET OF RELEASE HOLE SIZES TO DETERMINE THE POSSIBLE RANGE OF CONSEQUENCE IN THE RISK CALCULATION

2.1 RELEASE HOLE SIZE SELECTION

A descrete set of release events or release hole sizes are used since it would be impractical to perform the consequence analysis for a continous spectrum of release hole sizes. Limiting the number of of release hole sizes allows for an analysis that is manageable, yet still reflects the range of possible outcomes.

STEP 2.1 Calculate of release hole sizes by determining each diameter (d_n)

The following steps are repeated of each release hole size, typically four hole sizes are evaluated.

According to Annex 3.A of API 581 Chapter 3.2.3 committs that the standard four release hole sizes are assumed for all sizes in pressure vessel type.

Table 4.4. Release Hole Sizes and Areas Used in Level 1 and 2 Consequences Analysis

Release Hole Number	Release Hole Sizes	Range of Hole Diameter (mm)	Release Hole Diameter, d_n (inch)
1	Small	0 - 1/4	$d_1 = 0.25$
2	Medium	> 1/4 - 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 gff_n, for the n^{th} release hole size

Determining the generic failure frequency (gff_n), for the n^{th} release hole size can be seen from API 581 Part 2, Table 3.1

Table 3.1. Suggested Component Generic Failure Frequency

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
Note: See references [1] through [8] for discussion of failure frequencies for equipment						

The total of generic failuure frequency (gff) can be taken from the table value or calculated using the equation below:

$$gff_{total} = \sum_{n=1}^{4} gff n$$

Because the total vallue of generic failure frequency has been availabled from the table. So, we can directly put the value from the table into the calculation.

gff_{total} = 0.0000306 failures/year

gff_{small} = 0.000008 failures/year

gff_{medium} = 0.00002 failures/year

gff_{large} = 0.000002 failures/year

$gff_{rupture}$ = 0.0000006 failures/year

SUMMARY of Step 2:

1. According to Annex 3.A Part 3 of API RP 581 committs that for pressure vessels, all of model of release hole size must be assumed.
2. The total generic failure frequency per years for every type of pressure vessel has been adjusted by the Table of 3.1 in Part 2 of API RP 581.

   gff_{small} = 0.000008 failures/year

   gff_{medium} = 0.00002 failures/year

   gff_{large} = 0.000002 failures/year

   $gff_{rupture}$ = 0.0000006 failures/year

PART 3 : CALCULATE THE THEORETICAL RELEASE RATE

3.1 RELEASE RATE

Release rate has a close correlation within the physical properties of the material, the initial phase, the process operating conditions, and the assigned release hole sizes. As we know that initial phase is the phase of the stored fluid prior contacting to the atmosphere. for special case, two-phases systems which contain gaseos and liquid containmment inside the pressure vessel, so, according t the API 581 Part 3, choosing liquid as the initial state inside the equipment is more conservative and may be preferred.

3.2 VAPOR RELEASE RATE EQUATIONS

There are two regimes for flow gases through an orifice: aonic (choked) for higher internal pressure, and subssonic flow for lower pressure (nominally 15 psig (103.4 kPa) or less). The transition pressure at which the flow regime changes from sonic to subsonic is determined using below equation.

P_{atm} = 14.696 psi

k = 1.3429

$$P_{trans} = Patm \left(\frac{k+1}{2}\right)^{\frac{k}{k-1}}$$

$$P_{trans} = 14.69 \left(\frac{1+1}{2}\right)^{\frac{1}{1-1}}$$

= 27.3111523 psi

STEP 3.1 Select the appropriate release rate equation

Because of the phase inside the Steam Scrubber is GASEOUS PHASE and the storage pressure (P_s) within the equipment item is greater than the transition pressure (P_{trans}), so the equation chosen is shown below:

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

Abbreviation list :

C_d	=	Discharge coefficient, for turbulent liquid flow from the sharp-edge orifices in the range of $0.85 \leq C_d \leq 1.00$			
	=	0.9			
A_n	=	Release hole sized area			
P_s	=	Storage operating pressure	=	143.59	psi
P_{atm}	=	Atmosphere pressure	=	14.696	psi
k	=	Ideal gas specific heat capacity ratio	=	1.3429	
MW	=	Molecular weight	=	34.00	(kg/kg-mol)
g_c	=	Gravitational constant	=	9.8	m/s^2
R	=	Universal gas constant	=	8.314	J/(kg-mol-K)
T_s	=	Storage operating temperature	=	185.4	℃
			=	365.72	°F
			=	458.55	K

STEP 3.2 For every release hole size, calculate the release hole size area based on d_n

Release Hole Number	Release Hole Sizes	Range of Hole Diameter (inch)	Release Hole Diameter, d_n (inch)
1	Small	0 - 1/4	d1 = 0.25
2	Medium	> 1/4 - 2	d2 = 1
3	Large	> 2 - 6	d3 = 4
4	Rupture	> 6	d4 = min[D,16]

The release hole size area can be determined by formulating below equation:

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

1). SMALL RELEASE HOLE SIZE AREA

d_1 = 0.25 inch
= 0.0064 m
π = 3.14

$$An = \frac{\pi dn^2}{4} = \frac{3.14\ x\ (0.25)^2}{4}$$

= 0.0491 $inch^2$
= 3E-05 m^2

2). MEDIUM RELEASE HOLE SIZE AREA

d_1 = 1 inch
= 0.0254 m
π = 3.14

$$An = \frac{\pi dn^2}{4} = \frac{3.14\ x\ (1)^2}{4}$$

= 0.785 $inch^2$
= 0.0005 m^2

3). LARGE RELEASE HOLE SIZE AREA

d_1 = 4 inch
= 0.1016 m
π = 3.14

$$An = \frac{\pi dn^2}{4} = \frac{3.14\ x\ (4)^2}{4}$$

= 12.56 $inch^2$
= 0.0081 m^2

4). RUPTURE RELEASE HOLE SIZE AREA

d_1 = 16 inch
= 0.4064 m
π = 3.14

$$An = \frac{\pi dn^2}{4} = \frac{3.14\ x\ (16)^2}{4}$$

= 200.96 $inch^2$
= 0.1296 m^2

STEP 3.3 For liquid releases, for each release hole size, calculate the viscosity correction factor ($K_{v,n}$)

Viscosity Correction Factor ($K_{v,n}$) can be determined using both equation 4 of graph below, which have been printed from API Standard 520 Part 1. Another option, the conservative value of viscosity correction factor may be used the value of 1.0

$$K_{v,n} = \left(0.9935 + \frac{2.878}{Ren^{0.5}} + \frac{342.75}{Ren^{1.5}}\right)^{-1}$$

Because the store fluid phase determined in STEP 1.2 is gaseous or vapor phase, then, this step is no neeed to be considered.

STEP 3.4 For each hole size, calculate the release rate, W_n, for each release area A_n

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

Abb

C_d	=	0.9	
k	=	1.34289575	
A_{n1}	=	3.1645E-05	m^2
A_{n2}	=	0.00050645	m^2
A_{n3}	=	0.00810321	m^2
A_{n4}	=	0.1296192	m^2
gc	=	1	kgm/Ns^2
	=	32.2	$lb_m\ ft/lb_f\ S^2$
Ps	=	990	Kpa
P_{atm}	=	101.325	KPa
C_2	=	1	
R	=	8.314	J/(kg-mol-K)
g_c	=	9.8	m/s^2
T_s	=	458.55	K
MW	=	34.00	(kg/kg-mol)

1). SMALL RELEASE HOLE SIZE AREA

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

$$W_n = \frac{0.9}{C2}\, x\ 0.000031645 \text{ x } 990 \sqrt{\left(\frac{1.34\ x\ 34\ x\ 9.8}{8.314\ x\ 458.55}\right)\left(\frac{2}{1.34+1}\right)^{\frac{1.34+1}{1.34-1}}}$$

= 0.00192733 kg/s

2). MEDIUM RELEASE HOLE SIZE AREA

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

$$W_n = \frac{0.9}{C2}\, x\ 0.000506451 \text{ x } 990 \sqrt{\left(\frac{1.34x\ 34\ x\ 9.8}{8.314\ x\ 458.55}\right)\left(\frac{2}{1.34+1}\right)^{\frac{1.34+1}{1.34-1}}}$$

= 0.09003454 kg/s

3). LARGE RELEASE HOLE SIZE AREA

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

$$W_n = \frac{0.9}{C2}\ x\ 0.00810321 \text{ x } 990 \sqrt{\left(\frac{1.34x\ 34\ x\ 9.8}{8.314\ x\ 458.55}\right)\left(\frac{2}{1.34+1}\right)^{\frac{1.34+1}{1.34-1}}}$$

= 0.46016768 kg/s

4). RUPTURE RELEASE HOLE SIZE AREA

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

$$W_n = \frac{0.9}{C2}\ x\ 0.1296192 \text{ x } 990 \sqrt{\left(\frac{1.34x\ 34\ x\ 9.8}{8.314\ x\ 458.55}\right)\left(\frac{2}{1.34+1}\right)^{\frac{1.34+1}{1.34-1}}}$$

= 23.0431273 kg/s

SUMMARY:

1 The chosen equation for determining the theoretical release rate (W_n) is using equation below because, the release fluid is modeled as gas-gas and the storage pressure is greater than the transition pressure.

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

2 For calculating the release hole size area (A_n), all of assumed size of release hole for the pressure vessel (steam scrubber) must be considered to determine theoretical release rate.

3 It is no need to calculate the viscosity correction factor because the release fluid is modeled as gas-gas. The voscosity correction factor calculation is adjusted for only the liquid phase.

4 After determining each release hole sie are from the small until the rupture, then, the theoretical release rate can be calculated.

W_{n1} = 0.00192733 kg/s

W_{n2} = 0.09003454 kg/s

W_{n3} = 0.46016768 kg/s

W_{n4} = 23.0431273 kg/s

PART 4 : ESTIMATE THE TOTAL AMOUNT OF OF FLUID INVENTORY AVAILABLE FOR RELEASE

4.1 RELEASE RATE

The leaking component's inventory is combined with inventory with the other attached components that can contribute fluid mass.

Table 3.A.3.2 — Assumptions Used When Calculating Liquid Inventories Within Equipment

Equipment Description	Component Type	Examples	Default Liquid Volume Percent
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

4.2 MAXIMUM MASS AVAILABLE FOR RELEASE

The available mass for release is estimated for each release hole size as the lesser of two quantities:

INVENTORY GROUP MASS

The component being evaluated is part of a larger group of components that can be expected to provide fluid inventory to the release. The inventory calculation as presented here is used as an upper-limit and does not indicate that this amount of fluid would be released in all leak scenarios. The inventory group mass can be calculated using this below equation:

$$Mass_{inv} = \sum_{i=1}^{N} \left(Mass_{comp,i} \right)$$

COMPONENT MASS

It is assumed that for large leaks and above, operator intervension will occur within 3 minutes, thereby limiting the amount of release material. Therefore, the amount of available mass for the release is limmited to the mass of the component plus an additional mass, $mass_{add,n}$, that is calculated based on three minutes of leakage from the component's inventory group.

STEP 4.1 Group components and equipment items into inventory groups

This step of determining the group components and equipment items can be referred to API 581 Part 3 Annex 3.A.3.3 says that when a component or equipment type is evaluated, the inventory of the component is combined with inventory from associated equipment that can contribute fluid mass to the leaking components. **Theoritically, the total amount of fluid that can be released is the amount that is held within pressure containing equiment between isolation valves that can be quickly closed.**

STEP 4.2 Calculate the fluid mass, $mass_{comp}$, in the component being evaluated

OD = 2195 mm L = 10283 mm

V_{tot}	=	34.96	m^3	V_{gas}	=	31.464	m^3
		1234.6	ft^3			1111.1	ft^3
ρ_{gas}	=	5.8	kg/m^3	V_{liq}	=	3.496	m^3
		0.3621	lb/ft^3			123.46	ft^3

ρ_{liq} = 660 kg/m^3

$Mass_{comp}$ = 182.49 kg

STEP 4.3 Calculate the fluid mass in each of the other component that are included in the inventory group mass

Based on the design of the gas plant, there is no other component or equipment type that can be combined to contribute the fluid mass to the leaking components.

STEP 4.4 Calculate the fluid mass in the inventory group, $mass_{inv}$

$$Mass_{inv} = \sum_{i=1}^{N} (Mass_{comp,i})$$

Where

$Mass_{comp}$ = is the inventory fluid mass for the component or piece of equipment being evaluated, kgs [lbs]

$Mass_{inv}$ = is the inventory group fluid mass, kgs [lbs]

= 2489.9 kg

STEP 4.5 Calculate the flow rate from a 203 mm (8 inch) diameter hole, W_{max8}

Calculate the flow rate from a 203 mm (8 inch) diameter hole, Wmax8, using the equation 5 as applicable with $A_n = A_8$ = 32.450 mm^2 (50.3 inch^2). This is the maximum flow rate that can be added to the equipment fluid mass from the surrounding equipment in the inventory group.

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

Where

C_d	=	Discharge coefficient, for turbulent gas flow from the sharp-edge orifices in the range of $0.85 \le C_d \le 1.00$			
			=	0.9	
A_n	=	Release hole sized area	=	50.3	inch^2
			=	32444	mm^2
			=	0.0324	m^2
P_s	=	Storage operating pressure	=	143.59	psi
			=	990	Kpa
P_{atm}	=	Atmosphere pressure	=	14.696	psi
			=	101.33	Kpa
MW	=	Molecular weight	=	34.00	(kg/kg-mol)
g_c	=	Gravitational constant	=	9.8	m/s^2
R	=	Universal gas constant	=	8.314	J/(kg-mol-K)
T_s	=	Storage or normal operating temperature	=	185.4	°C
			=	365.72	°F
			=	458.55	K
C_2	=	SI and US customary conversion factors	=	1	
k	=	Ideal gas specific heat ratio	=	1.3429	

So,

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

$$W_{max8} = \frac{0.9}{1}\ x\ 0.03244 \text{ x } 2895.9 \sqrt{(\frac{1.3429\ x\ 34\ x\ 9.8}{8.314\ x\ 458.55})(\frac{2}{1.3429+1})^{\frac{1..3429+1}{1.3429-1}}}$$

= 5.76766174 kg/s

STEP 4.6 Calculate the added fluid mass $mass_{add,n}$ for each release hole size

Determining the additional fluid mass for each release hole size resulting from three minutes of flow from the inventory group usin this below equation:

$$Mass_{add\ n} = 180 . \min[W_n , W_{max8}]$$

1). SMALL RELEASE HOLE SIZE AREA

$$Mass_{add\ n} = 180 . min[W_n , W_{max8}]$$

$$Mass_{add\ 1} = 180 . min[0.0019273,5.76766174]$$

= 0.3469 kgs

2). MEDIUM RELEASE HOLE SIZE AREA

$$Mass_{add\ n} = 180 . min[W_n , W_{max8}]$$

$$Mass_{add\ 2} = 180 . min[0.0900345,5.76766174]$$

= 16.206 kgs

3). LARGE RELEASE HOLE SIZE AREA

$$Mass_{add\ 3} = 180 . min[W_n , W_{max8}]$$

$$Mass_{add\ 3} = 180 . min\ [0.4601677,5.76766174]$$

= 82.83 kgs

4). RUPTURE RELEASE HOLE SIZE AREA

$$Mass_{add\ 4} = 180 . min[W_n , W_{max8}]$$

$$Mass_{add\ 4} = 180 . min[23.043127,5.76766174]$$

= 1038.2 kgs

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

For each release hole size, calculate the available mass for release usinng this below equation:

$$Mass_{avail\ n} = min . [\{Mass_{comp} + Mass_{add,n}\}, Mass_{inv}]$$

1). SMALL RELEASE HOLE SIZE AREA

$$Mass_{avail\ n} = min . [\{Mass_{comp} + Mass_{add,n}\}, Mass_{inv}]$$

$$Mass_{avail\ 1} = min . [\{146.99+0.3469199\},2005.6]$$

= 182.84 kgs

2). MEDIUM RELEASE HOLE SIZE AREA

$$\text{Mass}_{avail\ n} = min\,.\,[\{\text{Mass}_{comp} + \text{Mass}_{add,n}\}, \text{Mass}_{inv}]$$

$$\text{Mass}_{avail\ 2} = min\,.\,[\{146.99+16.206218\}, 2005.6]$$

$$= 198.7\ \text{kgs}$$

3). LARGE RELEASE HOLE SIZE AREA

$$\text{Mass}_{avail\ n} = min\,.\,[\{\text{Mass}_{comp} + \text{Mass}_{add,n}\}, \text{Mass}_{inv}]$$

$$\text{Mass}_{avail\ 3} = min\,.\,[\{146.99+82.830183\}, 2005.6]]$$

$$= 265.32\ \text{kgs}$$

4). RUPTURE RELEASE HOLE SIZE AREA

$$\text{Mass}_{avail\ n} = min\,.\,[\{\text{Mass}_{comp} + \text{Mass}_{add,n}\}, \text{Mass}_{inv}]$$

$$\text{Mass}_{avail\ 4} = min\,.\,[\{146.99+1038.1791\}, 2005.6]$$

$$= 1220.7\ \text{kgs}$$

SUMMARY:

1. For group inventory, theoritically, the total amount of fluid that can be released is the amount that is held within pressure containing equiment between isolation valves that can be quickly closed.
2. Calculating the fluid mass and the mass of component to determine the mass inventory.
3. There is no other components contributing the mass of the equipment evaluated.
4. Mass_{inv} = 2489.9 kg
5. Determining the maximum flow rate of a hole size within the diameter of 203 mm (8 inch) with the hole size area of 32.450 mm^2 (50.3 $inch^2$).

   W_{max8} = 5.76766174 kg/s
6. Determining the additional fluid mass for release hole size starting for the small release hole size until the rupture release hole size.

   Mass_{add1} = 0.34691994 kgs

   Mass_{add2} = 16.206218 kgs

   Mass_{add3} = 82.8301833 kgs

   Mass_{add4} = 1038.17911 kgs
7. Determining the available mass for each release hole size

   Mass_{avail1} = 182.838 kgs

   Mass_{avail2} = 198.697 kgs

   Mass_{avail3} = 265.321 kgs

   Mass_{avail4} = 1220.670 kgs

PART 5 : DETERMINE THE RELEASE TYPE (CONTINOUS OR INSTATANENOUS)

5.1 RELEASE TYPE

The release is modeled as one of these two followinng types:

A). INSTANTANEOUS RELEASE

An instataneous or puff release is one that occurs so rapidly that the fluid disperses as a single large cloud or pool.

B). CONTINOUS RELEASE

A continous or plume release is one that occurs over a longer period of time, allowing the fluid to dispers in the shape of elongated ellipse (dependening in the weather conditions).

The process for determining the appropriate type for release to model requires to determine the time required to release 4536 kgs (10000 lbs) of fluid, tn, through each release hole size.

STEP 5.1 Calculate the time required to release 4536 kgs (10000 lbs) of fluid for each hole size.

To determine the time required to release 4536 kgs (10000 lbs) of fluid for each hole size can be adopted from the equation below:

$$t_n = \frac{C3}{W_n}$$

Where

t_n = time required to release 4536 kgs (10000 lbs) of fluid

C_3 = SI and US customary conversion factors
= 4536 kgs
= 10000 lbs

W_n = Theoretical release rate associated with the n^{th} release hole size, kg/s

W_{n1} = 0.00192733 kg/s

W_{n2} = 0.09003454 kg/s

W_{n3} = 0.46016768 kg/s

W_{n4} = 23.0431273 kg/s

1). SMALL RELEASE HOLE SIZE AREA

$$t_n = \frac{C3}{W_n}$$

$$t_1 = \frac{4536}{0.00192733}$$

= 2353511.3 s

2). MEDIUM RELEASE HOLE SIZE AREA

$$t_n = \frac{C3}{W_n}$$

$$t_2 = \frac{4536}{0.09003454}$$

= 50380.6624 s

3). LARGE RELEASE HOLE SIZE AREA

$$t_n = \frac{C3}{W_n}$$

$$t_3 = \frac{4536}{0.46016768}$$

= 9857.27627 s

4). RUPTURE RELEASE HOLE SIZE AREA

$$t_n = \frac{C3}{W_n}$$

$$t_4 = \frac{4536}{23.0431273}$$

$= 196.848281$ s

STEP 5.2 Determine the release type for each release hole size.

For each release hole size, determine the release type either instataneous or continous using this following criteria:

a. If the release hole size is 6.35 mm(0.25 inch) or less, then the release type is continous

b. If t_n<180 sec and the releaase mass is gretaer than 4536 kgs (100000 lbs), then the release is instataneous: otherwise the release is continous

1). SMALL RELEASE HOLE SIZE AREA

d_1 = 0.25 inch

t_1 = 2E+06 s (Continous)

2). MEDIUM RELEASE HOLE SIZE AREA

d_2 = 1 inch

t_2 = 50381 s (Continous)

3). LARGE RELEASE HOLE SIZE AREA

d_3 = 4 inch

t_3 = 9857.3 s (Continous)

4). RUPTURE RELEASE HOLE SIZE AREA

d_4 = 16 inch

t_4 = 196.85 s (Continous)

SUMMARY:

1. Calculating the time required to release 4536 kgs (10000 lbs) of fluid for each hole size, starting for the small until the rupture release hole size.

   t_{n1} = 2353511.3 s

   t_{n2} = 50380.6624 s

   t_{n3} = 9857.27627 s

   t_{n4} = 196.848281 s

2. Based on the characteristic that if the release hole size is 0.25 inch or less, then, automatically including into the continuous release type. And the other hand, if t_n<180 sec and the release mass is gretaer than 4356 kgs (10000 lbs), it is including into instantaneous release type.

PART 6 : ESTIMATE THE IMPACT OF DETECTION AND ISOLATION SYSTEMS ON RELEASE MAGNITUDE

STEP 6.1 Determine the detection and isolation systems present in the unit using Table 4.5 and 4.6 API 581 Part 3

Table 4.5- Detection and Isolation System Rating Guide

Type of Detection System	Det. 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	**Iso. 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 location remote from the leak	B
Isolation dependent on manually operated valves	C

Table 4.6 - Adjustment to Release Based on Detection and Isolation Systems

System Classification		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 systems present	=	Visual or detection in marginal area *
	Isolation systems present	=	HV *
STEP 6.2	Type of detection system	=	Visual detection, cameras, or detectors with marginal coverage *
	Detection Classification	=	C
STEP 6.3	Type of isolation system	=	Isolation or shutdown systems activated directly from process instrumentation or detectors, with no oprator intervention *
	Isolation Classification	=	C

STEP 6.4 Determine the release reduction factor $fact_{di}$ using Table 4.6

Release Magnitude Adjustment	=	No adjustment to release rate or mass
Reduction Factor, $fact_{di}$	=	**0**

STEP 6.5 Determine the total leak durations for each release hole sizes using Table 4.7

Table 4.7 - Leak Durations Based on detection and Isolation Systems

Detection System Rating	Isolation System Rating	Maximum Leak Duration, ld_{max}
A	A	20 minutes for 1/4 inch leaks
		10 minutes for 1 inch leaks
		5 minutes for 4 inch leaks
A	B	30 minutes for 1/4 inch leaks
		20 minutes for 1 inch leaks
		10 minutes for 4 inch leaks
A	C	40 minutes for 1/4 inch leaks
		30 minutes for 1 inch leaks
		20 minutes for 4 inch leaks
B	A or B	40 minutes for 1/4 inch leaks
		30 minutes for 1 inch leaks
		20 minutes for 4 inch leaks
B	C	1 hour for 1/4 inch leaks
		30 minutes for 1 inch leaks
		20 minutes for 4 inch leaks
C	A, B, or C	1 hour for 1/4 inch leaks
		40 minutes for 1 inch leaks
		20 minutes for 4 inch leaks

1). SMALL RELEASE HOLE SIZE AREA

d_1 = 0.25 inch

t_1 = 2E+06 s (Continous)

$ld_{max,1}$ = 1 hour for 1/4 inch leaks

2). MEDIUM RELEASE HOLE SIZE AREA

d_2 = 1 inch

t_2 = 50381 s (Continous)

$ld_{max,2}$ = 40 minutes for 1 inch leaks

3). LARGE RELEASE HOLE SIZE AREA

d_3 = 4 inch

t_3 = 9857.3 s (Continous)

$ld_{max,3}$ = 20 minutes for 4 inch leaks

4). RUPTURE RELEASE HOLE SIZE AREA

d_4 = 16 inch

t_4 = 196.85 s (Continous)

$ld_{max,4}$ = 20 minutes for 4 inch leaks

PART 7:DETERMINE THE RELEASE RATE AND MASS FOR CONSEQUENCE OF FAILU

7.1 CONTINOUS RELEASE RATE

For continous releases, the release is modeled as a steady state plume: therefore, the release rate is used as an input to the consequence analysis. The release rate that is used in the analysis is the theoretical release adjusted for the presence of unit detection and isolations as formulated in the equation below:

$$Rate_n = W_n \, (1 - fact_{di})$$

7.2 INSTANTANEOUS RELEASE RATE

For transient instataneous puff releases, the release mass is required to perform the analysis. The available release mass for each hole size, $mass_{avail,n}$, is used ass an upper bound for the release mass, $mass_n$, as shown in the equation below:

$$Mass_n = min\,.\,[\{Rate_n \,.\, ld_n\}, Mass_{avail,n}]$$

STEP 7.1 Calculate the adjusted release rate, $rate_n$ for each release hole size

For each release hole size, determine the adjusted release rate, $rate_n$, using equation 12 above where the theoreical release rate, W_n, and also note that the release reduction factor, $fact_{di}$, account for any detection and isolation systemss that are present.

Reduction Factor, $fact_{di}$ = 0

W_{n1} = 0.00192733 kg/s

W_{n2} = 0.09003454 kg/s

W_{n3} = 0.46016768 kg/s

W_{n4} = 23.0431273 kg/s

1). SMALL RELEASE HOLE SIZE AREA

$$Rate_1 = W_n \, (1 - fact_{di})$$

$$Rate_1 = 0.00192733 \, (1 - 0.20)$$

= 0.0019 kg/s

2). MEDIUM RELEASE HOLE SIZE AREA

$$Rate_2 = W_n \, (1 - fact_{di})$$

$$Rate_2 = 0.0900345 \, (1 - 0.20)$$

= 0.09 kg/s

3). LARGE RELEASE HOLE SIZE AREA

$$Rate_3 = W_n \, (1 - fact_{di})$$

$$Rate_3 = 0.46016768 \, (1 - 0.20)$$

= 0.4602 kg/s

4). RUPTURE RELEASE HOLE SIZE AREA

$$Rate_4 = W_n \, (1 - fact_{di})$$

$$Rate_4 = 23.0431273 \, (1 - 0.20)$$

= 23.043 kg/s

STEP 7.2 Calculate the leak duration, ld_n, for each release hole size

For each release hole size, calculate the leak duration, ld_n, of the release using this equation below, ,. Note that the leak duration cannot exceed the maximum duration $ld_{max,n}$.

$$ld_n = min.[\{\frac{Mass_{avail,n}}{Rate_n}\},\{60 . ld_{max,n}]$$

$ld_{max,1}$	=	1 hour for 1/4 inch leaks	60	$Mass_{avail,1}$	=	182.84 kgs
$ld_{max,2}$	=	40 minutes for 1 inch leaks	40	$Mass_{avail,2}$	=	198.70 kgs
$ld_{max,3}$	=	20 minutes for 4 inch leaks	20	$Mass_{avail,3}$	=	265.32 kgs
$ld_{max,4}$	=	20 minutes for 4 inch leaks	20	$Mass_{avail,4}$	=	1220.7 kgs

1). SMALL RELEASE HOLE SIZE AREA

$$ld_1 = min.[\{\frac{Mass_{avail,n}}{Rate_1}\},\{60 . ld_{max,1}]$$

$$ld_1 = min.[\{\frac{147.34}{0.00192}\},\{60 . 60\}]$$

= 3600 s

2). MEDIUM RELEASE HOLE SIZE AREA

$$ld_2 = min.[\{\frac{Mass_{avail,n}}{Rate_2}\},\{60 . ld_{max,2}]$$

$$ld_2 = min.[\{\frac{163.20}{0.0900345}\},\{60 . 40\}]$$

= 2206.9 s

3). LARGE RELEASE HOLE SIZE AREA

$$ld_3 = min.[\{\frac{Mass_{avail,n}}{Rate_3}\},\{60 . ld_{max,3}]$$

$$ld_3 = min.[\{\frac{229.83}{0.46016771}\},\{60 . 20\}]$$

= 576.58 s

4). RUPTURE RELEASE HOLE SIZE AREA

$$ld_4 = min.[\{\frac{Mass_{avail,n}}{Rate_4}\},\{60 . ld_{max,4}]$$

$$ld_4 = min.[\{\frac{1185.2}{23.043127}\},\{60 . 20\}]$$

= 52.973 s

STEP 7.3 Calculate the release mass, $mass_n$, for each release hole size

For each release hole size, calculate the release mass, $mass_n$, using equation in section 7.2 above based on the release rate, $rate_n$, the leak duration, Id_n, and the available mass,

1). SMALL RELEASE HOLE SIZE AREA

$$Mass_1 = min.[\{Rate_1 . ld_1\},Mass_{avail.1}]$$

$$Mass_1 = min . [\{0.00192739 . 3600\},147.34212]$$

$= 6.93839882$ kgs

2). MEDIUM RELEASE HOLE SIZE AREA

$$Mass_2 = min . [\{Rate_2 . ld_2\},Mass_{avail,n}]$$

$$Mass_2 = min . [\{0.0900345 . 1812.7\},163.20142]$$

$= 198.697418$ kgs

3). LARGE RELEASE HOLE SIZE AREA

$$Mass_3 = min . [\{Rate_3 . ld_3\},Mass_{avail,n}]$$

$$Mass_3 = min . [\{0.460167. 499.4\},229.82538]$$

$= 265.321383$ kgs

3). RUPTURE RELEASE HOLE SIZE AREA

$$Mass_4 = min . [\{Rate_4 . ld_4\},Mass_{avail,n}]$$

$$Mass_4 = min . [\{23.043127 . 51.433\},1185.1743]$$

$= 1220.67031$ kgs

SUMMARY:

1 Determining the adjusted release rate, $rate_n$, for each release hole size. This adjusted release rate is quite different with the theoretical release rate, W_n, because the adjusted release rate is based on the real condition with the theoretical release rate referrence. Otherwise, the theoretical release rate, $W_{n,}$ is purely based on the theory and approching equationg provided by API RP 581.

$Rate_1$	=	0.00192733 kg/s
$Rate_2$	=	0.09003454 kg/s
$Rate_3$	=	0.46016768 kg/s
$Rate_4$	=	23.0431273 kg/s

2 Determining the leak duration, ld_n, for each release hole size.

ld_1	=	3600 s
ld_2	=	2206.90202 s
ld_3	=	576.575435 s
ld_4	=	52.9732921 s

3 Determining the release mass for each release hole size based on the release rate, leak duration, and available mass for each release hole size.

$Mass_1$	=	6.93839882 kgs
$Mass_2$	=	198.697418 kgs
$Mass_3$	=	265.321383 kgs
$Mass_4$	=	1220.67031 kgs

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PART 8 : DETERMINE FLAMMABLE AND EXPLOSIVE CONSEQUENCE

8.1 CONSEQUENCE AREA EQUATIONS

The following equations are used to determine the flammable consequence areas for comoponent damage and personnel injury. There are two kind of equantions explained based on its type of release, either continous release or instataneous release as mentioned below:

1). $CA_n^{CONT} = \alpha(rate_n)^b$

2). $CA_n^{CONT} = \alpha(mass_n)^b$

The coefficients for those equations for component damage areas and personel injury are provided in Table 4.8 and 4.9 in API RP 581 Part 3 of COF.

STEP 8.1 Select the consequence area mitigation reduction factor, factmit, from Table 4.10

Mitigation System	Consequence Area Adjustment	Consequence Area Reduction Factor, factor mit
Inventory blowdown , couple 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%	0.2
Fire water monitor only	Reduce consequence area by 5%	0.05
Foam spray system	Reduce consequence area by 15%	0.15

Mitigation system	=	Fire water deluge system and monitors
Consequence Area	=	Reduce consequence area by 5% *
$fact_{mit}$	=	0.05

STEP 8.2 Calculate the energy efficiency, $eneff_n$, for each hole size using equation mentioned below.

$$eneff_n = 4.\,log_{10}[C_{4A}\,.mass_n] - 15$$

This correction is made for instantaneous events exceeding a release mass of 4,536 kgs (10,000 Ibs). Comparison of calculated consequence with those of actual historical releases indicates that there is need to correct large instantaneous releases for energy efficiency.

C_{4A} = 2205 1/kg

A) SMALL RELEASE HOLE SIZE AREA

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

$eneff_1$ = 1.73867

B) MEDIUM RELEASE HOLE SIZE AREA

$$eneff_2 = 4.\,log_{10}[C_{4A}\,.mass_2] - 15$$

$eneff_2$ = 7.5664

C) LARGE RELEASE HOLE SIZE AREA

$$eneff_3 = 4.\,log_{10}[C_{4A}\,.mass_3] - 15$$

$eneff_3$ = 8.06872

D) RUPTURE RELEASE HOLE SIZE AREA

$$eneff_4 = 4.\,log_{10}[C_{4A}\,.mass_4] - 15$$

$eneff_4$ = 10.72

STEP 8.3 Determine the fluid type

Determine the fluid type, either TYPE 0 or TYPE 1 based on Table 4.1 of API RP 581 Part 3 of COF.

Table 4.1 – List of Representative Fluids Available for Level 1 Consequence Analysis

Representative Fluid	Fluid TYPE (see Section 4.1.5)	Examples of Applicable Materials
H_2	TYPE 0	Hydrogen
H_2S	TYPE 0	Hydrogen Sulfide
HF	TYPE 0	Hydrogen Fluoride
water	TYPE 0	Water
steam	TYPE 0	Steam
Acid	TYPE 0	Acid, Caustic

H_2S	=	TYPE 0		T	=	185.4	(^oC)
MW	=	34.00	(kg/kg-mol)	T	=	365.72	(^oF)
AIT	=	500	(^oC)	T	=	458.55	(K)
AIT	=	773.15	(K)				

STEP 8.4 For each release hole size, calculate the component damage consequence areas for Auto-Ignition Not Likely, Continous Release (AINT-CONT), $CA^{AINL\text{-}CONT}$

1). Determine the appropriate constant a and b from the Table 4.8

Table 4.8M - Component Damage Flammable Consequence Equation Constants

Fluid	Continuous Release Constant								Instantaneous Release Constant							
	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	
	α	b	α	b	α	b	α	b	α	b	α	b	α	b	α	b
H_2S	6.6	1.00			38.1	0.89			22.6	0.63			53.72	0.61		

α = $\alpha_{cmd,n}^{AINL-CONT}$ = 6.6 b = $b_{cmd}^{AINL-CONT}$ = 1.00

2). Calculate the consequence of area using equation below

$Rate_1$ = 0.0019 kg/s
$Rate_2$ = 0.0900 kg/s
$Rate_3$ = 0.4602 kg/s
$Rate_4$ = 23.0431 kg/s

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

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{cmd,1}^{AINL-CONT} = \alpha(rate_1)^b \, . \, (1 - fact_{mit})$$

= 0.012 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{cmd,2}^{AINL-CONT} = \alpha(rate_2)^b \, . \, (1 - fact_{mit})$$

= 0.56058 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{cmd,3}^{AINL-CONT} = \alpha(rate_3)^b \, . \, (1 - fact_{mit})$$

= 2.86514 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{cmd,4}^{AINL-CONT} = \alpha(rate_4)^b \, . \, (1 - fact_{mit})$$

= 143.473 m^2

STEP 8.5 For ech release hole size, calculate the component damage consequence areas for Auto-Ignition Likely, Continous Release (AIL-CONT), $CA^{AIL-CONT}$

1). Determine the appropriate constant a and b from the Table 4.8

α = $\alpha_{cmd,n}^{AIL-CONT}$ = 38.1 b = $b_{cmd}^{AIL-CONT}$ = 0.89

2). Calculate the consequence of area using equation below

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

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{cmd,1}^{AINL-CONT} = \alpha(rate_1)^b \, . \, (1 - fact_{mit})$$

= 0.1388 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{cmd,2}^{AINL-CONT} = \alpha(rate_2)^b \, . \, (1 - fact_{mit})$$

= 4.24802 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{cmd,3}^{AINL-CONT} = \alpha(rate_3)^b \, . \, (1 - fact_{mit})$$

= 18.145 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA^{AINL-CONT}_{cmd,4} = \alpha(rate_4)^b \, . (1 - fact_{mit})$$

= 590.778 m^2

STEP 8.6 For each release hole size, calculate the component damage consequence areas for Auto-ignition Not Likely, Instaneous Release, (AINL-INST), $CA^{AINL-INST}$

1). Determine the appropriate constant a and b from the Table 4.8

α = $\alpha^{AINL-INST}_{cmd,n}$ = 22.6 b = $b^{AINL-INST}_{cmd}$ = 0.63

2). Calculate the consequence of area using equation below

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

From step 7, known that:

Mass1	=	6.93839882 kgs	Mass3	=	265.321383 kgs
Mass2	=	198.697418 kgs	Mass4	=	1220.670313 kgs

A) SMALL RELEASE HOLE SIZE AREA

$$CA^{AINL-INST}_{cmd,1} = \alpha(mass_1)^b \, . \left(\frac{1-fact_{mit}}{eneff_1}\right)$$

= 41.8971 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA^{AINL-INST}_{cmd,2} = \alpha(mass_2)^b \, . \left(\frac{1-fact_{mit}}{eneff_2}\right)$$

= 79.6856 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$CA^{AINL-INST}_{cmd,3} = \alpha(mass_3)^b \, . \left(\frac{1-fact_{mit}}{eneff_3}\right)$$

= 89.6561 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA^{AINL-INST}_{cmd,4} = \alpha(mass_4)^b \, . \left(\frac{1-fact_{mit}}{eneff_4}\right)$$

= 176.51 m^2

STEP 8.7 For ech release hole size, calculate the component damage consequence areas for Auto-Ignition Likely, Instataneous Release (AIL-INST), $CA^{AIL-INST}$

1). Determine the appropriate constant a and b from the Table 4.8

α = $\alpha^{AIL-INST}_{cmd,n}$ = 53.7 b = $b^{AIL-INST}_{cmd}$ = 0.61

2). Calculate the consequence of area using equation below

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

From step 7, known that:

Mass1	=	6.93839882 kgs	Mass3	=	265.321383 kgs
Mass2	=	198.6974180 kgs	Mass4	=	1220.67031 kgs

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{cmd,1}^{AINL-INST} = \alpha(mass_1)^b \cdot \left(\frac{1-fact_{mit}}{eneff_1}\right)$$

= 95.6776 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{cmd,2}^{AINL-INST} = \alpha(mass_2)^b \cdot \left(\frac{1-fact_{mit}}{eneff_2}\right)$$

= 170.164 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{cmd,3}^{AINL-INST} = \alpha(mass_3)^b \cdot \left(\frac{1-fact_{mit}}{eneff_3}\right)$$

= 190.351 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{cmd,4}^{AINL-INST} = \alpha(mass_4)^b \cdot \left(\frac{1-fact_{mit}}{eneff_4}\right)$$

= 363.487 m^2

STEP 8.8 For each release hole size, calculate the personnel injury consequence areas for Auto-ignition Not Likely, Continous Release (AINL-CONT), $CA_{inj,n}^{AINL-CONT}$

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phas as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

Table 4.9M - Personnel Injury Flammable Consequence Equation Constants

Fluid	Continuous Release Constant								Instantaneous Release Constant							
	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	
	α	b	α	b	α	b	α	b	α	b	α	b	α	b	α	b
H_2S	10.7	1.00			73	0.94			41.4	0.63			191.5	0.63		

α = $\alpha_{inj,n}^{AINL-CONT}$ = 10.7   b = $b_{inj,n}^{AINL-CONT}$ = 1.00

2). Calculate the consequence of area using equation below

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

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AINL-CONT} = \left[\alpha.\left(rate_1^{AINL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 0.0195 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AINL-CONT} = \left[\alpha.\left(rate_2^{AINL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 0.91092 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AINL-CONT} = \left[\alpha.\left(rate_3^{AINL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 4.65575 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AINL-CONT} = \left[\alpha.\left(rate_4^{AINL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 233.139 m^2

STEP 8.9 For each release hole size, calculate the personnel injury consequence areas for Auto-ignition Likely, Continous Release (AIL-CONT), $CA_{inj,n}^{AIL-CONT}$

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phasE as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

α = $\alpha_{inj,n}^{AIL-CONT}$ = 73.3   b = $b_{inj,n}^{AIL-CONT}$ = 0.94

2). Calculate the consequence of area using equation below

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

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AIL-CONT} = \left[\alpha.\left(rate_1^{AIL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 0.19516 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AIL-CONT} = \left[\alpha.\left(rate_2^{AIL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 7.23895 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AIL-CONT} = \left[\alpha.\left(rate_3^{AIL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 33.5484 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AIL-CONT} = \left[\alpha.\left(rate_4^{AIL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 1328.37 m^2

STEP 8.10 For each release hole size, calculate the personnel injury consequence areas for Auto-ignition Not Likely, Instataneous Release (AINL-INST), $CA_{inj,n}^{AINL-INST}$

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phase as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

α = $\alpha_{inj,n}^{AINL-INST}$ = 41.4 b = $b_{inj,n}^{AINL-INST}$ = 0.63

2). Calculate the consequence of area using equation below

$$CA_{inj,n}^{AINL-INST} = [\alpha.(mass_n^{AINL-INST})^b].\left(\frac{1 - fact_{mit}}{eneff_n}\right)$$ (equation 24)

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AINL-INST} = \left[\alpha.\left(mass_1^{AINL-INST}\right)^b\right].\left(\frac{1 - fact_{mit}}{eneff_1}\right)$$

= 76.7034 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AINL-INST} = \left[\alpha.\left(mass_2^{AINL-INST}\right)^b\right].\left(\frac{1 - fact_{mit}}{eneff_2}\right)$$

= 145.885 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AINL-INST} = \left[\alpha.\left(mass_3^{AINL-INST}\right)^b\right].\left(\frac{1 - fact_{mit}}{eneff_3}\right)$$

= 164.138 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AINL-INST} = \left[\alpha.\left(mass_4^{AINL-INST}\right)^b\right].\left(\frac{1 - fact_{mit}}{eneff_4}\right)$$

= 323.147 m^2

STEP 8.11 For each release hole size, calculate the personnel injury consequence areas for Auto-ignition Likely, Instataneous Release (AIL-INST), $CA_{inj,n}^{AIL-INST}$

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phas as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

α = $\alpha_{inj,n}^{AIL-INST}$ = 191.5 b = $b_{inj,n}^{AIL-INST}$ = 0.63

2). Calculate the consequence of area using equation below

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

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AIL-INST} = \left[\alpha.\left(mass_1^{AIL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_1}\right)$$

= 354.542 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AIL-INST} = \left[\alpha.\left(mass_2^{AIL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_2}\right)$$

= 674.317 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AIL-INST} = \left[\alpha.\left(mass_3^{AIL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_3}\right)$$

= 758.69 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AIL-INST} = \left[\alpha.\left(mass_4^{AIL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_4}\right)$$

= 1493.67 m^2

STEP 8.12 For each release hole size, calculate the instataneous/continous blending factor, $fact_n^{IC}$.

1). FOR CONTINOUS RELEASE

C_5 = 25.2 kg/s

$$fact_n^{IC} = \min\left[\left\{\frac{rate_n}{C_5}\right\}, 1.0\right]$$ ……………………………

A) SMALL RELEASE HOLE SIZE AREA

$$fact_1^{IC} = \min\left[\left\{\frac{rate_1}{C_5}\right\}, 1.0\right]$$

= 7.64815E-05

B) MEDIUM RELEASE HOLE SIZE AREA

$$fact_2^{IC} = \min\left[\left\{\frac{rate_2}{C_5}\right\}, 1.0\right]$$

= 0.003572799

C) LARGE RELEASE HOLE SIZE AREA

$$fact_3^{IC} = \min\left[\left\{\frac{rate_3}{C_5}\right\}, 1.0\right]$$

= 0.018260622

D) **RUPTURE RELEASE HOLE SIZE AREA**

$$fact_4^{IC} = \min\left[\left\{\frac{rate_3}{C_5}\right\}, 1.0\right]$$

= 0.914409814

2). FOR INSTATANEOUS RELEASE

$fact_n^{IC} =$ 1

STEP 8.13 Calculate the AIT blending factor, $fact^{AIT}$, using these optional equation below.

$fact^{AIT}$	=	0	for, $T_S + C_6 \le AIT$
$fact^{AIT}$	=	$\frac{(T_s - AIT + C_6)}{2 . C_6}$	for, $T_S + C_6 > AIT > T_S - C_6$
$fact^{AIT}$	=	1	for, $T_S - C_6 \ge AIT$

Ts	=	185.4	(^oC)	AIT	=	500	(^oC)
Ts	=	365.72	(^oF)	AIT	=	773.15	(K)
Ts	=	458.55	(K)	C_6	=	55.6	(K)

$T_s + C_6$ = 514.15 (K)

$T_s - C_6$ = 402.95 (K)

$\frac{(T_s - AIT + C_6)}{2 . C_6}$ = 4.623651 (K)

So, $fact^{AIT}$ = 0

STEP 8.14 Calculate the continuous/instantaneous blended consequence area for the component using equation (3.53) through (3.56) based on the consequence areas calculated in previous steps $fact_n^{IC}$

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

A) SMALL RELEASE HOLE SIZE AREA

$CA_{cmd,1}^{AIL-INST}$ = 95.68 m^2

$fact_1^{IC}$ = 7.65E-05

$CA_{cmd,1}^{AIL-CONT}$ = 0.14 m^2

$CA_{cmd,1}^{AIL}$ = 0.146102027 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{cmd,2}^{AIL-INST}$ = 170.16 m^2

C) LARGE RELEASE HOLE

$CA_{cmd,3}^{AIL-INST}$ = 190.35 m^2

$fact_3^{IC}$ = 1.8E-02

$CA_{cmd,3}^{AIL-CONT}$ = 18.15 m^2

$CA_{cmd,3}^{AIL}$ = 21.2896 m^2

D) RUPTURE RELEASE HOLE

$CA_{cmd,4}^{AIL-INST}$ = 363.49 m^2

$fact_2^{IC}$ = 0.003573

$CA_{cmd,2}^{AIL-CONT}$ = 4.25 m²

$CA_{cmd,2}^{AIL}$ = 4.840805692 m²

$fact_4^{IC}$ = 0.9144

$CA_{cmd,4}^{AIL-CONT}$ = 590.78 m²

$CA_{cmd,4}^{AIL}$ = 382.941 m²

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

A) SMALL RELEASE HOLE SIZE AREA

$CA_{inj,1}^{AIL-INST}$ = 354.5424189 m²

$fact_1^{IC}$ = 7.65E-05

$CA_{inj,1}^{AIL-CONT}$ = 0.1951599 m²

$CA_{inj,1}^{AIL}$ = 0.222260899 m²

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{inj,2}^{AIL-INST}$ = 674.3168315 m²

$fact_2^{IC}$ = 0.0035728

$CA_{inj,2}^{AIL-CONT}$ = 7.238954659 m²

$CA_{inj,2}^{AIL}$ = 9.622290091 m²

C) LARGE RELEASE HOLE

$CA_{inj,3}^{AIL-INST}$ = 758.69 m²

$fact_3^{IC}$ = 0.01826 m²

$CA_{inj,3}^{AIL-CONT}$ = 33.5484 m²

$CA_{inj,3}^{AIL}$ = 46.79 m²

D) RUPTURE RELEASE HOLE

$CA_{inj,4}^{AIL-INST}$ = 1493.67 m²

$fact_4^{IC}$ = 0.9144 m²

$CA_{inj,4}^{AIL-CONT}$ = 1328.37 m²

$CA_{inj,4}^{AIL}$ = 1479.52 m²

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

A) SMALL RELEASE HOLE SIZE AREA

$CA_{cmd,n}^{AINL-INST}$ = 95.67759362 m²

$fact_1^{IC}$ = 7.65E-05

$CA_{cmd,1}^{AINL-CONT}$ = 0.012000153 m²

$CA_{cmd,1}^{AINL}$ = 0.019316799 m²

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{cmd,n}^{AINL-INST}$ = 170.1638807 m²

$fact_2^{IC}$ = 0.003573

C) LARGE RELEASE HOLE

$CA_{cmd,n}^{AINL-INST}$ = 190.351 m²

$fact_3^{IC}$ = 0.0183

$CA_{cmd,3}^{AINL-CONT}$ = 2.86514 m²

$CA_{cmd,3}^{AINL}$ = 6.28876 m²

D) RUPTURE RELEASE HOLE

$CA_{cmd,4}^{AINL-INST}$ = 363.487 m²

$fact_4^{IC}$ = 0.9144

$CA_{cmd,2}^{AINL-CONT}$ = 0.560582085 m^2

$CA_{cmd,2}^{AINL}$ = 1.166540647 m^2

$CA_{cmd,4}^{AINL-CONT}$ = 143.473 m^2

$CA_{cmd,4}^{AINL}$ = 344.656 m^2

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

A) SMALL RELEASE HOLE SIZE AREA

$CA_{inj,n}^{AINL-INST}$ = 76.70335465 m^2

$fact_1^{IC}$ = 0.0001

$CA_{inj,1}^{AINL-CONT}$. = 0.019499792 m^2

$CA_{inj,1}^{AINL}$ = 0.025364686 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{inj,n}^{AINL-INST}$ = 145.8848372 m^2

$fact_2^{IC}$ = 0.003573

$CA_{inj,2}^{AINL-CONT}$. = 0.910924506 m^2

$CA_{inj,2}^{AINL}$ = 1.428887213 m^2

C) LARGE RELEASE HOLE

$CA_{inj,n}^{AINL-INST}$ = 164.138 m^2

$fact_3^{IC}$ = 0.0183

$CA_{inj,3}^{AINL-CONT}$.= 4.65575 m^2

$CA_{inj,3}^{AINL}$ = 7.568 m^2

D) RUPTURE RELEASE HOLE

$CA_{inj,4}^{AINL-INST}$ = 323.147 m^2

$fact_4^{IC}$ = 0.9144

$CA_{inj,4}^{AINL-CONT}$.= 233.139 m^2

$CA_{inj,4}^{AINL}$ = 315.443 m^2

STEP 8.15 Calculate the AIT blended consequence areas for the component using equations (3.57) and (3.58) based on the consequence areas determined in step 8.14 and the AIT blending factors, $fact^{AIT}$, calculate in step 8.13. the resulting consequence areas are the component damage and personnel injury flammable consequence areas, $CA_{icmd,n}^{flam}$ and $CA_{inj,n}^{flam}$ for each release hole size selected in step 2.2

$$CA_{cmd,n}^{flam} = CA_{smd,n}^{AIL} . fact^{AIT} + CA_{cmd,n}^{AINL} . (1 - fact^{AIT})$$

A) SMALL RELEASE HOLE SIZE AREA

$CA_{cmd,1}^{AIL}$ = 0.14610203 m^2

$fact^{AIT}$ = 0

$CA_{cmd,1}^{AINL}$ = 0.0193168 m^2

$CA_{cmd,1}^{flam}$ = 0.0193168 m^2

C) LARGE RELEASE HOLE

$CA_{cmd,3}^{AIL}$ = 21.28963 m^2

$fact^{AIT}$ = 0

$CA_{cmd,3}^{AINL}$ = 6.288756 m^2

$CA_{cmd,3}^{flam}$ = 6.288756 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

D) RUPTURE RELEASE HOLE

$CA_{cmd,2}^{AIL}$ = 4.84080569 m²

$fact^{AIT}$ = 0

$CA_{cmd,2}^{AINL}$ = 1.16654065 m²

$CA_{cmd,2}^{flam}$ = 1.16654065 m²

$CA_{cmd,4}^{AIL}$ = 382.9407561 m²

$fact^{AIT}$ = 0

$CA_{cmd,4}^{AINL}$ = 344.6558622 m²

$CA_{cmd,4}^{flam}$ = 344.6558622 m²

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

A) SMALL RELEASE HOLE SIZE AREA

$CA_{inj,1}^{flam-AIL}$ = 0.2222609 m²

$fact^{AIT}$ = 0

$CA_{inj,1}^{AINL}$ = 0.02536469 m²

$CA_{inj,1}^{flam}$ = 0.02536469 m2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{inj,2}^{flam-AIL}$ = 9.62229009 m²

$fact^{AIT}$ = 0

$CA_{inj,2}^{AINL}$ = 1.42888721 m²

$CA_{inj,2}^{flam}$ = 1.42888721 m2

C) LARGE RELEASE HOLE

$CA_{inj,3}^{flam-AIL}$ = 46.78997128 m²

$fact^{AIT}$ = 0

$CA_{inj,3}^{AINL}$ = 7.567999312 m²

CA_{inj3}^{flam} = 7.567999312 m²

D) RUPTURE RELEASE HOLE

$CA_{inj,4}^{flam-AIL}$ = 1479.518429 m²

$fact^{AIT}$ = 0

$CA_{inj,4}^{AINL}$ = 315.4428279 m²

$CA_{inj,4}^{flam}$ = 315.4428279 m²

STEP 8.16 Determine the consequence areas (probability weighted on release hole size) for component damage and personnel injury using equations (3.59) and (3.60) based on the consequence ara from step 8.15

Equipment Type	Component Type	gff as a function of hole size (failure/yr)				gff total (failure/yr)
		Small	Medium	Large	Rupture	
Vessel/ FinFan	KODRUM COLBTM FINFAN FILTER DRUM REACTOR COLTOP COLMID	8.0E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05

CONSEQUENCE AREA FOR COMPONENT DAMAGE

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

$$CA_{cmd}^{flam} = \left(\frac{(gff_{1} \cdot CA_{cmd,1}^{flam}) + (gff_{2} \cdot CA_{cmd,2}^{flam}) + (gff_{3} \cdot CA_{cmd,3}^{flam}) + (gff_{4} \cdot CA_{cmd,4}^{flam})}{gff_{total}} \right)$$

= 7.94 m^2

CONSEQUENCE AREA FOR PERSONNEL INJURY

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

$$CA_{inj}^{flam} = \left(\frac{(gff_1 \cdot CA_{inj,1}^{flam}) + (gff_2 \cdot CA_{inj,2}^{flam}) + (gff_3 \cdot CA_{inj,3}^{flam}) + (gff_4 \cdot CA_{inj,4}^{flam})}{gff_{total}} \right)$$

= 7.620 m^2

Halaman ini sengaja dikosongkan

PART 9 : CALCULATE THE TOXIC CONSEQUENCES AREA

STEP 9.1 For each release hole size selected in STEP 2.2, calculate the effective duration of the toxic release using this equation below.

$$ld_n^{tox} = \min\left(3600, \left\{\frac{mass_n}{W_n}\right\}, \{60. ld_{max,n}\}\right)$$

W_{n1}	=	0.00192733	kg/s	$Mass_1$	=	6.938399	kgs
W_{n2}	=	0.09003454	kg/s	$Mass_2$	=	198.69742	kgs
W_{n3}	=	0.46016768	kg/s	$Mass_3$	=	265.32138	kgs
W_{n4}	=	23.0431273	kg/s	$Mass_4$	=	1220.67031	kgs

$ld_{max,1}$ = 1 hour for 1/4 inch leaks
$ld_{max,2}$ = 40 minutes for 1 inch leaks
$ld_{max,3}$ = 20 minutes for 4 inch leaks
$ld_{max,4}$ = 20 minutes for 4 inch leaks

A). SMALL RELEASE HOLE SIZE AREA

$$ld_1^{tox} = \min\left(3600, \left\{\frac{mass_1}{W_1}\right\}, \{60. ld_{max,1}\}\right)$$

= 60 s

B). MEDIUM RELEASE HOLE SIZE AREA

$$ld_2^{tox} = \min\left(3000, \left\{\frac{mass_2}{W_2}\right\}, \{60. ld_{max,2}\}\right)$$

= 2206.9 s

C). LARGE RELEASE HOLE SIZE AREA

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

= 576.58 s

D). RUPTURE RELEASE HOLE SIZE AREA

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

= 52.973 s

STEP 9.2 Determine the toxic percentage of the toxic component, $mfrac^{tox}$, in the release material. The release fluid is a pure fluid, $mfrac^{tox}$ = 1.0. note that if there is more than one toxic component in the release fluid mixture, this procedure can be repeated for each toxic component

H_2S	=	0.74%	NH_3	=	0.037%
$mfrac^{tox}$	=	0.0074	$mfrac^{tox}$	=	0.0003704

STEP 9.3 For each release hole size, calculate the release the release rate, $rate_n^{tox}$, and release mass, $mass_n^{tox}$,to be used in the toxic analysis

$$rate_n^{tox} = mfrac^{tox}.W_n$$

$$mass_n^{tox} = mfrac^{tox}.mass_n$$

For H_2S

A) SMALL RELEASE HOLE SIZE AREA

$rate_1^{tox} = mfrac^{tox}.W_1$ = 1.42E-05 kg/s

$mass_1^{tox} = mfrac^{tox}.mass_1$ = 0.05122065 kgs

B) MEDIUM RELEASE HOLE SIZE AREA

$rate_2^{tox} = mfrac^{tox}.W_2$ = 6.65E-04 kg/s

$mass_2^{tox} = mfrac^{tox}.mass_2$ = 1.46682408 kgs

C) LARGE RELEASE HOLE SIZE AREA

$rate_3^{tox} = mfrac^{tox}.W_3$ = 3.40E-03 kg/s

$mass_3^{tox} = mfrac^{tox}.mass_3$ = 1.95865552 kgs

D) RUPTURE RELEASE HOLE SIZE AREA

$rate_4^{tox} = mfrac^{tox}.W_4$ = 1.70E-01 kg/s

$mass_4^{tox} = mfrac^{tox}.mass_4$ = 9.01123239 kgs

For NH_3

A) SMALL RELEASE HOLE SIZE AREA

$rate_1^{tox} = mfrac^{tox}.W_1$ = 7.14E-07 kg/s

$mass_1^{tox} = mfrac^{tox}.mass_1$ = 0.00256998 kgs

B) MEDIUM RELEASE HOLE SIZE AREA

$rate_2^{tox} = mfrac^{tox}.W_2$ = 3.33E-05 kg/s

$mass_2^{tox} = mfrac^{tox}.mass_2$ = 0.07359752 kgs

C) LARGE RELEASE HOLE SIZE AREA

$rate_3^{tox} = mfrac^{tox}.W_3$ = 1.70E-04 kg/s

$mass_3^{tox} = mfrac^{tox}.mass_3$ = 0.09827504 kgs

D) RUPTURE RELEASE HOLE SIZE AREA

$rate_4^{tox} = mfrac^{tox}.W_4$ = 8.54E-03 kg/s

$mass_4^{tox} = mfrac^{tox}.mass_4$ = 0.45213628 kgs

STEP 9.4 For each release hole size, calculate the toxic consequence area for each of the release hole size.

1) Calculate $CA_{inj,n}^{toxCONT}$ for HF acid and H_2S , using equation 41 for continous release or equation 42 for instantaneous releasing Table 4.11

Continous Release Duration (minutes)	HF Acid		H_2S	
	c	d	c	d
5	1.1401	3.5683	1.2411	3.9686
10	1.1031	3.8431	1.241	4.0948
20	1.0816	4.104	1.237	4.238
40	1.0942	4.3295	1.2297	4.3626
60	1.4056	4.4576	1.2266	4.4365
Instantaneous	1.4056	33606	0.9674	2.784

For continous release (equation 40) or instantaneous release (equation 41):

$$CA_{inj,n}^{toxCONT} = C_8 . 10^{(c.log_{10}[C_{4B}.rate_n^{tox}]+d)}$$

$$CA_{inj,n}^{toxINST} = C_8 . 10^{(c.log_{10}[C_{4B}.mass_n^{tox}]+d)}$$

C_8 = 0.0929 m^2.sec C_{4B} = 2.25 sec/kg

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{toxCONT} = C_8 . 10^{(c.log_{10}[C_{4B}.rate_1^{tox}]+d)}$$

$CA_{inj,1}^{toxCONT}$ = 0.00779 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{toxCONT} = C_8 . 10^{(c.log_{10}[C_{4B}.rate_2^{tox}]+d)}$$

$CA_{inj,2}^{toxCONT}$ = 0.719 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{toxCONT} = C_8 . 10^{(c.log_{10}[C_{4B}.rate_3^{tox}]+d)}$$

$CA_{inj,3}^{toxCONT}$ = 3.87 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{toxCONT} = C_8 . 10^{(c.log_{10}[C_{4B}.rate_4^{tox}]+d)}$$

$CA_{inj,4}^{toxCONT}$ = 489.86 m^2

2) Calculate $CA_{inj,n}^{toxCONT}$ for Ammonia and Chlorine, using equation 42 for continous release or equation 43 for instantaneous releasing Table 4.12M

Continous Release Duration (minutes)	Ammonia		Chlorine	
	e	f	e	f
20	1256	1.178	4191	1.089
40	2029	1.169	6860	1.072
60	2714	1.145	10994	1.026
Instantaneous	2.684	0.9011	3.528	1.177

For continous release (equation 42) or instantaneous release (equation 43):

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

$$CA_{inj,n}^{toxINST} = e(Mass_n^{tox})^f$$

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{toxCONT} = e(Rate_1^{tox})^f$$

$CA_{inj,1}^{toxCONT}$ = 0.00024889 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{toxCONT} = e(Rate_2^{tox})^f$$

$CA_{inj,2}^{toxCONT}$ = 0.01185121 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{toxCONT} = e(Rate_3^{tox})^f$$

$CA_{inj,3}^{toxCONT}$ = 0.04568769 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{toxCONT} = e(Rate_4^{tox})^f$$

$CA_{inj,4}^{toxCONT}$ = 4.5915344 m^2

STEP 9.5 If there are additional toxic component in the released fluid mixture, the STEP 9.2 througt 9.4 should be repeated for each toxic component.
There are no additional toxic components.

STEP 9.6 Determine the final toxic consequence areas for personnel injury in accordance with equation 44.

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

Equipment Type	Component Type	gff as a function of hole size (failure/yr)				gff total (failure/yr)
		Small	Medium	Large	Rupture	
Vessel/ FinFan	KODRUM COLBTM FINFAN FILTER DRUM REACTOR COLTOP COLMID	8.0E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05

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

$$CA_{inj}^{tox} = \left(\frac{(gff_1 \cdot CA_{inj,1}^{tox}) + (gff_2 \cdot CA_{inj,2}^{tox}) + (gff_3 \cdot CA_{inj,3}^{tox}) + (gff_4 \cdot CA_{inj,4}^{tox})}{gff_{total}}\right)$$

= 10.43 m^2

PART 10 : CALCULATE THE NON-FLAMMABLE, NON-TOXIC CA

Step 10.1 For each release hole size, calculate the non-flammable , non-toxic consequence For steam-calculate using equation (45) $CA_{inj,N}^{CONT}$ for continous release or equation (46) $CA_{inj,N}^{INST}$ for instantaneous release.

1). FOR STEAM

Steam represents a hazard to personnel who are exposed to it at high temperatures. In general, steam is at 100°C (212°F) immediately after exiting a hole in an equipment item. Within a few feet, the steam will begin to mix with air cool, and condensed. The approach used here is that injury occurs above 60°C (140°F). In this case of Steam Scrubber, the temperatur inside the presssure vessel is working around 185.4°C. So, steam leaks is potentially occur at this situation.

$Mass_1$	=	6.938399	kgs	$Rate_1$	=	0.0019	kg/s
$Mass_2$	=	198.69742	kgs	$Rate_2$	=	0.0900	kg/s
$Mass_3$	=	265.32138	kgs	$Rate_3$	=	0.4602	kg/s
$Mass_4$	=	1220.67031	kgs	$Rate_4$	=	23.0431	kg/s
$fact_1^{IC}$	=	7.6481E-05		C_9	=	0.123	m^2.sec/kg
$fact_2^{IC}$	=	0.0035728		C_{10}	=	9.744	$m^2/kg^{0.06384}$
$fact_3^{IC}$	=	0.01826062					
$fact_4^{IC}$	=	0.91440981					

$CA_{inj,n}^{CONT} = C_9 \cdot Rate_n$

$CA_{inj,n}^{INST} = C_{10} \cdot (Mass_n)^{0.6384}$

A) SMALL RELEASE HOLE SIZE AREA

$CA_{inj,1}^{CONT} = C_9 \cdot Rate_1$

= 0.00024 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{inj,2}^{CONT} = C_9 \cdot Rate_2$

= 0.01107 m^2

C) LARGE RELEASE HOLE SIZE AREA

$CA_{inj,3}^{CONT} = C_9 \cdot Rate_3$

= 0.05660 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$CA_{inj,4}^{CONT} = C_9 \cdot Rate_4$

= 2.83430466 m^2

2). FOR ACIDS AND CAUSTIC

For Acids or caustics- compute, $CA_{inj,N}^{CONT}$ using equation (3.72), (3.73), (3.74). Note that the data is not provided for an instantaneous release
No acid or caustic, thus value are 0.

Step 10.2 For each release hole size, calculate the instantaneous/continuous blending factor . For steam, use equation (3.71), for acids or caustics, $fact_n^{IC} = 0$

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

C_5 = 25.2 kg/sec

A) SMALL RELEASE HOLE SIZE AREA

$$fact_1^{IC} = \min\left[\left\{\frac{rate_1}{C_5}\right\}, 1.0\right]$$

= 7.6481E-05 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$fact_2^{IC} = \min\left[\left\{\frac{rate_2}{C_5}\right\}, 1.0\right]$$

= 0.0035728 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$fact_3^{IC} = \min\left[\left\{\frac{rate_3}{C_5}\right\}, 1.0\right]$$

= 0.01826062 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$fact_4^{IC} = \min\left[\left\{\frac{rate_4}{C_5}\right\}, 1.0\right]$$

= 0.91440981 m^2

Step 10.3 For each release hole size , compute the blended non-flammable , non-toxic personnel injury consequence area for steam or acid leaks, $CA_{inj,n}^{leak}$, using equation (3.76) based on the consequence are from step 10.1 and the blending factor ,$fact_n^{IC}$, from step 10.2. Note that there is no need to calculate component damage area for the level 1 non-flammable release (steam or acid/caustic) :

$CA_{cmd,n}^{leak}$ = 0 m^2

$$CA_{inj,n}^{leak} = CA_{inj,n}^{INST} . fact_n^{IC} + CA_{inj,n}^{CONT} . (1 - fact_n^{IC})$$

A). SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{leak} = CA_{inj,1}^{INST} . fact_1^{IC} + CA_{inj,1}^{CONT} . (1 - fact_1^{IC})$$

= 0.00023704 m^2

B). MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{leak} = CA_{inj,2}^{INST} . fact_2^{IC} + CA_{inj,2}^{CONT} . (1 - fact_2^{IC})$$

= 0.01103468 m^2

C). LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{leak} = CA_{inj,3}^{INST} . fact_3^{IC} + CA_{inj,3}^{CONT} . (1 - fact_3^{IC})$$

= 0.05556706 m^2

D). RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{leak} = CA_{inj,4}^{INST} . fact_4^{IC} + CA_{inj,4}^{CONT} . (1 - fact_4^{IC})$$

= 2.67730618 m^2

Step 10.4 Determine the final non-flammable, non toxic consequence areas for personnil injury, CA_{inj}^{nfnt} 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-flammable, non-toxic consequence area for component damage area for the level 1 non-flammable release (steam or acid/caustic, or :

$$CA_{cmd,n}^{lnfnt} = 0 \ m^2$$

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

$$CA_{inj}^{nfnt} = \left(\frac{(gff_1 . CA_{inj,1}^{leak}) + (gff_2 . CA_{inj,2}^{leak}) + (gff_3 . CA_{inj,3}^{leak}) + (gff_4 . CA_{inj,4}^{leak})}{gff_{total}} \right)$$

= 0.06340 m^2

Equipment Type	Component Type	gff as a function of hole size (failure/yr)				gff total (failure/yr)
		Small	Medium	Large	Rupture	
Vessel/ FinFan	KODRUM	8.0E-06	2.00E-05	2.0E-06	6.00E-07	3.06E-05
	COLBTM					
	FINFAN					
	FILTER					
	DRUM					
	REACTOR					
	COLTOP					
	COLMID					

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PART 11 : CALCULATION OF FINAL CONSEQUENCE AREA

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, $CAcmd^{flam}$.

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

$$= 7.94 \ m^2$$

Step 11.2 Calculate the final personnel injury consequence area, CA_{inj}

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

CA_{inj}^{flam} = 7.6203385 m^2

CA_{inj}^{tox} = 10.430550 m^2

CA_{inj}^{nfnt} = 0.06340222 m^2

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

$$= 10.430550 \ m^2$$

Step 11.3 Calculate the final consequence area, CA, using equation below:

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

$$= 10.430550 \ m^2$$

$$= 112.27351 \ ft^2$$

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LAMPIRAN 6:

DAMAGE FACTOR SCREENING QUESTION DARI STEAM EJECTOR (GAS REMOVAL SYSTEM)

DAMAGE FACTOR SCREENING QUESTION

DETERMINATION OF PROBABILITY OF FAILURE

API 581 PART 2

I. DAMAGE FACTOR

Damage Factor(s) provides a screening tool to determine inspection priorities and optimize inspection. The basic function of the DF is to statistically evaluate the amount of damage that may be present as a function of time in service and the effectiveness of an inspection activity. DFs are calculated based on the 3 different techniques as mentioned below, but are not intended to reflect the actual POF for the purposes of reliability analysis. DFs reflect a relative level of concern about the component based on the stated assumptions in each of the applicable sectiion of the document.

a. Structural reliability modes

b. Statistical models based on generic data

c. Expert judgement

Table of Damage Factor Screening Questions

No	Damage Factor	Screening Criteria	Yes/No
1.	Thining	All component should be checked for thining	Yes
2.	Component Lining	If the component has organic or inorganic lining, then the component should be evaluated for lining damage	No
3.	SCC Damage Factor-Caustic Cracking	If the component's material of construction is carbon or low alloy steel and the process environment contains caustic in any concentration, then the component should be evaluated for susceptibility to caustic cracking.	No
4.	SCC Damage Factor-Amine Cracking	If the component's material of construction is carbon or low alloy steel and process environment contains acid gas treating amines (MEA, DEA, DIPA, MDEA, etc.) in any concentration, then the component should be evaluated for susceptibility to amine cracking.	No
5.	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 H_2S in any concentration, then the component should be evaluated to Sulfide Ctress Cracking (SCC).	Yes
6.	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 H_2S in any concentration, then the component should be evaluated to HIC/SOHIC-H_2S cracking.	Yes

<table>
<tr><th>No</th><th>Damage Factor</th><th colspan="3">Screening Criteria</th><th>Yes/No</th></tr>
<tr><td rowspan="3">7.</td><td rowspan="3">SCC Damage Factor-Carbonate Stress Corrosion Cracking</td><td colspan="3">If the component’s material of construction is carbon or low alloy steel and the process environment contains sour water at pH > 7.5 in any concentration, then the component should be evaluated for susceptibility to carbonate cracking.</td><td>No</td></tr>
<tr><td colspan="3">There is no data for Heat Material Balance</td><td>No</td></tr>
<tr><td colspan="3">Another trigger would be changes in FCCU feed sulfurr and nitrogen contents particularly when feed changes have reduced sulfur (low sulfur feeds or hydroprocessed feeds) or increased nitrogen.</td><td>No</td></tr>
<tr><td>8.</td><td>SCC Damage Factor-Polythionic Acid Stress Corrosion Cracking</td><td colspan="3">If the component's material of construction is an austenitic stainless steel or nickel based alloys and the components is exposed to sulfur bearing compunds, then the component should be evaluated for susceptibility to PASCC.</td><td>No</td></tr>
<tr><td rowspan="4">9.</td><td rowspan="4">SCC Damage Factor-Chloride Stress Corrosion Cracking</td><td colspan="3">If <u>ALL</u> of the following are true, then the component should evaluated for suscepibility to CLSCC cracking:</td><td rowspan="4">No</td></tr>
<tr><td>a.</td><td>The component's material of construction is an austenitic stainless</td><td>N</td></tr>
<tr><td>b.</td><td>The component is exposed or potentially exposed to chlorides and water also considering upsets and hydrotest water remaining in component, and cooling tower drift (consider both under insulation and</td><td>Y</td></tr>
<tr><td>c.</td><td>The operating temperature is above 38°C (100°F)</td><td>N</td></tr>
<tr><td>10.</td><td>SCC Damage Factor-Hydrogen Stress Cracking-HF</td><td colspan="3">If the component's material of construction is ccarbon or low alloy steel and the component is exposed too hydrofluoric acid in any concentration, then the component should be evaluated for susceptibility to HSC-HF.</td><td>No</td></tr>
<tr><td>11.</td><td>SCC Damage Factor HIC/SOHIC-HF</td><td colspan="3">If the component's material of construction is ccarbon or low alloy steel and the component is exposed too hydrofluoric acid in any concentration, then the component should be evaluated for susceptibility to HIC/SOHIC-HF.</td><td>No</td></tr>
</table>

No	Damage Factor	Screening Criteria			Yes/No
12.	External Corrosion Damage Factor-Ferritic component	If the component is un-insulated and subject to any of the following , then the component should be evaluated for external damage from corrosion.			No
		a.	Areas exposed to mist overspray from cooling towers.	N	
		b.	Areas exposed to steam vents	N	
		c.	Areas exposed to deluge system	N	
		d.	Areas subject to process spills, ingress of moisture, or acid vapors.	N	
		e.	Carbon steel system, operatinng between -12^{o}C and 177^{o}C (10^{o}F and 350^{o}F). External corrosion is particulartly aggressive where operating temperatures cause frequent or continuous condensation and re-evaporation of atmospheric moisture. (Operating Temperature is 185.4 ^{o}C.	N	
		f.	Systems that do not operating in normally temperature between -12^{o} and 177^{o}C (10^{o}F and 350^{o}F) but cool or heat into this range intermitterntly or are subjected to frequent outages.	N	
		g.	Systems with deteoriated coating and/or wrappings.	N	
		h.	Cold service equipment consistently operating below the atmospheric dew point.	N	
		i.	Un-insulated nozzles or other prostrusions components of insulated equipment in cold service conditions.	N	

<table>
<tr><th>No</th><th>Damage Factor</th><th colspan="3">Screening Criteria</th><th>Yes/No</th></tr>
<tr><td rowspan="3">13.</td><td rowspan="3">Corrosion Under Insulation Damage Factor-Ferritic Commponent</td><td colspan="3">Specific locations and/or systems as stated below are highly suspect and should be considered during inspection program development. Examples the areas include, but are not limited to, the following:</td><td rowspan="3">No</td></tr>
<tr><td>a.</td><td>Penetrations
1. All penetrations or breaches in the insulation jacketing systems, such as dead legs (vents, drains, and other similar items), hangers and other supports, valves and fittings, bolted-on pipe shoes, ladders, and platforms.
2. Steam tracer tubing penetrations.
3. Termination of insulation at flanges and other components.
4. Poorly designed insulation support rings.
5. Stiffener rings</td><td>N</td></tr>
<tr><td>b.</td><td>Damaged Insulation Areas
1. Damaged or missing insulation jacketing.
2. Termination of insulation in a vertical pipe or piece of equipment.
3. Caulking that has hardened, has separated, or is missing.
4. Bulges, staining of the jacketing system or missing bands (bulges may indicate corrosion product build-up).
5. Low points in systems that have a known breach in the insulation system, including low points in long unsupported piping runs.
6. Carbon or low alloy steel flanges, bolting, and other components under insulation in high alloy piping.</td><td>N</td></tr>
<tr><td rowspan="4">14.</td><td rowspan="4">External Chloride Stress Corrosion Cracking Damage Factor-Austenitic Component</td><td colspan="3">If <u>ALL</u> of the following are true, then the component should evaluated for suscepibility to CLSCC:</td><td rowspan="4">No</td></tr>
<tr><td>a.</td><td>The component's material of construction is an austenitic stainless</td><td>N</td></tr>
<tr><td>b.</td><td>The component external surface is exposed to chloride containing fluids, mists, or solids.</td><td>N</td></tr>
<tr><td>c.</td><td>The operating temperature is between 50^{o}C and 150^{o}C (120^{o}F and 300^{o}F) , or the system heats or cools into this range intermittently.</td><td>N</td></tr>
</table>

No	Damage Factor	Screening Criteria			Yes/No
15.	External Chloride Stress Corrosion Cracking Under Insulation Damage Factor-Austenitic Component	If **ALL** of the following are true, then the component should be evaluated for susceptibiity to CUI CLSCC:			No
		a.	The component's material of construction is an austenitic stainless	N	
		b.	The component is insulated	Y	
		c.	The component external surface is exposed to chloride containing fluids, mists, or solids.	N	
		d.	The operating temperature is between 50^{o}C and 150^{o}C (120^{o}F and 300^{o}F) , or the system heats or cools into this range intermittently.	N	
16.	High Temperature Hydrogen Attack Damage Factor	If **ALL** of the following are true, then the component should be evaluated for susceptibiity to HTHA:			No
		a.	The material is carbon steel, C-$^{1}/_{2}$Mo, or a CrMo low alloy steel (such as $^{1}/_{2}$Cr-$^{1}/_{2}$Mo, 1Cr-$^{1}/_{2}$Mo, $1^{1}/_{4}$Cr-^{1}/2Mo, $2^{1}/_{4}$Cr-1Mo, 3Cr-1Mo, 5Cr-1Mo, 7Cr-1Mo, 9Cr-1Mo).	N	
		b.	The operating temperature is greater than 177^{o}C (350^{o}F).	Y	
		c.	The operating hydrogen partial presssure is greater than 0.345 Mpa (50 psia).	N	
17.	Brittle Fracture Damage Factor	If **BOTH** of the following are true, then the component should be evaluated for susceptibility to brittle fracture:			
		a.	The material is carbon steel or low alloy steel (see Table 20.1).	Y	
		b.	If Minimum Design Metal Temperature (MDMT), T_{MDMT}, or Minimum Allowable Metal Temperature (MAT), T_{MAT}, is unknown, or the component is known to operate at below MDMT or MAT under normal or upset conditions.	N	

No	Damage Factor	Screening Criteria			Yes/No
18.	Low Alloy Steel Embrittlement Damage Factor	If **ALL** of the following are true, then the component should be evaluated for susceptibility to low alloy steel embrittlement:			No
		a.	The material is 1Cr--0.5Mo, 1.25Cr-0.5Mo, or 3Cr-1Mo low alloy steel.	N	
		b.	The operating temperature is between 343^{o}C and 577^{o}C (650^{o}F and 1070^{o}F).	N	
19.	885^{o}F Embrittlement Damage Factor	If **BOTH** of the following are true, then the component should be evaluated for susceptibiity to 885^{o}F embrittlemet:			No
		a.	The material is high chromium (>12% Cr) ferritic steel	N	
		b.	The operating temperature is between 371^{o}C and 566^{o}C (700^{o}F and 1050^{o}F).	N	
20.	Sigma Phase Embrittlement Damage Factor	If **BOTH** of the following are true, then the component should be evaluated for susceptibiity to sigma phase embrittlemet:			No
		a.	The component's material of construction is an austenitic stainless steel.	N	
		b.	The operating temperature is between 593^{o}C and 927^{o}C (1100^{o}F and 1700^{o}F).	N	
21.	Piping Mechanical Fatigue Damage Factor	If **BOTH** of the following are true, then the component should be evaluated for susceptibiity to mechanical fatigue:			No
		a.	The component is pipe	N	
		b.	There have been past fatigue failure in this piping system or there is visible/audibble shaking in this piping system or there is a source of cyclic vibration within approximately 15.24 meters (50 feet) and connected to the piping (directly or indirectly via structure). Shaking and source of shaking can be continuous or intermittent. Transient conditions often cause intermittent virbration.	N	

LAMPIRAN 7:

PERHITUNGAN PROBABILITY OF FAILURE (POF) DARI STEAM EJECTOR (GAS REMOVAL SYSTEM)

THINNING DAMAGE FACTOR CALCULATION

1. RLA DATA

REQUIRED DATA

The basic component data required for analysis is given in Table 4.1. Component types and geometry data are shown in Tables 4.2 and 4.3, respectively. The data required for determination of the thinning DF is provided in Table 4.4.

Table 4.1. Basic Component Data Required for Analysis

Basic Data	Value	Unit	Comments
Start Date	01/05/2000		The date the component was placed in service.
Thickness	6.4	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	30	^{o}C	The design temperature, shell side and tube side for heat exchanger.
Design Pressure	1100	kpa	The design pressure, shell side and tubbe side for heat exchanger.
Operating Tempearture	26.5	^{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	990	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 1 2007 Edition		The designing of the component containing the component.
Equipment Type	Steam ejector		The type of equipment.
Component Type	Ejector		The type of component.
Geometry Data	-		Component geometry data depending on the type of component.
Material Specification	SA 516 Gr. 70		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	262000	Kpa	The design yield strength of the material based on material specification.
Tensile Strength	485000	Kpa	The design tensile strength of the material based on material specification.
Weld Joint Efficiency	1.00		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 = 0.252 inch

= 6.400 mm (It is assumed on 13 February 2008)

age = 11 years

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? Actual relatively pH is 4.14	Y	
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)? The operating temperature is 26.5°C.	N	
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?	N	No
		2.	Is the operating temperature > 204°C (400°F)? The operating temperature is 26.5°C.	N	

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
			H_2S concentration is 0.015%		
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 26.5°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	Yes
			Actual relatively pH is 4.13		
		2.	Does the proocess contain < 50 ppm chlorides?	Y	
			Contains 0,12 ppm of chlorides		
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?	Y	
12.	CO_2 Corrosion	1.	Is the free water with CO_2 present (including consideration for dew point condensation)?	Y	Yes
		2.	Is the material of construction carbon steel or < 13% Cr?	Y	
			Low alloy steel with 0,3% Cr		
13.	AST Bottom	1.	Is the equipment item an AST tank bottom?	N	No

1. Corrosion Rate (Cr) from the RLA data

Cr = 0.001378 inch/year

= 0.035000 mm/year

2.a. Corrosion Rate (Cr) based on the Annex 2B alkaline sour water

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

Table 2.B.7.1-Alkaline Sour Water Corrosion – Basic Data Required for Analysis

Basic Data	Comments
NH_4HS concentration (wt%)	Determine the NH4HS 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 H2S and NH3 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)
Stream 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.

From chemical composition report company, known that:

wt% H_2S = 0.015

wt% NH_3 = 0.000324

2 wt% NH_3 = 0.000648

So wt% H2S > 2 x (wt% NH3), the wt% NH4HS can be calculated by:

wt% NH4HS =3.0 x (wt% H2S)

wt% NH4HS = 0.045

Table 2.B.7.1-Alkaline Sour Water Corrosion – Baseline Corrosion Rates for Carbon Steel (mpy)

NH4HS (wt%)	Velocity (m/s)				
	3.05	4.57	6.1	7.62	9.14
2	0.08	0.1	0.13	0.2	0.28
5	0.15	0.23	0.3	0.38	0.46
10	0.51	0.69	0.89	1.09	1.27
15	1.14	1.78	2.54	3.81	5.08

1.	for pH2S < 345 kPa, Adjusted CR = max $\left[\left\{\left(\frac{Baseline\ CR}{173}\right).(pH2S - 345) + Baseline\ CR\right\}, 0\right]$
2.	for pH2S ≥ 345 kPa, Adjusted CR = max $\left[\left\{\left(\frac{Baseline\ CR}{276}\right).(pH2S - 345) + Baseline\ CR\right\}, 0\right]$

mole% of H2S in gas phase = 0.0074 % pH2S = 0.0731 kPa
Baseline CR = 0.08 mm/year

<u>Adjusted alkaline sour water corrosion rate :</u> 0.000 mm/year

2.b. Corrosion Rate (Cr) based on the Annex 2B acid sour water

The steps required to determine the corrosion rate are shown in Figure 2.B.10.1. If the pH is less than 4.5, then the corrosion rate shall be calculated using paragraph 2.B.2. If the pH is greater than 7, then the corrosion rate is calculated using paragraph 2.B.7. Otherwise, the corrosion rate of carbon steel exposed to acid sour water is computed using Equation (2.B.1)

$$CR = CR_{ph}.F_O F_V$$

The base corrosion rate, C_{pH} , of carbon steel exposed to acid sour water as a function of pH is provided in Table 2.B.10.2. The modification factor for the corrosion rate as a function of the oxygen content factor, F_O , is provided in Table 2.B.10.3. The corrosion rate also varies with fluid velocity. The modification factor for fluid velocity is given by the following equations.

Fv = 1 *when velocity < 1.83 m/s*
Fv = 0.82 . Velocity -0.5 *when 1,83 m/s ≤ velocity ≤ 6,1 m/s*
Fv = 5 *when velocity > 6,1 m/s*

Table 2.B.10.2M – Acid Sour Water Corrosion Estimated Corrosion Rates for Carbon and Low Alloy Steel (mm/y) – CRpH

pH	Temperature (°C)			
	38	52	79	93
4.75	0.03	0.08	0.13	0.18
5.25	0.02	0.05	0.08	0.1
5.75	0.01	0.04	0.05	0.08
6.25	0.01	0.03	0.04	0.05
6.75	0.01	0.01	0.02	0.03

Table 2.B.10.3 – Acid Sour Water Corrosion – Basic Data Required for Analysis

Oxygen content	Adjustment factor - F_O
Not significant (≤ 50 pbb)	1.0
High (> 50 pbb)	2.0

CR_{pH} = 0.03 Fv = 1.000 F_O = 1.0

So, CR = 0.03000

Acid sour water corrosion rate is : 0.0300 mm/year

2.c. Corrosion Rate (Cr) based on the Annex 2B CO_2 Corrosion Calculation

CR = $CR_B . \min[F_{glycol}, F_{inhib}]$

Base Corrosion Rate

CR_B = f(T,pH) . $f_{CO2}^{0.62}$. $(\frac{S}{19})^{0.146+0.0324\, fco2}$

Where ;

CR_B = Base corrosion rate (mm/y)

f(T,pH) = Temperature-pH function tabulated in Table 2.B.13.2

f_{CO2} = CO_2 fugacity

S = Shear stress yo calculate the flow velocity (Pa)

a. Determine the calculated pH

$pH = 2.5907 + 0.8668.log_{10}[T] - 0.49log_{10}[p_{CO2}]$..

T = 26.5 °C

= 79.7 °F

= 299.5 K

mole% of CO2 in dry gas = 85.72 %

P_{CO2} = 848.63 kPa

= 123.08 psi

= 8.4863 bar

$pH = 2.5907 + 0.8668.log_{10}[T] - 0.49log_{10}[p_{CO2}]$

= 3.252716036

b. Determine the CO_2 fugacity

$log_{10}[f_{CO2}] = log_{10}[p_{CO2}] + \min[250, p_{CO2}].(0.0031 - \frac{1.4}{T+273})$

$log_{10}[f_{CO2}] = log_{10}[8.4863] + \min[250, 8.4863].(0.0031 - \frac{1.4}{185.4+273})$

= 0.5067

c. Determine the flow velocity

To determine the flow velocity, the API 581 reffers to the NORSOK M-506. and both of the Recommended Practice use the fluid flow shear stress, S, to model the effect of flow velocity n the base corrosion rate.

$$S = \frac{f.\rho m.um^2}{2}$$

In the calculation for the corrosion rate, the shear stress need not exceed 150 Pa.

Where;

f = Friction factor

ρ_m = Mixture mass density kg/m^3

= 5.8 kg/m^3

u_m = Mixture flow velocity m/s

= 1.8 m/s

$$f = 0.001375 \, [\, 1+ (20000(\frac{e}{D}) + (\frac{10^6}{Re})^{0.33}]$$

$\frac{\varepsilon}{D}$ = Relative roughness of the material

0.1

Based on the Table below that for the Carbon Steel (SA 516 GR 70) material of construction which is assumed as slighly corroded is approximately ranging from 0.5-1.5.

Material	Absolute Roughness (mm)
Copper, Lead, Brass, Aluminum (new)	0.001 - 0.002
PVC and Plastic Pipes	0.0015 - 0.007
Flexible Rubber Tubing - Smooth	0.006-0.07
Stainless Steel	0.0015
Steel Commercial Pipe	0.045 - 0.09
Weld Steel	0.045
Carbon Steel (New)	0.02-0.05
Carbon Steel (Slightly Corroded)	0.05-0.15
Carbon Steel (Moderately Corroded)	0.15-1
Carbon Steel (Badly Corroded)	1-3
Asphalted Cast Iron	0.1-1
New Cast Iron	0.25 - 0.8
Worn Cast Iron	0.8 - 1.5
Rusty Cast Iron	1.5 - 2.5
Galvanized Iron	0.025-0.15
Wood Stave	0.18-0.91
Wood Stave, used	0.25-1
Smoothed Cement	0.3
Ordinary Concrete	0.3 - 1
Concrete – Rough, Form Marks	0.8-3

Source by: https://www.nuclear-power.net/nuclear-engineering/fluid-dynamics/major-head-loss-friction-loss/relative-roughness-of-pipe/

$$Re = \frac{D.\rho m.um}{\mu m}$$

Re = Reynolds number

D = Diameter

= 900 mm

= 0.9 m

µm = Viscosity of the mixture cp

= 0.4 Cp

= 0.0004 Pa s

$$Re = \frac{D.\rho m.um}{\mu m}$$

= 26845.714

$$f = 0.001375\ [\ 1 + (20000(\frac{e}{D}) + (\frac{10^6}{Re})^{0.33}]$$

= 0.008

After the value of relative roughness, Reynolds number, and the friction factor have been determines. Then, the value of the flow velocity can be calculated.

$$S = \frac{f.\rho m.um^2}{2}$$

= 0.0786442 Pa

Those calculated pH, CO_2 fugacity, and also flow velocity have been known. So, the value of Base Corrosion Rate (Cr_{base}) can be determined.

$$CR_B = f(T,pH)\ .\ f_{CO2}{}^{0.62}\ .\ (\frac{S}{19})^{0.146+0.0324\, fco2}$$

Where;

f(T,pH) = Temperature-pH function tabulated in Table 2.B.13.2

= 7.77

Cr_{base} = 3.1247344 mpy

= 0.0793683 mm/y

Because there is no any mixture for glycol and the other inhibitors inside the Steam ejector, then, Cr is equal to Cr_{base}. The glycol or inhibitor is placed in another equipment not being process in the Steam Ejector itself.

Where;

CR = $CR_B.\ \min[F_{glycol}, F_{inhib}]$

<u>CR</u> = Cr_{base}

= 0.0793683 mm/y

<u>Calculated corrosion rate =</u> 0.0794 mm/year

STEP 3 Determine the time in service, age_{tk}, since the last known inspection, t_{rdi}.

t_{rdi} = 0.3917 inch		Last inspection is on:		03/07/2014
= 9.95 mm		RBI Date is on:		01/07/2019
		Planned Date is on:		01/07/2022

age_{tk} = 4.994 years. Last inspection was held on July 2014

age_{PD} = 7.995 years. Inspection is held every 4 years

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:

$$age_{rc} = \max\left[\left(\frac{t_{rdi} - tbm}{C_{r\,cm}}\right), 0.0\right]$$

Because the steam scrubber is not cladding/weld overlay. Then, the equation above does not need to be considered.

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}.

$$t_{min} = \frac{PR_C}{S\,E - 0.6P}$$

$$R_C = \frac{D_i + 2CA}{2}$$

Where,

Rc : Inside radius in the corroded condition (mm)

P : Designed Pressure (psig)

S : Allowable stress (psig)

E : Joint efficiency

Di : Inside diameter (mm)

CA : Corrosion allowance

$$t_{min} = \frac{159.54\ x\ 453}{17500\ x1 - 0.6(159.54)}$$

t_{min} = 0.1635 inch

= 4.1526 mm

$$R_C = \frac{900 + 2(3)}{2}$$

Rc = 453 mm

STEP 6 Determine the A_{rt} Parameter

For component without clading/weld overlay then use the equation following.

A_{rt} on RBI Date:

$$A_{rt} = \frac{Cr_{b,m}.age_{tk}}{t_{rdi}}$$

= 0.039834407 **(For calculated corrosion rate based on ANNEX 2B)**

Where,

$Cr_{b.m}$	:	Corrosion base material	=	0.0794	mm/yr
age_{tk}	:	Component in-service time since the last inspection	=	4.994	yr
t_{rdi}	:	Furnished thickness since last inspection	=	9.95	mm

$$A_{rt} = \frac{Cr_{b,m}.age_{tk}}{t_{rdi}}$$

= 0.017566271 **(For corrosion rate based on RLA Data)**

Where,

$Cr_{b.m}$	:	Corrosion base material	=	0.035	mm/yr
age_{tk}	:	Component in-service time since the last inspection	=	4.994	yr
t_{rdi}	:	Furnished thickness since last inspection	=	9.95	mm

A_{rt} on Plan Date:

$$A_{rt} = \frac{Cr_{b,m}.age_{tk}}{t_{rdi}}$$

= 0.063769994 **(For calculated corrosion rate based on ANNEX 2B)**

Where,

$Cr_{b.m}$	:	Corrosion base material	=	0.0794	mm/yr
age_{tk}	:	Component in-service time since the last inspection	=	4.994	yr
t_{rdi}	:	Furnished thickness since last inspection	=	9.95	mm

$$A_{rt} = \frac{Cr_{b,m}.age_{tk}}{t_{rdi}}$$

= 0.028121442 **(For corrosion rate based on RLA Data)**

Where,

$Cr_{b.m}$	:	Corrosion base material	=	0.035	mm/yr
age_{tk}	:	Component in-service time since the last inspection	=	4.994	yr
t_{rdi}	:	Furnished thickness since last inspection	=	9.95	mm

STEP 7 Calculate the Flow Stress, FS^{Thin} using E from STEP 5 and equation below.

$$FS^{Thin} = \frac{(YS+TS)}{2}. \text{ E.1,1}$$

Where;

YS	=	262000 KPa	https://www.sidastico.com/en/steels-for-high-temperature-compartments-steels-for-pressurised-compartments/sa516-gr-70-mechanical-properties/
TS	=	485000 KPa	
E	=	1	

$$FS^{Thin} = \frac{(YS+TS)}{2}.\ E.1,1$$

= 410850

STEP 8 Calculate the strength ratio parameter, SR_P^{Thin} using the appropriate equation.

$$SR_P^{Thin} = \frac{S.E}{FS^{Thin}}.\frac{Max\ (t_{min},t_c)}{t_{rdi}}$$

Where;

t_c = is the minimum structural thickness of the component base material

= 0.1634866 inch

= 4.1525605 mm

$$SR_P^{Thin} = \frac{S.E}{FS^{Thin}}.\frac{Max\ (t_{min},t_c)}{t_{rdi}}$$

= 0.0177766

STEP 9 Determine the number of inspections for each of the correspondesing inspection effectiveness, $N_A^{Thin}, N_B^{Thin}, N_C^{Thin}, N_D^{Thin}$ 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, $I_1^{Thin}, I_2^{Thin}, I_3^{Thin}$ ig equation 61 below, prior probabilities, $Pr_{p1}^{Thin}, Pr_{p2}^{Thin}$ and Pr_{p3}^{Thin} Table 4.5. The Conditional Probabilities (for each inspection effectiveness level), , from Table 4.6, and the number of inspection, N_A^{Thin} $N_B^{Thin}, N_C^{Thin}, N_D^{Thin}$, in each effectiveness level from STEP 9.

$$I_1^{Thin} = Pr_{P1}^{Thin}(Co_{P1}^{ThinA})^{N_A^{Thin}}(Co_{P1}^{ThinB})^{N_B^{Thin}}(Co_{P1}^{ThinC})^{N_C^{Thin}}(Co_{P1}^{ThinD})^{N_D^{Thin}}$$

$$I_2^{Thin} = Pr_{P2}^{Thin}(Co_{P2}^{ThinA})^{N_A^{Thin}}(Co_{P2}^{ThinB})^{N_B^{Thin}}(Co_{P2}^{ThinC})^{N_C^{Thin}}(Co_{P2}^{ThinD})^{N_D^{Thin}}$$

$$I_3^{Thin} = Pr_{P3}^{Thin}(Co_{P3}^{ThinA})^{N_A^{Thin}}(Co_{P3}^{ThinB})^{N_B^{Thin}}(Co_{P3}^{ThinC})^{N_C^{Thin}}(Co_{P3}^{ThinD})^{N_D^{Thin}}$$

Table 4.5 - Prior Probability for Thinning Corrosion Rate

Damage State	Low Confidence Data	Medium Confidence	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

$$I_1^{Thin} = Pr_{P1}^{Thin}(Co_{P1}^{ThinA})^{N_A^{Thin}}(Co_{P1}^{ThinB})^{N_B^{Thin}}(Co_{P1}^{ThinC})^{N_C^{Thin}}(Co_{P1}^{ThinD})^{N_D^{Thin}}$$

= 0.50

$$I_2^{Thin} = Pr_{P2}^{Thin}(Co_{P2}^{ThinA})^{N_A^{Thin}}(Co_{P2}^{ThinB})^{N_B^{Thin}}(Co_{P2}^{ThinC})^{N_C^{Thin}}(Co_{P2}^{ThinD})^{N_D^{Thin}}$$

= 0.30

$$I_3^{Thin} = Pr_{P3}^{Thin}(Co_{P3}^{ThinA})^{N_A^{Thin}}(Co_{P3}^{ThinB})^{N_B^{Thin}}(Co_{P3}^{ThinC})^{N_C^{Thin}}(Co_{P3}^{ThinD})^{N_D^{Thin}}$$

= 0.20

STEP 11 Calculate the Posteroir Probability, Po_{p1}^{Thin}, Po_{p2}^{Thin} and Po_{p3}^{Thin}, using equations:

$$Po_{p1}^{Thin} = \frac{I_1^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

= 0.5

$$Po_{p2}^{Thin} = \frac{I_2^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

= 0.3

$$Po_{p3}^{Thin} = \frac{I_3^{Thin}}{I_1^{Thin} + I_2^{Thin} + I_3^{Thin}}$$

= 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 $COV_P = 0.05$.

$$ß_1^{Thin} = \frac{1 - D_{S1} .A_{rt} - SR_P^{Thin}}{\sqrt{D_{S1}{}^2 .A_{rt}{}^2 .COV_{\Delta t}{}^2 + (1 - D_{S1}.A_{rt})^2.COV_{sf}{}^2 + (SR_P^{Thin})^2.(COV_P)^2}}$$

$$ß_2^{Thin} = \frac{1 - D_{S2} .A_{rt} - SR_P^{Thin}}{\sqrt{D_{S2}{}^2 .A_{rt}{}^2 .COV_{\Delta t}{}^2 + (1 - D_{S2}.A_{rt})^2.COV_{sf}{}^2 + (SR_P^{Thin})^2.(COV_P)^2}}$$

$$ß_3^{Thin} = \frac{1 - D_{S3} .A_{rt} - SR_P^{Thin}}{\sqrt{D_{S3}{}^2 .A_{rt}{}^2 .COV_{\Delta t}{}^2 + (1 - D_{S3}.A_{rt})^2.COV_{sf}{}^2 + (SR_P^{Thin})^2.(COV_P)^2}}$$

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

RBI DATE:

BASED ON CORROSION RATE FROM RLA DATA

$$ß_1^{Thin} = \frac{1-D_{S1}.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S1}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S1}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$
= 4.9087

$$ß_2^{Thin} = \frac{1-D_{S2}.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S2}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S2}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$
= 4.9046

$$ß_3^{Thin} = \frac{1-D_{S3}.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S3}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S3}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$
= 4.8904

BASED ON CORROSION RATE FROM ANNEX 2B DATA

$$ß_1^{Thin} = \frac{1-D_{S1}.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S1}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S1}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$
= 4.9032

$$ß_2^{Thin} = \frac{1-D_{S2}.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S2}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S2}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$
= 4.8851

$$ß_3^{Thin} = \frac{1-D_{S3}.A_{rt}-SR_P^{Thin}}{\sqrt{D_{S3}{}^2.A_{rt}{}^2.COV_{\Delta t}{}^2+(1-D_{S3}.A_{rt})^2.COV_{sf}{}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$
= 4.8086

PLANNED DATE:

BASED ON CORROSION RATE FROM RLA DATA

$$\text{ß}_1^{Thin} = \frac{1-D_{S1}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S1}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S1}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

= 4.9064

$$\text{ß}_2^{Thin} = \frac{1-D_{S2}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S2}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S2}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

= 4.8971

$$\text{ß}_3^{Thin} = \frac{1-D_{S3}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S3}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S3}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

= 4.8609

BASED ON CORROSION RATE FROM ANNEX 2B DATA

$$\text{ß}_1^{Thin} = \frac{1-D_{S1}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S1}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S1}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

= 4.8937

$$\text{ß}_2^{Thin} = \frac{1-D_{S2}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S2}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S2}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

= 4.8466

$$\text{ß}_3^{Thin} = \frac{1-D_{S3}\,.A_{rt}-SR_P^{Thin}}{\sqrt{{D_{S3}}^2.{A_{rt}}^2.{COV_{\Delta t}}^2+(1-D_{S3}.A_{rt})^2.{COV_{sf}}^2+(SR_P^{Thin})^2.(COV_P)^2}}$$

= 4.6174

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, then this step of calculation can be skipped.

STEP 14 For all components (excluding tank bottoms covered in STEP 13), calculate the base damage factor, . D_{fB}^{Thin}

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi\left(-\beta_1^{Thin}\right)\right)+\left(Po_{P2}^{Thin}\Phi\left(-\beta_2^{Thin}\right)\right)+\left(Po_{P3}^{Thin}\Phi\left(-\beta_3^{Thin}\right)\right)}{1.56E\ -0.4}$$

RBI DATE:

BASED ON CORROSION RATE FROM RLA DATA

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi\left(-\beta_1^{Thin}\right)\right)+\left(Po_{P2}^{Thin}\Phi\left(-\beta_2^{Thin}\right)\right)+\left(Po_{P3}^{Thin}\Phi\left(-\beta_3^{Thin}\right)\right)}{1.56E\ -0.4}$$

= 0.2410253

BASED ON CORROSION RATE FROM ANNEX 2B

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi(-\beta_1^{Thin})\right)+\left(Po_{P2}^{Thin}\Phi(-\beta_2^{Thin})\right)+\left(Po_{P3}^{Thin}\Phi(-\beta_3^{Thin})\right)}{1.56E-0.4}$$

= 0.2410253

PLANNED DATE:

BASED ON CORROSION RATE FROM RLA DATA

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi(-\beta_1^{Thin})\right)+\left(Po_{P2}^{Thin}\Phi(-\beta_2^{Thin})\right)+\left(Po_{P3}^{Thin}\Phi(-\beta_3^{Thin})\right)}{1.56E-0.4}$$

= 0.2410253

BASED ON CORROSION RATE FROM ANNEX 2B

$$D_{fb}^{Thin} = [\frac{\left(Po_{P1}^{Thin}\Phi(-\beta_1^{Thin})\right)+\left(Po_{P2}^{Thin}\Phi(-\beta_2^{Thin})\right)+\left(Po_{P3}^{Thin}\Phi(-\beta_3^{Thin})\right)}{1.56E-0.4}$$

= 0.2410251

STEP 15 Determine the DF for thinning, D_f^{Thin}, using equation equation below.

$$D_f^{Thin} = \text{Max}[(\frac{(D_{fb}^{Thin}.\ F_{IP}\ .\ F_{DL}\ .F_{WD}.F_{AM}\ .F_{SM})}{F_{OM}}),0.1]$$

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

RBI DATE:

BASED ON CORROSION RATE FROM RLA DATA

$$D_f^{Thin} = \text{Max}[(\frac{(D_{fb}^{Thin}.}{F_{OM}}),0.1]$$

= 0.2410253

BASED ON CORROSION RATE FROM ANNEX 2B

D_f^{Thin} = Max[($\frac{(D_{fb}^{Thin}.}{F_{OM}}$),0.1]

= 0.2410253

PLANNED DATE:

BASED ON CORROSION RATE FROM RLA DATA

D_f^{Thin} = Max[($\frac{(D_{fb}^{Thin}.}{F_{OM}}$),0.1]

= 0.2410253

BASED ON CORROSION RATE FROM ANNEX 2B

D_f^{Thin} = Max[($\frac{(D_{fb}^{Thin}.}{F_{OM}}$),0.1]

= 0.2410251

DAMAGE FACTOR FOR THINNING

The governing thinning DF is determined based on the presence of an internal liner using equation below.

D_{f-gov}^{Thin} = min[D_f^{Thin}, D_f^{elin}] When internal liner is present

$D_{f-gov}^{Thin} = D_f^{Thin}$ When internal liner is not present

According to above calculaton, there is no any presence of liner, then, we can consider to use the second governing thinning DF calculation.

$D_{f-gov}^{Thin} = D_f^{Thin}$

RBI DATE:

Based on RLA Data		Based on Corrosion Rate from Annex 2B	
D_{f-gov}^{Thin} =	0.2410253	D_{f-gov}^{Thin} =	0.2410253

PLANNED DATE:

Based on RLA Data		Based on Corrosion Rate from Annex 2B	
D_{f-gov}^{Thin} =	0.2410253	D_{f-gov}^{Thin} =	0.2410251

TYPE OF THINNING

The type of thinning (wheter it is local or general) can be determined from table 2.B.1.2 from API RP 581 3rd Edition Part 2 - Annex 2.B, as follow:

Table 2.B.1.2 Type of Thinning

Thinning Mechanism	Condition	Type of Thinning
Hydrochloric Acid (HCl) Corrosion	---	Local
High Temperature Sulfidic/Naphthenic Acid Corrosion	TAN ≤ 0.5	General
	TAN > 0.5	Local
High Temperature H_2S/H_2 Corrosion	---	General
Sulfuric Acid (H_2SO_4) Corrosion	Low Velocity ≤ 0.61 m/s (2 ft/s) for carbon steel, ≤ 1.22 m/s (4 ft/s) for SS, and ≤ 1.83 m/s (6 ft/s) for higher alloys	General
	High Velocity ≥ 0.61 m/s (2 ft/s) for carbon steel, ≥ 1.22 m/s (4 ft/s) for SS, and ≥ 1.83 m/s (6 ft/s) for higher alloys	Local
Hydrofluoric Acid (HF) Corrosion	---	Local
Sour Water Corrosion	Low Velocity: ≤ 6.1 m/s (20 ft/s)	General
	High Velocity: > 6.1 m/s (20 ft/s)	Local
Amine Corrosion	Low Velocity < 1.5 m/s (5 ft/s) rich amine < 6.1 m/s (20 ft/s) lean amine	General
	High Velocity > 1.5 m/s (5 ft/s) rich amine > 6.1 m/s (20 ft/s) lean amine	Local
High Temperature Oxidation	---	General
Acid Sour Water Corrosion	< 1.83 m/s (6 ft/s) ≥ 1.83 m/s (6 ft/s)	General Local
Cooling Water Corrosion	≤ 0.91 m/s (3 ft/s) 0.91-2.74 m/s (3-9 ft/s) > 2.74 m/s (9 ft/s)	Local General Local
Soil Side Corrosion	---	Local
CO_2 Corrosion	---	Local
AST Bottom	Product Side Soil Side	Local Local

From the data, the the velocity of fluid is 1.8 m/s

And the thinning mechanisms are sour water, acid sour water, and CO_2 corrosion

If both general and localized thinning mechanisms are possible, then the type of thinning should be designated as localized. The type of thinning designated will be used to determine the effectiveness of inspection performed.

So, the thinning damage is designated as localized

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<u>**SCC DAMAGE FACTOR - SULFIDE STRESS CRACKING CALCULATION**</u>

REQUIRED DATA

The basic component data required for analysis is given in Table 4.1 and the specific data required for determination of the sulfide stress cracking DF is provided in Table 8.1.

STEP 1 Determine the environmental severity (potential level of hydrogen flux) for cracking based on the H_2S content of the water and its pH using Table 8.2.

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				

pH: 4.14 H_2S concentration: 73.8 ppm

Based on table 8.2 the environmental severity: **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 Brinnell hardness of weldments, and knowledge of whether the component was subject to PWHT. Note that a HIGH susceptibility should be used if cracking is confirmed to be present.

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.						

Max Brinnell Hardness: TS (psi) = 500 x HB PWHT: No

HB = 140.69

Susceptibility to SSC as a Function of Heat Treatment: **Low**

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

Severity Index (S_{VI}) = 1

STEP 4 Determine the time in-service, age_{tk} , 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.

age_{PD} =	7.99452 years	Last inspection is on:	03/07/2014
		RBI Date is on:	01/07/2019
age_{tk} =	4.99384 years	Planned Date is on:	01/07/2022

STEP 5

Determine the number of inspections, and the corresponding inspection effectiveness category using Section 8.6.2 for past inspections performed during the in service time. Combine the inspections to the highest effectiveness performed using Section 3.4.3.

Inspections are ranked according to their expected effectiveness at detecting SSC. Examples of inspection activities that are both intrusive (requires entry into the equipment) and non-intrusive (can be performed externally), are provided in Annex 2.C, Table 2.C.9.6 (Section 8.6.2 API RP 3rd Edition Part 2)

Table 2.C.9.6 – LoIE Example for SSC

Inspection Category	Inspection Effectiveness Category	Intrusive Inspection Example[1,2]	Non-intrusive Inspection Example[1,2]
A	Highly Effective	For the total weld area: 100% WFMT/ACFM with UT follow-up of relevant indications.	For the total weld area: 100% automated or manual ultrasonic scanning.
B	Usually Effective	For selected welds / weld area: >75% WFMT/ACFM with UT follow-up of all relevant indications.	For selected welds / weld area: >75% automated or manual ultrasonic scanning OR AE testing with 100% follow-up of relevant indications.
C	Fairly Effective	For selected welds / weld area: >35% WFMT/ACFM with UT follow-up of all relevant indications.	For selected welds / weld area: >35% automated or manual ultrasonic scanning OR >35% radiographic testing.
D	Poorly Effective	For selected welds / weld area: >10% WFMT/ACFM with UT follow-up of all relevant indications or	For selected welds / weld area: >10% automated or manual ultrasonic scanning **OR** >10% radiographic testing.
E	Ineffective	Ineffective inspection technique/plan was utilized	Ineffective inspection technique/plan was utilized

Notes:
1. Inspection quality is high.
2. Suspect Area shall be considered the Total Surface Area unless defined by knowledgeable individual (subject matter expert).

If multiple inspections have been performed, equivalent relationships are used for SCC, External Damage (external chloride stress corrosion cracking, external chloride stress corrosion cracking under insulation) and HTHA. Inspections of different grades (A, B, C and D) are approximated as equivalent inspection effectiveness in accordance with the following relationships (Section 3.4.3 API RP 3rd Edition Part 2):

a) 2 Usually Effective (B) Inspections = 1 Highly Effective (A) Inspection, or 2B = 1A

b) 2 Fairly Effective (C) Inspections = 1 Usually Effective (B) inspection, or 2C = 1B

c) 2 Poorly Effective (D) Inspections = 1 Fairly Effective (C) inspection, or 2D = 1C

Note:

1. Equivalent inspection valuesare not used for Thinning and External Corrosion DF calculations.
2. The equivalent higher inspection rules shall not be applied to No Inspections (E).

Number of inspections: 2 Effectiveness category: Ineffective (D)

Inspection effectiveness: **E**

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

S_{VI} = 1 Number of inspection = 2 Effectiveness = E

Base damage factor (D_{fb}^{scc}): 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 below. 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.

$$D_f^{scc} = D_{fB}^{scc}.(Max[age, 1.0])^{1.1}$$

RBI DATE:

$$D_f^{scc} = 1.(Max[5,1.0])^{1.1}$$

D_f^{scc} = 5.8651

PLANNED DATE:

$$D_f^{scc} = 1.(Max[9,1.0])^{1.1}$$

D_f^{scc} = 9.8417

SCC DAMAGE FACTOR - HIC/SOHIC - H_2S

REQUIRED DATA

The basic component data required for analysis is given in Table 4.1 and the specific data required for determination of the HIC/SOHIC-H_2S cracking DF is provided in Table 9.1

STEP 1 Determine the environmental severity (potential level of hydrogen flux) for cracking based on the H_2S content of the water and its pH using Table 9.2. Note that a HIGH environmental severity should be used if cracking is confirmed to be present.

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				

pH: 4.14 H2S concentration: 73.8 ppm

Based on table 9.2 the environmental 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 sulfur content of the carbon steel, product form 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 % https://www.azom.com/article.aspx?ArticleID=4787

Environmental severity: Moderate

Post Weld Heat Treatment (PWHT): No

Susceptibility for Cracking: **High**

STEP 3 Based on the susceptibility in STEP 2, determine the severity index, SVI , from 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

Severity Index (S_{VI}) = 100

STEP 4 Determine the time in-service, age , since the last Level A, B or C inspection was performed 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.

age_{PD} = 7.9945 year		Last inspection is on:	03/07/2014
		RBI Date is on:	01/07/2019
age_{tk} = 4.9938 year		Planned Date is on:	01/07/2022

STEP 5

Determine the number of inspections, and the corresponding inspection effectiveness category using Section 9.6.2 for past inspections performed during the in service time. Combine the inspections to the highest effectiveness performed using Section 3.4.3.

Inspections are ranked according to their expected effectiveness at detecting SSC. Examples of inspection activities that are both intrusive (requires entry into the equipment) and non-intrusive (can be performed externally), are provided in Annex 2.C, Table 2.C.9.6 (Section 8.6.2 API RP 3rd Edition Part 2)

Table 2.C.9.6 – LoIE Example for SSC

Inspection Category	Inspection Effectiveness Category	Intrusive Inspection Example[1,2]	Non-intrusive Inspection Example[1,2]
A	Highly Effective	For the total weld area: 100% WFMT/ACFM with UT follow-up of relevant indications.	For the total weld area: 100% automated or manual ultrasonic scanning.
B	Usually Effective	For selected welds / weld area: >75% WFMT/ACFM with UT follow-up of all relevant indications.	For selected welds / weld area: >75% automated or manual ultrasonic scanning OR AE testing with 100% follow-up of relevant indications.
C	Fairly Effective	For selected welds / weld area: >35% WFMT/ACFM with UT follow-up of all relevant indications.	For selected welds / weld area: >35% automated or manual ultrasonic scanning OR >35% radiographic testing.
D	Poorly Effective	For selected welds / weld area: >10% WFMT/ACFM with UT follow-up of all relevant indications or	For selected welds / weld area: >10% automated or manual ultrasonic scanning **OR** >10% radiographic testing.
E	Ineffective	Ineffective inspection technique/plan was utilized	Ineffective inspection technique/plan was utilized

Notes:
1. Inspection quality is high.
2. Suspect Area shall be considered the Total Surface Area unless defined by knowledgeable individual (subject matter expert).

If multiple inspections have been performed, equivalent relationships are used for SCC, External Damage (external chloride stress corrosion cracking, external chloride stress corrosion cracking under insulation) and HTHA. Inspections of different grades (A, B, C and D) are approximated as equivalent inspection effectiveness in accordance with the following relationships (Section 3.4.3 API RP 3rd Edition Part 2):

a) 2 Usually Effective (B) Inspections = 1 Highly Effective (A) Inspection, or 2B = 1A

b) 2 Fairly Effective (C) Inspections = 1 Usually Effective (B) inspection, or 2C = 1B

c) 2 Poorly Effective (D) Inspections = 1 Fairly Effective (C) inspection, or 2D = 1C

Note:

1. Equivalent inspection valuesare not used for Thinning and External Corrosion DF calculations.
2. The equivalent higher inspection rules shall not be applied to No Inspections (E).

Number of inspections: 2 Effectiveness category: Ineffective (D)

Inspection effectiveness: **E**

STEP 6 Determine the base DF for HIC/SOHIC-H_2S cracking, $D_{fB}^{HIC/SOHIC-H_2S}$, using Table 6.3 based on the number of, and the highest inspection effectiveness determined in STEP 5, and the severity index, 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

S_{VI} = 100 Number of inspection = 2 Effectiveness = E

Base damage factor ($D_{fB}^{HIC/SOHIC-H_2S}$): **100**

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.	

On-Line monitoring adjustment factor (F_{OM}): 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 below. 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

$$D_f^{HIC/SOHIC-H_2S} = \frac{D_{fB}^{HIC/SOHIC-H_2S}.(Max[age,1.0])^{1.1}}{F_{OM}}$$

RBI DATE:

$$D_f^{HIC/SOHIC-H_2S} = \frac{33.(Max[5,1.0])^{1.1}}{2}$$

$D_{fB}^{HIC/SOHIC-H_2S}$ = 293.26

PLANNED DATE:

$$D_f^{HIC/SOHIC-H_2S} = \frac{33.(Max[9,1.0])^{1.1}}{2}$$

$D_{fB}^{HIC/SOHIC-H_2S}$ = 492.09

<u>DAMAGE FACTOR FOR STRESS CORROSION CRACKING</u>

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 as follow.

$$D_{f-gov}^{scc} = max\left[\begin{matrix} D_f^{caustic}, D_f^{amine}, D_f^{scc}, D_f^{HIC/SOHIC-H_2S}, D_f^{ACSCC}, \\ D_f^{PASCC}, D_f^{CLSCC}, D_f^{HSC\_HF}, D_f^{HIC/SOHIC-HF} \end{matrix}\right]$$

RBI DATE:

D_{f-gov}^{scc} = 293.257

PLANNED DATE:

D_{f-gov}^{scc} = 492.09

PROBABILITY OF FAILURE

The probability of failure can be calculated using the equation of;

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

Where,

pf (t) = The PoF as a function of time
gff = General failure frequency
Fms = Management system factor
Df (t) = Total damage factor

DETERMINING DAMAGE FACTOR (Df)

In the case of multiple damage mechanisms, the combination of those damage mechanims is explained in section 3.4.2 API RP 581 Part 2 3rd Edition. Total DF, $D_{f\text{-}total}$ - If more than one damage mechanism is present, the following rules are used to combine the DFs. The total DF is given by Equation below when the external and/or thinning damage are classified as local and therefore, unlikely to occur at the same location.

$$D_{f-total} = max\left[D_{f-gov}^{thin}, D_{f-gov}^{extd}\right] + D_{f-gov}^{scc} + D_{f}^{htha} + D_{f-gov}^{brit} + D_{f}^{mfat}$$

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 as follow.

$$D_{f-total} = D_{f-gov}^{thin} + D_{f-gov}^{extd} + D_{f-gov}^{scc} + D_{f}^{htha} + D_{f-gov}^{brit} + D_{f}^{mfat}$$

Note that the summation of DFs can be less than or equal to 1.0. This means that the component can have a POF less than the generic failure frequency.
Acccording to the observation and last inspection to Steam ejector of gas removal system is categorized as local thinning and also it does not likely occur at the same location. So, we used this equation correlated to local thinning.

RBI DATE:

Based on RLA Data

$D_{f\text{-total}}$ = 293.49781

Based on Corrosion Rate from Annex 2B

$D_{f\text{-total}}$ = 293.49781

PLANNED DATE:

Based on RLA Data

$D_{f\text{-total}}$ = 492.32803

Based on Corrosion Rate from Annex 2B

$D_{f\text{-total}}$ = 492.32803

DETERMINING GENERAL FAILURE FREQUENCY (gff)

To determine the value of gff, we can use the recommended list from table 3.1 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

gff : 3.06.E-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

fms = 869.5

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

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 = 0.1823896

CALCULATING PROBABILITY OF FAILURE

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

RBI DATE:

Based on Corrosion Rate from RLA Data

Pf (t) = 3,06,E−0,5 . 9,6 . 293,5

Pf (t) = 1.64E-03

Based on Corrosion Rate from Annex 2B

Pf (t) = 3,06,E−0,5 . 9,6 . 293,5

Pf (t) = 1.64.E-03

PLANNED DATE:

Based on Corrosion Rate from RLA Data

Pf (t) = 3,06,E−0,5 . 9,6 . 560,4

Pf (t) = 2.75E-03

Based on Corrosion Rate from Annex 2B

Pf (t) = 3,06,E−0,5 . 9,6 . 560,4

Pf (t) = 2.75.E-03

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LAMPIRAN 8:

PERHITUNGAN CONSEQUENCE OF FAILURE (COF) DARI STEAM EJECTOR (GAS REMOVAL SYSTEM)

PART 1 : DETERMINE THE RELEASE FLUID AND ITS PROPERTIES, INCLUDING T RELEASE PHASE

1.1 REPRESENTATIVE FLUIDS

A representative fluid that most closely matches the fluid contained pressurized system being evaluated is selected from the representative fluids table shown in Table 4.1 API 581 Part 3 of COF.

1.2 FLUID PROPERTIES

The required fluid properties estimated for each representattive fluids are provided in the Table 4.2 API 581 Part 3 of COF and are dependent on the stored phase of the fluid below:

A). Stored Liquid

1. Normal Boiling Point (NBP)
2. Density (ρt)
3. Auto-iIgnition Temperature (AIT)

B). Stored Vapor or Gas

1. Normal Boiling Point (NBP)
2. Morcular Weight (MW)
3. Ideal Gas Specific Heat Capacity (k)
4. Constant Pressure Specific Heat (Cp)
5. Auto-iIgnition Temperature (AIT)

1.3 RELEASE PHASE

The dispersion characteristics of fluids and probability of consequence outcomes (events) after release are strongly dependent on the phase (gas, liquid, or two-phase) of the fluid after it is released into the environment. Guidelines for determining the phase of the released fluid can be seen on Table 4.3 API 581 Part 3 of COF. For this, the release phase is gas/vapor.

STEP 1.1 Select the representative fluid group from Table 4.1 Annex 3.A

Gas in Steam (%)					
H_2O	**Total gas content**	**CO_2**	**H_2S**	**NH_3**	**Rsd**
99.343	0.657016748	0.610713	0.014271	0.000324	0.036059
Note: those values are average of the values sample taken on different date in September 2018.					

mmole/100 mole H2O							
CO_2	**H_2S**	**NH_3**	**N_2**	**CH_4**	**He**	**H_2**	**Ar**
239.871	7.38218	0.22971	24.5565	0.4563	0.08704	1.2557	0.02902
Note: those values are average of the values sample taken on different date in September 2018.							

The representative fluid is **water steam** but for fluid mixture, there are some other considerations of representative fluid in API RP 581 - Annex 3.A section 3.A.3.1.2 Choice of Representative Fluids of Mixtures stated in the following paragraph.

If a mixture contains inert materials such as CO2 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.

Table 4.1 – List of Representative Fluids Available for Level 1 Consequence Analysis

Representative Fluid	Fluid TYPE (see Section 4.1.5)	Examples of Applicable Materials
H_2	TYPE 0	Hydrogen
H_2S	TYPE 0	Hydrogen Sulfide
HF	TYPE 0	Hydrogen Fluoride
water	TYPE 0	Water
steam	TYPE 0	Steam
Acid	TYPE 0	Acid, Caustic

The representative fluid is H_2S

STEP 1.2 Determine the stored fluid phase

The Steam Scrubber of Star Energy Geothermal Wayang Windu Unit 2 is vapor stored fluid phase.

STEP 1.3 Determine the stored fluid properties

For a stored vapor or gas fluid, the properties are dependent on these parameters such as:

1). Molecular Weight (MW), kg/kg-mol (lb/lb-mol)

The stored vapor Molecular Weight (MW) can be estimated from Table 4.2

MW = 34.00 (kg/kg-mol)

2). Auto-Ignition Temperature, K

The stored liquid Auto-Ignition Temperature (AIT) can be estimated from Table 4.2 of API 581 Part 3 of COF.

AIT = 500 (^{o}C)

AIT = 773.15 (K)

3). Ideal gas specific heat ratio, k

Cp_A = 31.9 J/kmol-K

Cp_B = 1.44E-03 J/kmol-K

Cp_C = 2.43E-05 J/kmol-K

Cp_D = -1.18E-08 J/kmol-K

T = 26.5 °C

T = 79.7 °F

T = 299.65 K

R = 8.314 J/kg-mol-K

$$Cp = A + BT + CT^2 + DT^3$$

$= 3.34x10^4 + (2.68x10^4 \text{ x } 458.55) + (2.61x10^3 \text{ x } 458.55)^2 + (8.9x10^3 \text{ x } 458.55)^3$

= 3.23E+01 J/kmol-K

$$k = \frac{Cp}{Cp - R}$$ ………………………………………………… (equation 2)

$$= \frac{8.29x10^{22}}{8.29x10^{22} - 8.314}$$

= 1.346164

STEP 1.4 Determine the steady state phase of the fluid after release to the atmosphere

Determining the ateady state phase of the fluid after release to the atmosphere can be adopted from the Table 4.3 API 581 Part 3 of COF shown below:

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^{o}F, then model as a liquid
Liquid	Liquid	Model as liquid

SUMMARY of STEP 1:

1 According the data of Company chemical analysis, the major fluids are water steam and H2S which has the percentage of 99.316% and 0.0155% of all.

2 The fluid stored in the pressure vessel (Steam Scrubber) is assumed as gas, because the gaseous constituent is dominant.

3 Fluid properties id based on the STEP 1.3 which has been adjusted by using Table 4.2 in API RP 581 Part 3 of COF

MW = 34.00 (kg/kg-mol)

AIT = 773.15 (K)

T = 299.65 (K)

Cp = 3.2E+01 (J/kmol-K)

k = 1.3462

4 The steady state phase after release to the atmoshpere is gaseous type.

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PART 2: SELECT A SET OF RELEASE HOLE SIZES TO DETERMINE THE POSSIBLE RANGE OF CONSEQUENCE IN THE RISK CALCULATION

2.1 RELEASE HOLE SIZE SELECTION

A descrete set of release events or release hole sizes are used since it would be impractical to perform the consequence analysis for a continous spectrum of release hole sizes. Limiting the number of of release hole sizes allows for an analysis that is manageable, yet still reflects the range of possible outcomes.

STEP 2.1 Calculate of release hole sizes by determining each diameter (d_n)

The following steps are repeated of each release hole size, typically four hole sizes are evaluated.

According to Annex 3.A of API 581 Chapter 3.2.3 committs that the standard four release hole sizes are assumed for all sizes in pressure vessel type.

Table 4.4. Release Hole Sizes and Areas Used in Level 1 and 2 Consequences Analysis

Release Hole Number	Release Hole Sizes	Range of Hole Diameter (mm)	Release Hole Diameter, d_n (inch)
1	Small	0 - 1/4	$d_1 = 0.25$
2	Medium	> 1/4 - 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 gff_n, for the n^{th} release hole size

Determining the generic failure frequency (gff_n), for the n^{th} release hole size can be seen from API 581 Part 2, Table 3.1

Table 3.1. Suggested Component Generic Failure Frequency

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
Note: See references [1] through [8] for discussion of failure frequencies for equipment						

The total of generic failuure frequency (gff) can be taken from the table value or calculated using the equation below:

$$gff_{total} = \sum_{n=1}^{4} gffn \qquad \text{(equation 3)}$$

Because the total vallue of generic failure frequency has been availabled from the table. So, we can directly put the value from the table into the calculation.

gff_{total} = 0.0000306 failures/year

gff_{small} = 0.000008 failures/year

gff_{medium} = 0.00002 failures/year

gff_{large} = 0.000002 failures/year

$gff_{rupture}$ = 0.0000006 failures/year

SUMMARY of Step 2:

1 According to Annex 3.A Part 3 of API RP 581 committs that for pressure vessels, all of model of release hole size must be assumed.

2 The total generic failure frequency per years for every type of pressure vessel has been adjusted by the Table of 3.1 in Part 2 of API RP 581.

gff_{small} = 0.000008 failures/year

gff_{medium} = 0.00002 failures/year

gff_{large} = 0.000002 failures/year

$gff_{rupture}$ = 0.0000006 failures/year

PART 3 : CALCULATE THE THEORETICAL RELEASE RATE

3.1 RELEASE RATE

Release rate has a close correlation within the physical properties of the material, the initial phase, the process operating conditions, and the assigned release hole sizes. As we know that initial phase is the phase of the stored fluid prior contacting to the atmosphere. for special case, two-phases systems which contain gaseos and liquid containmment inside the pressure vessel, so, according t the API 581 Part 3, choosing liquid as the initial state inside the equipment is more conservative and may be preferred.

3.2 VAPOR RELEASE RATE EQUATIONS

There are two regimes for flow gases through an orifice: aonic (choked) for higher internal pressure, and subssonic flow for lower pressure (nominally 15 psig (103.4 kPa) or less). The transition pressure at which the flow regime changes from sonic to subsonic is determined using below equation.

P_{atm} = 14.696 psi

k = 1.3462

$$P_{trans} = Patm\left(\frac{k+1}{2}\right)^{\frac{k}{k-1}} \quad \text{(equation 4)}$$

$$P_{trans} = 14.69\left(\frac{1+1}{2}\right)^{\frac{1}{1-1}}$$

= 27.3402211 psi

STEP 3.1 Select the appropriate release rate equation

Because of the phase inside the Steam Ejector is GASEOUS PHASE and the storage pressure (P_s) within the equipment item is less than the transition pressure (P_{trans}), so the equation chosen is shown below:

$$W_n = \frac{Cd}{C2}\ x\ An\ \text{x Ps}\sqrt{\left(\frac{k.MW.g_c}{R.T_s}\right)\left(\frac{2.k}{k-1}\right)\left(\frac{P_{atm}}{P_s}\right)^{\frac{2}{k}}\left(1-\left(\frac{2}{k+1}\right)^{\frac{k-1}{k}}\right)} \quad \text{(equation 5)}$$

Abbreviation list :

C_d	=	Discharge coefficient, for turbulent liquid flow from the sharp-edge orifices in the range of $0.85 \leq C_d \leq 1.00$			
	=	0.9			
A_n	=	Release hole sized area			
P_s	=	Storage operating pressure	=	143.59	psi
P_{atm}	=	Atmosphere pressure	=	14.696	psi
k	=	Ideal gas specific heat capacity ratio	=	1.3462	
MW	=	Molecular weight	=	34.00	(kg/kg-mol)
g_c	=	Gravitational constant	=	9.8	m/s^2
R	=	Universal gas constant	=	8.314	J/(kg-mol-K)
T_s	=	Storage operating temperature	=	26.5	°C
			=	79.7	°F
			=	299.65	K

STEP 3.2 For every release hole size, calculate the release hole size area based on d_n

Release Hole Number	Release Hole Sizes	Range of Hole Diameter (inch)	Release Hole Diameter, d_n (inch)
1	Small	0 - 1/4	d1 = 0.25
2	Medium	> 1/4 - 2	d2 = 1
3	Large	> 2 - 6	d3 = 4
4	Rupture	> 6	d4 = min[D,16]

The release hole size area can be determined by formulating below equation:

$$An = \frac{\pi dn^2}{4} \quad \text{...} \quad \text{(equation 6)}$$

1). SMALL RELEASE HOLE SIZE AREA

d_1 = 0.25 inch
= 0.0064 m
π = 3.14

$$An = \frac{\pi dn^2}{4} = \frac{3.14\ x\ (0.25)^2}{4}$$

= 0.0491 inch^2
= 3E-05 m^2

2). MEDIUM RELEASE HOLE SIZE AREA

d_1 = 1 inch
= 0.0254 m
π = 3.14

$$An = \frac{\pi dn^2}{4} = \frac{3.14\ x\ (1)^2}{4}$$

= 0.785 inch^2
= 0.0005 m^2

3). LARGE RELEASE HOLE SIZE AREA

d_1 = 4 inch
= 0.1016 m
π = 3.14

$$An = \frac{\pi dn^2}{4} = \frac{3.14\ x\ (4)^2}{4}$$

= 12.56 inch^2
= 0.0081 m^2

4). RUPTURE RELEASE HOLE SIZE AREA

d_1 = 16 inch
= 0.4064 m
π = 3.14

$$An = \frac{\pi dn^2}{4} = \frac{3.14\ x\ (16)^2}{4}$$

= 200.96 inch^2
= 0.1296 m^2

STEP 3.3 For liquid releases, for each release hole size, calculate the viscosity correction factor ($K_{v,n}$)

Viscosity Correction Factor ($K_{v,n}$) can be determined using both equation 4 of graph below, which have been printed from API Standard 520 Part 1. Another option, the conservative value of viscosity correction factor may be used the value of 1.0

$$K_{v,n} = \left(0.9935 + \frac{2.878}{Ren^{0.5}} + \frac{342.75}{Ren^{1.5}}\right)^{-1}$$ ……………………… (equation 7)

Because the store fluid phase determined in STEP 1.2 is gaseous or vapor phase, then, this step is no neeed to be considered.

STEP 3.4 For each hole size, calculate the release rate, W_n, for each release area A_n

$$W_n = \frac{Cd}{C2}\ x\ An \text{ x } Ps \sqrt{\left(\frac{k.MW.g_c}{R.T_s}\right)\left(\frac{2.k}{k-1}\right)\left(\frac{P_{atm}}{P_s}\right)^{\frac{2}{k}}\left(1-\left(\frac{2}{k+1}\right)^{\frac{k-1}{k}}\right)}$$

Abb

C_d	=	0.9	
k	=	1.3461635	
A_{n1}	=	3.1645E-05	m^2
A_{n2}	=	0.00050645	m^2
A_{n3}	=	0.00810321	m^2
A_{n4}	=	0.1296192	m^2
gc	=	1	kgm/Ns^2
	=	32.2	$lb_m\ ft/lb_f\ S^2$
Ps	=	990	Kpa
P_{atm}	=	101.325	KPa
C_2	=	1	
R	=	8.314	J/(kg-mol-K)
g_c	=	9.8	m/s^2
T_s	=	299.65	K
MW	=	34.00	(kg/kg-mol)

1). SMALL RELEASE HOLE SIZE AREA

$$W_n = \frac{Cd}{C2}\ x\ An \text{ x } Ps \sqrt{\left(\frac{k.MW.g_c}{R.T_s}\right)\left(\frac{2.k}{k-1}\right)\left(\frac{P_{atm}}{P_s}\right)^{\frac{2}{k}}\left(1-\left(\frac{2}{k+1}\right)^{\frac{k-1}{k}}\right)}$$

$$W_1 = \frac{0.9}{1}\ x\ 3.164\text{x}10^{-5} \text{ x } 990\ x$$

$$\sqrt{\left(\frac{1.34x\ 34\ x\ 9.8}{8.314\ x\ 458.55}\right)\left(\frac{2.\,1.34}{1.34-1}\right)\left(\frac{101.3}{990_s}\right)^{\frac{2}{1.34}}\left(1-\left(\frac{2}{1.34+1}\right)^{\frac{1.34-1}{1.34}}\right)}$$

= 0.00123069 kg/s

2). MEDIUM RELEASE HOLE SIZE AREA

$$W_n = \frac{Cd}{C2}\ x\ An \text{ x Ps} \sqrt{\left(\frac{k.MW.g_c}{R.T_S}\right)\left(\frac{2.k}{k-1}\right)\left(\frac{P_{atm}}{P_S}\right)^{\frac{2}{k}}\left(1-\left(\frac{2}{k+1}\right)^{\frac{k-1}{k}}\right)}$$

$$W_2 = \frac{0.9}{1}\ x\ 0.000506451 \text{ x } 990\ x \sqrt{\left(\frac{1.34x\ 34\ x\ 9.8}{8.314\ x\ 458.55}\right)\left(\frac{2.1.34}{1.34-1}\right)\left(\frac{101.3}{990_s}\right)^{\frac{2}{1.34}}\left(1-\left(\frac{2}{1.34+1}\right)^{\frac{1.34-1}{1.34}}\right)}$$

= 0.01969598 kg/s

3). LARGE RELEASE HOLE SIZE AREA

$$W_n = \frac{Cd}{C2}\ x\ An \text{ x Ps} \sqrt{\left(\frac{k.MW.g_c}{R.T_S}\right)\left(\frac{2.k}{k-1}\right)\left(\frac{P_{atm}}{P_S}\right)^{\frac{2}{k}}\left(1-\left(\frac{2}{k+1}\right)^{\frac{k-1}{k}}\right)}$$

$$W_2 = \frac{0.9}{1}\ x\ 0.00810321 \text{ x } 990\ x \sqrt{\left(\frac{1.34x\ 34\ x\ 9.8}{8.314\ x\ 458.55}\right)\left(\frac{2.1.34}{1.34-1}\right)\left(\frac{101.3}{990_s}\right)^{\frac{2}{1.34}}\left(1-\left(\frac{2}{1.34+1}\right)^{\frac{1.34-1}{1.34}}\right)}$$

= 0.31513574 kg/s

4). RUPTURE RELEASE HOLE SIZE AREA

$$W_n = \frac{Cd}{C2}\ x\ An \text{ x Ps} \sqrt{\left(\frac{k.MW.g_c}{R.T_S}\right)\left(\frac{2.k}{k-1}\right)\left(\frac{P_{atm}}{P_S}\right)^{\frac{2}{k}}\left(1-\left(\frac{2}{k+1}\right)^{\frac{k-1}{k}}\right)}$$

$$W_2 = \frac{0.9}{1}\ x\ 0.1296192 \text{ x } 990\ x \sqrt{\left(\frac{1.34x\ 34\ x\ 9.8}{8.314\ x\ 458.55}\right)\left(\frac{2.1.34}{1.34-1}\right)\left(\frac{101.3}{990_s}\right)^{\frac{2}{1.34}}\left(1-\left(\frac{2}{1.34+1}\right)^{\frac{1.34-1}{1.34}}\right)}$$

= 5.04092137 kg/s

PART 4 : ESTIMATE THE TOTAL AMOUNT OF OF FLUID INVENTORY AVAILABLE FOR RELEASE

4.1 RELEASE RATE

The leaking component's inventory is combined with inventory with the other attached components that can contribute fluid mass.

Table 3.A.3.2 — Assumptions Used When Calculating Liquid Inventories Within Equipment

Equipment Description	Component Type	Examples	Default Liquid Volume Percent
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

4.2 MAXIMUM MASS AVAILABLE FOR RELEASE

The available mass for release is estimated for each release hole size as the lesser of two quantities:

INVENTORY GROUP MASS

The component being evaluated is part of a larger group of components that can be expected to provide fluid inventory to the release. The inventory calculation as presented here is used as an upper-limit and does not indicate that this amount of fluid would be released in all leak scenarios. The inventory group mass can be calculated using this below equation:

$$Mass_{inv} = \sum_{i=1}^{N} \left(Mass_{comp,i}\right)$$

COMPONENT MASS

It is assumed that for large leaks and above, operator intervension will occur within 3 minutes, thereby limiting the amount of release material. Therefore, the amount of available mass for the release is limmited to the mass of the component plus an additional mass, $mass_{add,n}$, that is calculated based on three minutes of leakage from the component's inventory group.

STEP 4.1 Group components and equipment items into inventory groups

This step of determining the group components and equipment items can be referred to API 581 Part 3 Annex 3.A.3.3 says that when a component or equipment type is evaluated, the inventory of the component is combined with inventory from associated equipment that can contribute fluid mass to the leaking components. **Theoritically, the total amount of fluid that can be released is the amount that is held within pressure containing equiment between isolation valves that can be quickly closed.**

STEP 4.2 Calculate the fluid mass, $mass_{comp}$, in the component being evaluated

V_{tot}	=	12.109	m^3	V_{gas}	=	10.898	m^3
		427.63	ft^3			384.87	ft^3
ρ_{gas}	=	5.8	kg/m^3	V_{liq}	=	1.2109	m^3
		0.3621	lb/ft^3			42.763	ft^3
				ρ_{liq}	=	660	kg/m^3
$Mass_{comp}$	=	63.21	kg				

STEP 4.3 Calculate the fluid mass in each of the other component that are included in the inventory group mass

Based on the design of the gas plant, there is no other component or equipment type that can be combined to contribute the fluid mass to the leaking components.

STEP 4.4 Calculate the fluid mass in the inventory group, $mass_{inv}$

$$Mass_{inv} = \sum_{i=1}^{N} \left(Mass_{comp,i}\right)$$

Where

$Mass_{comp}$	=	is the inventory fluid mass for the component or piece of equipment being evaluated, kgs [lbs]
$Mass_{inv}$	=	is the inventory group fluid mass, kgs [lbs]
	=	862.42 kg

STEP 4.5 Calculate the flow rate from a 203 mm (8 inch) diameter hole, W_{max8}

Calculate the flow rate from a 203 mm (8 inch) diameter hole, Wmax8, using the equation 5 as applicable with $A_n = A_8 = 32.450\ mm^2$ ($50.3\ inch^2$). This is the maximum flow rate that can be added to the equipment fluid mass from the surrounding equipment in the inventory group.

$$W_n = \frac{Cd}{C2}\ x\ An\ \text{x Ps}\sqrt{\left(\frac{k.MW.g_c}{R.T_s}\right)\left(\frac{2.k}{k-1}\right)\left(\frac{P_{atm}}{P_s}\right)^{\frac{2}{k}}\left(1-\left(\frac{2}{k+1}\right)^{\frac{k-1}{k}}\right)}$$

Where

C_d	=	Discharge coefficient, for turbulent gas flow from the sharp-edge orifices in the range of $0.85 \le C_d \le 1.00$			
			=	0.9	
A_n	=	Release hole sized area	=	50.3	$inch^2$
			=	32444	mm^2
			=	0.0324	m^2
P_s	=	Storage operating pressure	=	143.59	psi
			=	990	Kpa
P_{atm}	=	Atmosphere pressure	=	14.696	psi
			=	101.33	Kpa
MW	=	Molecular weight	=	34.00	(kg/kg-mol)
g_c	=	Gravitational constant	=	9.8	m/s^2
R	=	Universal gas constant	=	8.314	J/(kg-mol-K)
T_s	=	Storage or normal operating temperature	=	26.5	°C
			=	79.7	°F
			=	299.65	K
C_2	=	SI and US customary conversion factors	=	1	
k	=	Ideal gas specific heat ratio	=	1.3462	

So,

$$W_{max8} = \frac{0.9}{1}\ x\ 0.0324 \text{ x } 990\ x \sqrt{\left(\frac{1.34x\ 34\ x\ 9.8}{8.314\ x\ 458.55}\right)\left(\frac{2.1.34}{1.34-1}\right)\left(\frac{101.3}{990_s}\right)^{\frac{2}{1.34}}\left(1-\left(\frac{2}{1.34+1}\right)^{\frac{1.34-1}{1.34}}\right)}$$

= 4.24279931 kg/s

STEP 4.6 Calculate the added fluid mass $mass_{add,n}$ for each release hole size

Determining the additional fluid mass for each release hole size resulting from three minutes of flow from the inventory group usin this below equation:

$$Mass_{add\ n} = 180 . \min[W_n ,W_{max8}]$$

1). SMALL RELEASE HOLE SIZE AREA

$$Mass_{add\ n} = 180 . min[W_n ,W_{max8}]$$

$$Mass_{add\ 1} = 180 . min[0.0019273,5.76766174]$$

= 0.2215 kgs

2). MEDIUM RELEASE HOLE SIZE AREA

$$Mass_{add\ n} = 180 . min[W_n ,W_{max8}]$$

$$Mass_{add\ 2} = 180 . min[0.0900345,5.76766174]$$

= 3.5453 kgs

3). LARGE RELEASE HOLE SIZE AREA

$$Mass_{add\ 3} = 180 . min[W_n ,W_{max8}]$$

$$Mass_{add\ 3} = 180 . min\ [0.4601677,5.76766174]$$

= 56.724 kgs

4). RUPTURE RELEASE HOLE SIZE AREA

$$Mass_{add\ 4} = 180 . min[W_n ,W_{max8}]$$

$$Mass_{add\ 4} = 180 . min[23.043127,5.76766174]$$

= 763.7 kgs

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

For each release hole size, calculate the available mass for release usinng this below equation:

$$Mass_{avail\ n} = min . [\{Mass_{comp} + Mass_{add,n} \},Mass_{inv}]$$

1). SMALL RELEASE HOLE SIZE AREA

$$Mass_{avail\ n} = min . [\{Mass_{comp} + Mass_{add,n} \},Mass_{inv}]$$

$$Mass_{avail\ 1} = min . [\{146.99+0.3469199\},2005.6]$$

= 63.432 kgs

2). MEDIUM RELEASE HOLE SIZE AREA

$$Mass_{avail\ n} = min\ .[\{Mass_{comp} + Mass_{add,n}\}, Mass_{inv}]$$

$$Mass_{avail\ 2} = min\ .[\{146.99+16.206218\},2005.6]$$

$$= 66.755\ kgs$$

3). LARGE RELEASE HOLE SIZE AREA

$$Mass_{avail\ n} = min\ .[\{Mass_{comp} + Mass_{add,n}\}, Mass_{inv}]$$

$$Mass_{avail\ 3} = min\ .[\{146.99+82.830183\},2005.6]]$$

$$= 119.93\ kgs$$

4). RUPTURE RELEASE HOLE SIZE AREA

$$Mass_{avail\ n} = min\ .[\{Mass_{comp} + Mass_{add,n}\}, Mass_{inv}]$$

$$Mass_{avail\ 4} = min\ .[\{146.99+1038.1791\},2005.6]$$

$$= 826.91\ kgs$$

SUMMARY:

1. For group inventory, theoritically, the total amount of fluid that can be released is the amount that is held within pressure containing equiment between isolation valves that can be quickly closed.
2. Calculating the fluid mass and the mass of component to determine the mass inventory.
3. There is no other components contributing the mass of the equipment evaluated.
4. $Mass_{inv}$ = 862.42 kg
5. Determining the maximum flow rate of a hole size within the diameter of 203 mm (8 inch) with the hole size area of 32.450 mm^2 (50.3 $inch^2$).

   W_{max8} = 4.24279931 kg/s
6. Determining the additional fluid mass for release hole size starting for the small release hole size until the rupture release hole size.

   $Mass_{add1}$ = 0.22152486 kgs
   $Mass_{add2}$ = 3.54527707 kgs
   $Mass_{add3}$ = 56.7244331 kgs
   $Mass_{add4}$ = 763.703876 kgs
7. Determining the available mass for each release hole size

   $Mass_{avail1}$ = 63.432 kgs
   $Mass_{avail2}$ = 66.755 kgs
   $Mass_{avail3}$ = 119.934 kgs
   $Mass_{avail4}$ = 826.914 kgs

PART 5 : DETERMINE THE RELEASE TYPE (CONTINOUS OR INSTATANENOUS)

5.1 RELEASE TYPE

The release is modeled as one of these two following types:

A). INSTANTANEOUS RELEASE

An instataneous or puff release is one that occurs so rapidly that the fluid disperses as a single large cloud or pool.

B). CONTINOUS RELEASE

A continous or plume release is one that occurs over a longer period of time, allowing the fluid to dispers in the shape of elongated ellipse (dependening in the weather conditions).

The process for determining the appropriate type for release to model requires to determine the time required to release 4536 kgs (10000 lbs) of fluid, tn, through each release hole size.

STEP 5.1 Calculate the time required to release 4536 kgs (10000 lbs) of fluid for each hole size.

To determine the time required to release 4536 kgs (10000 lbs) of fluid for each hole size can be adopted from the equation below:

$$t_n = \frac{C3}{W_n}$$

Where

t_n = time required to release 4536 kgs (10000 lbs) of fluid

C_3 = SI and US customary conversion factors

= 4536 kgs

= 10000 lbs

W_n = Theoretical release rate associated with the n^{th} release hole size, kg/s

W_{n1} = 0.00123069 kg/s

W_{n2} = 0.01969598 kg/s

W_{n3} = 0.31513574 kg/s

W_{n4} = 5.04092137 kg/s

1). SMALL RELEASE HOLE SIZE AREA

$$t_n = \frac{C3}{W_n}$$

$$t_1 = \frac{4536}{0.00192733}$$

= 3685726.21 s

2). MEDIUM RELEASE HOLE SIZE AREA

$$t_n = \frac{C3}{W_n}$$

$$t_2 = \frac{4536}{0.09003454}$$

= 230300.759 s

3). LARGE RELEASE HOLE SIZE AREA

$$t_n = \frac{C3}{W_n}$$

$$t_3 = \frac{4536}{0.46016768}$$

= 14393.7975 s

4). RUPTURE RELEASE HOLE SIZE AREA

$$t_n = \frac{C3}{W_n}$$

$$t_4 = \frac{4536}{23.0431273}$$

= 899.835501 s

STEP 5.2 Determine the release type for each release hole size.

For each release hole size, determine the release type either instataneous or continous using this following criteria:

a. If the release hole size is 6.35 mm(0.25 inch) or less, then the release type is continous

b. If t_n<180 sec and the releaase mass is gretaer than 4536 kgs (100000 lbs), then the release is instataneous: otherwise the release is continous

1). SMALL RELEASE HOLE SIZE AREA

d_1 = 0.25 inch

t_1 = 4E+06 s (Continous)

2). MEDIUM RELEASE HOLE SIZE AREA

d_2 = 1 inch

t_2 = 230301 s (Continous)

3). LARGE RELEASE HOLE SIZE AREA

d_3 = 4 inch

t_3 = 14394 s (Continous)

4). RUPTURE RELEASE HOLE SIZE AREA

d_4 = 16 inch

t_4 = 899.84 s (Continous)

SUMMARY:

1 Calculating the time required to release 4536 kgs (10000 lbs) of fluid for each hole size, starting for the small until the rupture release hole size.

t_{n1} = 3685726.21 s

t_{n2} = 230300.759 s

t_{n3} = 14393.7975 s

t_{n4} = 899.835501 s

2 Based on the characteristic that if the release hole size is 0.25 inch or less, then, automatically including into the continuous release type. And the other hand, if t_n<180 sec and the release mass is gretaer than 4356 kgs (10000 lbs), it is including into instantaneous release type.

PART 6 : ESTIMATE THE IMPACT OF DETECTION AND ISOLATION SYSTEMS ON RELEASE MAGNITUDE

STEP 6.1 Determine the detection and isolation systems present in the unit using Table 4.5 and 4.6 API 581 Part 3

Table 4.5- Detection and Isolation System Rating Guide

Type of Detection System	Det. 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	**Iso. 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 location remote from the leak	B
Isolation dependent on manually operated valves	C

Table 4.6 - Adjustment to Release Based on Detection and Isolation Systems

System Classification		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 systems present = Visual or detection in marginal area *

Isolation systems present = HV *

STEP 6.2 Type of detection system = Visual detection, cameras, or detectors with marginal coverage *

Detection Classification = C

STEP 6.3 Type of isolation system = Isolation or shutdown systems activated directly from process instrumentation or detectors, with no oprator intervention *

Isolation Classification = C

STEP 6.4 Determine the release reduction factor $fact_{di}$ using Table 4.6

Release Magnitude Adjustment = No adjustment to release rate or mass

Reduction Factor, $fact_{di}$ = **0**

STEP 6.5 Determine the total leak durations for each release hole sizes using Table 4.7

Table 4.7 - Leak Durations Based on detection and Isolation Systems

Detection System Rating	Isolation System Rating	Maximum Leak Duration, ld_{max}
A	A	20 minutes for 1/4 inch leaks
		10 minutes for 1 inch leaks
		5 minutes for 4 inch leaks
A	B	30 minutes for 1/4 inch leaks
		20 minutes for 1 inch leaks
		10 minutes for 4 inch leaks
A	C	40 minutes for 1/4 inch leaks
		30 minutes for 1 inch leaks
		20 minutes for 4 inch leaks
B	A or B	40 minutes for 1/4 inch leaks
		30 minutes for 1 inch leaks
		20 minutes for 4 inch leaks
B	C	1 hour for 1/4 inch leaks
		30 minutes for 1 inch leaks
		20 minutes for 4 inch leaks
C	A, B, or C	1 hour for 1/4 inch leaks
		40 minutes for 1 inch leaks
		20 minutes for 4 inch leaks

1). SMALL RELEASE HOLE SIZE AREA

d_1 = 0.25 inch

t_1 = 4E+06 s (Continous)

$ld_{max,1}$ = 1 hour for 1/4 inch leaks

2). MEDIUM RELEASE HOLE SIZE AREA

d_2 = 1 inch

t_2 = 230301 s (Continous)

$ld_{max,2}$ = 40 minutes for 1 inch leaks

3). LARGE RELEASE HOLE SIZE AREA

d_3 = 4 inch

t_3 = 14394 s (Continous)

$ld_{max,3}$ = 20 minutes for 4 inch leaks

4). RUPTURE RELEASE HOLE SIZE AREA

d_4 = 16 inch

t_4 = 899.84 s (Continous)

$ld_{max,4}$ = 20 minutes for 4 inch leaks

PART 7:DETERMINE THE RELEASE RATE AND MASS FOR CONSEQUENCE OF FAILU

7.1 CONTINOUS RELEASE RATE

For continous releases, the release is modeled as a steady state plume: therefore, the release rate is used as an input to the consequence analysis. The release rate that is used in the analysis is the theoretical release adjusted for the presence of unit detection and isolations as formulated in the equation below:

$$Rate_n = W_n (1 - fact_{di})$$

7.2 INSTANTANEOUS RELEASE RATE

For transient instataneous puff releases, the release mass is required to perform the analysis. The available release mass for each hole size, $mass_{avail,n}$, is used ass an upper bound for the release mass, $mass_n$, as shown in the equation below:

$$Mass_n = min . [\{Rate_n . ld_n\}, Mass_{avail,n}]$$

STEP 7.1 Calculate the adjusted release rate, $rate_n$ for each release hole size

For each release hole size, determine the adjusted release rate, $rate_n$, using equation 12 above where the theoreical release rate, W_n, and also note that the release reduction factor, $fact_{di}$, account for any detection and isolation systemss that are present.

Reduction Factor, $fact_{di}$ = 0

W_{n1} = 0.00123069 kg/s

W_{n2} = 0.01969598 kg/s

W_{n3} = 0.31513574 kg/s

W_{n4} = 5.04092137 kg/s

1). SMALL RELEASE HOLE SIZE AREA

$$Rate_1 = W_n (1 - fact_{di})$$

$$Rate_1 = 0.00123069 (1 - 0)$$

= 0.0012 kg/s

2). MEDIUM RELEASE HOLE SIZE AREA

$$Rate_2 = W_n (1 - fact_{di})$$

$$Rate_2 = 0.01969598 (1 - 0)$$

= 0.0197 kg/s

3). LARGE RELEASE HOLE SIZE AREA

$$Rate_3 = W_n (1 - fact_{di})$$

$$Rate_3 = 0.31513574 (1 - 0)$$

= 0.3151 kg/s

4). RUPTURE RELEASE HOLE SIZE AREA

$$Rate_4 = W_n (1 - fact_{di})$$

$$Rate_4 = 5.04092137 (1 - 0)$$

= 5.0409 kg/s

STEP 7.2 Calculate the leak duration, ld_n, for each release hole size

For each release hole size, calculate the leak duration, ld_n, of the release using this equation 14 below, ,. Note that the leak duration cannot exceed the maximum duration $ld_{max,n}$.

$$ld_n = min.[\{\frac{Mass_{avail,n}}{Rate_n}\},\{60 . ld_{max,n}]$$ .... (equation 14)

$ld_{max,1}$	=	1 hour for 1/4 inch leaks	60	$Mass_{avail,1}$	=	63.432 kgs
$ld_{max,2}$	=	40 minutes for 1 inch leaks	40	$Mass_{avail,2}$	=	66.76 kgs
$ld_{max,3}$	=	20 minutes for 4 inch leaks	20	$Mass_{avail,3}$	=	119.93 kgs
$ld_{max,4}$	=	20 minutes for 4 inch leaks	20	$Mass_{avail,4}$	=	826.91 kgs

1). SMALL RELEASE HOLE SIZE AREA

$$ld_1 = min.[\{\frac{Mass_{avail,n}}{Rate_1}\},\{60 . ld_{max,1}]$$

$$ld_1 = min.[\{\frac{29.771}{0.0012307}\},\{60 . 60\}]$$

= 3600 s

2). MEDIUM RELEASE HOLE SIZE AREA

$$ld_2 = min.[\{\frac{Mass_{avail,n}}{Rate_2}\},\{60 . ld_{max,2}]$$

$$ld_2 = min.[\{\frac{33.1}{0.019696}\},\{60 . 40\}]$$

= 2400 s

3). LARGE RELEASE HOLE SIZE AREA

$$ld_3 = min.[\{\frac{Mass_{avail,n}}{Rate_3}\},\{60 . ld_{max,3}]$$

$$ld_3 = min.[\{\frac{86.274}{0.3151357}\},\{60 . 20\}]$$

= 380.58 s

4). RUPTURE RELEASE HOLE SIZE AREA

$$ld_4 = min.[\{\frac{Mass_{avail,n}}{Rate_4}\},\{60 . ld_{max,4}]$$

$$ld_4 = min.[\{\frac{403.17}{5.0409214}\},\{60 . 20\}]$$

= 164.04 s

STEP 7.3 Calculate the release mass, $mass_n$, for each release hole size

For each release hole size, calculate the release mass, $mass_n$, using equation 13 above based on the release rate, $rate_n$, the leak duration, Id_n, and the available mass, $mass_{avail,n}$.

1). SMALL RELEASE HOLE SIZE AREA

$$Mass_1 = min.[\{Rate_1 . ld_1\},Mass_{avail,1}]$$

$$Mass_1 = min.[\{0.0015419 . 3600\},29.771423]$$
$= 4.43049729$ kgs

2). MEDIUM RELEASE HOLE SIZE AREA

$$Mass_2 = min.[\{Rate_2 . ld_2\},Mass_{avail,n}]$$
$$Mass_2 = min.[\{0.019696 . 1680\},33.095175]$$
$= 47.2703609$ kgs

3). LARGE RELEASE HOLE SIZE AREA

$$Mass_3 = min.[\{Rate_3 . ld_3\},Mass_{avail,n}]$$
$$Mass_3 = min.[\{0.3151357. 273.77\},86.274331]$$
$= 119.934457$ kgs

3). RUPTURE RELEASE HOLE SIZE AREA

$$Mass_4 = min.[\{Rate_4 . ld_4\},Mass_{avail,n}]$$
$$Mass_4 = min.[\{5.0409214 . 79.979\},403.1693]$$
$= 826.9139$ kgs

SUMMARY:

1 Determining the adjusted release rate, $rate_n$, for each release hole size. This adjusted release rate is quite different with the theoretical release rate, W_n, because the adjusted release rate is based on the real condition with the theoretical release rate referrence. Otherwise, the theoretical release rate, $W_{n,}$ is purely based on the theory and approching equationg provided by API RP 581.

$Rate_1$	=	0.00123069	kg/s
$Rate_2$	=	0.01969598	kg/s
$Rate_3$	=	0.31513574	kg/s
$Rate_4$	=	5.04092137	kg/s

2 Determining the leak duration, ld_n, for each release hole size.

ld_1	=	3600	s
ld_2	=	2400	s
ld_3	=	380.580309	s
ld_4	=	164.04023	s

3 Determining the release mass for each release hole size based on the release rate, leak duration, and available mass for each release hole size.

$Mass_1$	=	4.43049729	kgs
$Mass_2$	=	47.2703609	kgs
$Mass_3$	=	119.934457	kgs
$Mass_4$	=	826.9139	kgs

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PART 8 : DETERMINE FLAMMABLE AND EXPLOSIVE CONSEQUENCE

8.1 CONSEQUENCE AREA EQUATIONS

The following equations are used to determine the flammable consequence areas for comoponent damage and personnel injury. There are two kind of equantions explained based on its type of release, either continous release or instataneous release as mentioned below:

1). $CA_n^{CONT} = \alpha(rate_n)^b$

2). $CA_n^{CONT} = \alpha(mass_n)^b$

The coefficients for those equations for component damage areas and personel injury are provided in Table 4.8 and 4.9 in API RP 581 Part 3 of COF.

STEP 8.1 Select the consequence area mitigation reduction factor, factmit, from Table 4.10

Mitigation System	Consequence Area Adjustemnet	Consequence Area Reduction Factor, factor mit
Inventory blowdown , couple 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%	0.2
Fire water monitor only	Reduce consequence area by 5%	0.05
Foam spray system	Reduce consequence area by 15%	0.15

Mitigation system = Fire water monitor only

Consequence Area = Reduce consequence area by 5% *

$fact_{mit}$ = 0.05

STEP 8.2 Calculate the energy efficiency, $eneff_n$, for each hole size using equation mentioned below.

$$eneff_n = 4.\,log_{10}[C_{4A}\,.mass_n] - 15 \quad \text{........................... (equation 17)}$$

This correction is made for instantaneous events exceeding a release mass of 4,536 kgs (10,000 Ibs). Comparison of calculated consequence with those of actual historical releases indicates that there is need to correct large instantaneous releases for energy efficiency.

C_{4A} = 2205 1/kg

A) SMALL RELEASE HOLE SIZE AREA

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

$eneff_1$ = 0.95944

B) MEDIUM RELEASE HOLE SIZE AREA

$eneff_2 = 4.\log_{10}[C_{4A}.mass_2] - 15$

$eneff_2$ = 5.07199

C) LARGE RELEASE HOLE SIZE AREA

$eneff_3 = 4.\log_{10}[C_{4A}.mass_3] - 15$

$eneff_3$ = 6.68941

D) RUPTURE RELEASE HOLE SIZE AREA

$eneff_4 = 4.\log_{10}[C_{4A}.mass_4] - 15$

$eneff_4$ = 10.0435

STEP 8.3 Determine the fluid type

Determine the fluid type, either TYPE 0 or TYPE 1 based on Table 4.1 of API RP 581 Part 3 of COF.

Table 4.1 – List of Representative Fluids Available for Level 1 Consequence Analysis

Representative Fluid	Fluid TYPE (see Section 4.1.5)	Examples of Applicable Materials
H_2	TYPE 0	Hydrogen
H_2S	TYPE 0	Hydrogen Sulfide
HF	TYPE 0	Hydrogen Fluoride
water	TYPE 0	Water
steam	TYPE 0	Steam
Acid	TYPE 0	Acid, Caustic

H_2S	=	TYPE 0		T	=	26.5	(°C)
MW	=	34.00	(kg/kg-mol)	T	=	79.7	(°F)
AIT	=	500	(°C)	T	=	299.65	(K)
AIT	=	773.15	(K)				

STEP 8.4 For each release hole size, calculate the component damage consequence areas for Auto-Ignition Not Likely, Continous Release (AINT-CONT), $CA^{AINL\text{-}CONT}$

1). Determine the appropriate constant a and b from the Table 4.8

Table 4.8M - Component Damage Flammable Consequence Equation Constants

Fluid	Continuous Release Constant								Instantaneous Release Constant							
	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	
	α	b	α	b	α	b	α	b	α	b	α	b	α	b	α	b
H_2S	6.6	1.00			38.1	0.89			22.6	0.63			53.72	0.61		

α = $\alpha_{cmd,n}^{AINL-CONT}$ = 6.6 b = $b_{cmd}^{AINL-CONT}$ = 1.00

2). Calculate the consequence of area using equation below

$Rate_1$ = 0.0012 kg/s
$Rate_2$ = 0.0197 kg/s
$Rate_3$ = 0.3151 kg/s
$Rate_4$ = 5.0409 kg/s

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

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{cmd,1}^{AINL-CONT} = \alpha(rate_1)^b \cdot (1 - fact_{mit})$$

= 0.00766 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{cmd,2}^{AINL-CONT} = \alpha(rate_2)^b \cdot (1 - fact_{mit})$$

= 0.12263 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{cmd,3}^{AINL-CONT} = \alpha(rate_3)^b \cdot (1 - fact_{mit})$$

= 1.96213 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{cmd,4}^{AINL-CONT} = \alpha(rate_4)^b \cdot (1 - fact_{mit})$$

= 31.3863 m^2

STEP 8.5 For ech release hole size, calculate the component damage consequence areas for Auto-Ignition Likely, Continous Release (AIL-CONT), $CA^{AIL\text{-}CONT}$

1). Determine the appropriate constant a and b from the Table 4.8

α = $\alpha_{cmd,n}^{AIL-CONT}$ = 38.1 b = $b_{cmd}^{AIL-CONT}$ = 0.89

2). Calculate the consequence of area using equation below

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

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{cmd,1}^{AINL-CONT} = \alpha(rate_1)^b \cdot (1 - fact_{mit})$$

= 0.09311 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{cmd,2}^{AINL-CONT} = \alpha(rate_2)^b \cdot (1 - fact_{mit})$$

= 1.0984 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{cmd,3}^{AINL-CONT} = \alpha(rate_3)^b \cdot (1 - fact_{mit})$$

= 12.9546 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$CA_{cmd,4}^{AINL-CONT} = \alpha(rate_4)^b \cdot (1 - fact_{mit})$

= 152.755 m^2

STEP 8.6 For each release hole size, calculate the component damage consequence areas for Auto-ignition Not Likely, Instaneous Release, (AINL-INST), $CA^{AINL-INST}$

1). Determine the appropriate constant a and b from the Table 4.8

α = $\alpha_{cmd,n}^{AINL-INST}$ = 22.6 b = $b_{cmd}^{AINL-INST}$ = 0.63

2). Calculate the consequence of area using equation below

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

From step 7, known that:

Mass1	=	4.43049729 kgs	Mass3	=	119.934457 kgs
Mass2	=	47.270361 kgs	Mass4	=	826.913900 kgs

A) SMALL RELEASE HOLE SIZE AREA

$CA_{cmd,1}^{AINL-INST} = \alpha(mass_1)^b \cdot \left(\frac{1-fact_{mit}}{eneff_1}\right)$

= 57.2339 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{cmd,2}^{AINL-INST} = \alpha(mass_2)^b \cdot \left(\frac{1-fact_{mit}}{eneff_2}\right)$

= 48.1084 m^2

C) LARGE RELEASE HOLE SIZE AREA

$CA_{cmd,3}^{AINL-INST} = \alpha(mass_3)^b \cdot \left(\frac{1-fact_{mit}}{eneff_3}\right)$

= 65.5775 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$CA_{cmd,4}^{AINL-INST} = \alpha(mass_4)^b \cdot \left(\frac{1-fact_{mit}}{eneff_4}\right)$

= 147.409 m^2

STEP 8.7 For ech release hole size, calculate the component damage consequence areas for Auto-Ignition Likely, Instataneous Release (AIL-INST), $CA^{AIL-INST}$

1). Determine the appropriate constant a and b from the Table 4.8

α = $\alpha_{cmd,n}^{AIL-INST}$ = 53.7 b = $b_{cmd}^{AIL-INST}$ = 0.61

2). Calculate the consequence of area using equation below

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

From step 7, known that:

Mass1	=	4.43049729 kgs	Mass3	=	119.934457 kgs
Mass2	=	47.2703609 kgs	Mass4	=	826.91390 kgs

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{cmd,1}^{AINL-INST} = \alpha(mass_1)^b \cdot \left(\frac{1-fact_{mit}}{eneff_1}\right)$$

= 131.879 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{cmd,2}^{AINL-INST} = \alpha(mass_2)^b \cdot \left(\frac{1-fact_{mit}}{eneff_2}\right)$$

= 105.726 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{cmd,3}^{AINL-INST} = \alpha(mass_3)^b \cdot \left(\frac{1-fact_{mit}}{eneff_3}\right)$$

= 141.458 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{cmd,4}^{AINL-INST} = \alpha(mass_4)^b \cdot \left(\frac{1-fact_{mit}}{eneff_4}\right)$$

= 305.933 m^2

STEP 8.8 For each release hole size, calculate the personnel injury consequence areas for Auto-ignition Not Likely, Continous Release (AINL-CONT), $CA_{inj,n}^{AINL-CONT}$

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phas as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

Table 4.9M - Personnel Injury Flammable Consequence Equation Constants

Fluid	Continuous Release Constant								Instantaneous Release Constant							
	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	
	α	b	α	b	α	b	α	b	α	b	α	b	α	b	α	b
H_2S	10.7	1.00			73	0.94			41.4	0.63			191.5	0.63		

α = $\alpha_{inj,n}^{AINL-CONT}$ = 10.7   b = $b_{inj,n}^{AINL-CONT}$ = 1.00

2). Calculate the consequence of area using equation below

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

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AINL-CONT} = \left[\alpha.\left(rate_1^{AINL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 0.01245 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AINL-CONT} = \left[\alpha.\left(rate_2^{AINL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 0.19927 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AINL-CONT} = \left[\alpha.\left(rate_3^{AINL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 3.18839 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AINL-CONT} = \left[\alpha.\left(rate_4^{AINL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 51.0015 m^2

STEP 8.9 For each release hole size, calculate the personnel injury consequence areas for Auto-ignition Likely, Continous Release (AIL-CONT), $CA_{inj,n}^{AIL-CONT}$

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phasE as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

α	=	$\alpha_{inj,n}^{AIL-CONT}$	=	73.3	b	=	$b_{inj,n}^{AIL-CONT}$	=	0.94

2). Calculate the consequence of area using equation below

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

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AIL-CONT} = \left[\alpha.\left(rate_1^{AIL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 0.12802 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AIL-CONT} = \left[\alpha.\left(rate_2^{AIL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 1.73479 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AIL-CONT} = \left[\alpha.\left(rate_3^{AIL-CONT}\right)^b\right].(1 - fact_{mit})$$

= 23.5028 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AIL-CONT} = \left[\alpha.\left(rate_4^{AIL-CONT}\right)^b\right].(1 - fact_{mit})$$

$$= \quad 318.34 \ m^2$$

STEP 8.10 For each release hole size, calculate the personnel injury consequence areas for Auto-ignition Not Likely, Instataneous Release (AINL-INST), $CA_{inj,n}^{AINL-INST}$

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phase as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

α = $\alpha_{inj,n}^{AINL-INST}$ = 41.4 b = $b_{inj,n}^{AINL-INST}$ = 0.63

2). Calculate the consequence of area using equation below

$$CA_{inj,n}^{AINL-INST} = [\alpha.(mass_n^{AINL-INST})^b].\left(\frac{1 - fact_{mit}}{eneff_n}\right)$$ (equation 24)

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AINL-INST} = \left[\alpha.\left(mass_1^{AINL-INST}\right)^b\right].\left(\frac{1 - fact_{mit}}{eneff_1}\right)$$

$$= \quad 104.781 \ m^2$$

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AINL-INST} = \left[\alpha.\left(mass_2^{AINL-INST}\right)^b\right].\left(\frac{1 - fact_{mit}}{eneff_2}\right)$$

$$= \quad 88.0747 \ m^2$$

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AINL-INST} = \left[\alpha.\left(mass_3^{AINL-INST}\right)^b\right].\left(\frac{1 - fact_{mit}}{eneff_3}\right)$$

$$= \quad 120.056 \ m^2$$

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AINL-INST} = \left[\alpha.\left(mass_4^{AINL-INST}\right)^b\right].\left(\frac{1 - fact_{mit}}{eneff_4}\right)$$

$$= \quad 269.87 \ m^2$$

STEP 8.11 For each release hole size, calculate the personnel injury consequence areas for Auto-ignition Likely, Instataneous Release (AIL-INST), $CA_{inj,n}^{AIL-INST}$

1). Determine the appropriate constant a and b from the Table 4.9 from API RP 581 Part 3. The release phas as determined in STEP 1.4 willl be needed to assure selection of the correct constant.

α = $\alpha_{inj,n}^{AIL-INST}$ = 191.5 b = $b_{inj,n}^{AIL-INST}$ = 0.63

2). Calculate the consequence of area using equation below

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

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{AIL-INST} = \left[\alpha.\left(mass_1^{AIL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_1}\right)$$

= 484.326 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{AIL-INST} = \left[\alpha.\left(mass_2^{AIL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_2}\right)$$

= 407.104 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{AIL-INST} = \left[\alpha.\left(mass_3^{AIL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_3}\right)$$

= 554.931 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{AIL-INST} = \left[\alpha.\left(mass_4^{AIL-INST}\right)^b\right].\left(\frac{1-fact_{mit}}{eneff_4}\right)$$

= 1247.41 m^2

STEP 8.12 For each release hole size, calculate the instataneous/continous blending factor, $fact_n^{IC}$.

1). FOR CONTINOUS RELEASE

C_5 = 25.2 kg/s

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

A) SMALL RELEASE HOLE SIZE AREA

$$fact_1^{IC} = \min\left[\left\{\frac{rate_1}{C_5}\right\}, 1.0\right]$$

= 4.88371E-05

B) MEDIUM RELEASE HOLE SIZE AREA

$$fact_2^{IC} = \min\left[\left\{\frac{rate_2}{C_5}\right\}, 1.0\right]$$

= 0.000781587

C) LARGE RELEASE HOLE SIZE AREA

$$fact_3^{IC} = \min\left[\left\{\frac{rate_3}{C_5}\right\}, 1.0\right]$$

= 0.012505386

D) **RUPTURE RELEASE HOLE SIZE AREA**

$$fact_4^{IC} = \min\left[\left\{\frac{rate_3}{C_5}\right\}, 1.0\right]$$

= 0.200036562

2). FOR INSTATANEOUS RELEASE

$fact_n^{IC} =$ 1

STEP 8.13 Calculate the AIT blending factor, $fact^{AIT}$, using these optional equation below.

$fact^{AIT}$	=	0	for, $T_S + C_6 \le AIT$
$fact^{AIT}$	=	$\frac{(T_s - AIT + C_6)}{2 \,.\, C_6}$	for, $T_S + C_6 > AIT > T_S - C_6$
$fact^{AIT}$	=	1	for, $T_S - C_6 \ge AIT$

Ts	=	26.5	(^oC)	AIT	=	500	(^oC)
Ts	=	79.7	(^oF)	AIT	=	773.15	(K)
Ts	=	299.65	(K)	C_6	=	55.6	(K)

$T_s + C_6$ = 355.25 (K)

$T_s - C_6$ = 244.05 (K)

$\frac{(T_s - AIT + C_6)}{2 \,.\, C_6}$ = 3.194694 (K)

So, $fact^{AIT}$ = 0

STEP 8.14 Calculate the continuous/instantaneous blended consequence area for the component using equation (3.53) through (3.56) based on the consequence areas calculated in previous steps $fact_n^{IC}$

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

A) SMALL RELEASE HOLE SIZE AREA

$CA_{cmd,1}^{AIL-INST}$ = 131.88 m^2

$fact_1^{IC}$ = 4.88E-05

$CA_{cmd,1}^{AIL-CONT}$ = 0.09 m^2

$CA_{cmd,1}^{AIL}$ = 0.099545974 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{cmd,2}^{AIL-INST}$ = 105.73 m^2

C) LARGE RELEASE HOLE

$CA_{cmd,3}^{AIL-INST}$ = 141.46 m^2

$fact_3^{IC}$ = #######

$CA_{cmd,3}^{AIL-CONT}$ = 12.95 m^2

$CA_{cmd,3}^{AIL}$ = 14.5616 m^2

D) RUPTURE RELEASE HOLE

$CA_{cmd,4}^{AIL-INST}$ = 305.93 m^2

$fact_2^{IC}$	=	0.000782		$fact_4^{IC}$	=	0.2000	
$CA_{cmd,2}^{AIL-CONT}$	=	1.10	m^2	$CA_{cmd,4}^{AIL-CONT}$	=	152.76	m^2
$CA_{cmd,2}^{AIL}$	=	1.180170634	m^2	$CA_{cmd,4}^{AIL}$	=	183.396	m^2

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

A) SMALL RELEASE HOLE SIZE AREA

$CA_{inj,1}^{AIL-INST}$	=	484.3258911	m^2
$fact_1^{IC}$	=	4.88E-05	
$CA_{inj,1}^{AIL-CONT}$	=	0.128018346	m^2
$CA_{inj,1}^{AIL}$	=	0.151665142	m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{inj,2}^{AIL-INST}$	=	407.1036622	m^2
$fact_2^{IC}$	=	0.0007816	
$CA_{inj,2}^{AIL-CONT}$	=	1.734787363	m^2
$CA_{inj,2}^{AIL}$	=	2.051618266	m^2

C) LARGE RELEASE HOLE

$CA_{inj,3}^{AIL-INST}$	=	554.931	m^2
$fact_3^{IC}$	=	0.01251	m^2
$CA_{inj,3}^{AIL-CONT}$	=	23.5028	m^2
$CA_{inj,3}^{AIL}$	=	30.1485	m^2

D) RUPTURE RELEASE HOLE

$CA_{inj,4}^{AIL-INST}$	=	1247.41	m^2
$fact_4^{IC}$	=	0.2000	m^2
$CA_{inj,4}^{AIL-CONT}$	=	318.34	m^2
$CA_{inj,4}^{AIL}$	=	504.187	m^2

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

A) SMALL RELEASE HOLE SIZE AREA

$CA_{cmd,n}^{AINL-INST}$	=	131.8790659	m^2
$fact_1^{IC}$	=	4.88E-05	
$CA_{cmd,1}^{AINL-CONT}$	=	0.007662668	m^2
$CA_{cmd,1}^{AINL}$	=	0.014102879	m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{cmd,n}^{AINL-INST}$	=	105.7256726	m^2
$fact_2^{IC}$	=	0.000782	

C) LARGE RELEASE HOLE

$CA_{cmd,n}^{AINL-INST}$	=	141.458	m^2
$fact_3^{IC}$	=	0.0125	
$CA_{cmd,3}^{AINL-CONT}$	=	1.96213	m^2
$CA_{cmd,3}^{AINL}$	=	3.70658	m^2

D) RUPTURE RELEASE HOLE

$CA_{cmd,4}^{AINL-INST}$	=	305.933	m^2
$fact_4^{IC}$	=	0.2000	

$CA_{cmd,2}^{AINL-CONT}$ = 0.122633103 m^2

$CA_{cmd,2}^{AINL}$ = 0.20517103 m^2

$CA_{cmd,4}^{AINL-CONT}$ = 31.3863 m^2

$CA_{cmd,4}^{AINL}$ = 86.3057 m^2

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

A) SMALL RELEASE HOLE SIZE AREA

$CA_{inj,n}^{AINL-INST}$ = 104.7813142 m^2

$fact_1^{IC}$ = 0.0000

$CA_{inj,1}^{AINL-CONT}$. = 0.012451543 m^2

$CA_{inj,1}^{AINL}$ = 0.017568146 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{inj,n}^{AINL-INST}$ = 88.07469831 m^2

$fact_2^{IC}$ = 0.000782

$CA_{inj,2}^{AINL-CONT}$. = 0.199274115 m^2

$CA_{inj,2}^{AINL}$ = 0.267956374 m^2

C) LARGE RELEASE HOLE

$CA_{inj,n}^{AINL-INST}$ = 120.056 m^2

$fact_3^{IC}$ = 0.0125

$CA_{inj,3}^{AINL-CONT}$.= 3.18839 m^2

$CA_{inj,3}^{AINL}$ = 4.64987 m^2

D) RUPTURE RELEASE HOLE

$CA_{inj,4}^{AINL-INST}$ = 269.87 m^2

$fact_4^{IC}$ = 0.2000

$CA_{inj,4}^{AINL-CONT}$.= 51.0015 m^2

$CA_{inj,4}^{AINL}$ = 94.7832 m^2

STEP 8.15 Calculate the AIT blended consequence areas for the component using equations (3.57) and (3.58) based on the consequence areas determined in step 8.14 and the AIT blending factors, $fact^{AIT}$, calculate in step 8.13. the resulting consequence areas are the component damage and personnel injury flammable consequence areas, $CA_{cmd,n}^{flam}$ and $CA_{inj,n}^{flam}$ for each release hole size selected in step 2.2

$$CA_{cmd,n}^{flam} = CA_{smd,n}^{AIL} . fact^{AIT} + CA_{cmd,n}^{AINL} . (1 - fact^{AIT})$$

A) SMALL RELEASE HOLE SIZE AREA

$CA_{cmd,1}^{AIL}$ = 0.09954597 m^2

$fact^{AIT}$ = 0

$CA_{cmd,1}^{AINL}$ = 0.01410288 m^2

$CA_{cmd,1}^{flam}$ = 0.01410288 m^2

C) LARGE RELEASE HOLE

$CA_{cmd,3}^{AIL}$ = 14.56163 m^2

$fact^{AIT}$ = 0

$CA_{cmd,3}^{AINL}$ = 3.70658 m^2

$CA_{cmd,3}^{flam}$ = 3.70658 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

D) RUPTURE RELEASE HOLE

$CA_{cmd,2}^{AIL}$ = 1.18017063 m^2

$fact^{AIT}$ = 0

$CA_{cmd,2}^{AINL}$ = 0.20517103 m^2

$CA_{cmd,2}^{flam}$ = 0.20517103 m^2

$CA_{cmd,4}^{AIL}$ = 183.3964731 m^2

$fact^{AIT}$ = 0

$CA_{cmd,4}^{AINL}$ = 86.30567401 m^2

$CA_{cmd,4}^{flam}$ = 86.30567401 m^2

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

A) SMALL RELEASE HOLE SIZE AREA

$CA_{inj,1}^{flam-AIL}$ = 0.15166514 m^2

$fact^{AIT}$ = 0

$CA_{inj,1}^{AINL}$ = 0.01756815 m^2

$CA_{inj,1}^{flam}$ = 0.01756815 m2

B) MEDIUM RELEASE HOLE SIZE AREA

$CA_{inj,2}^{flam-AIL}$ = 2.05161827 m^2

$fact^{AIT}$ = 0

$CA_{inj,2}^{AINL}$ = 0.26795637 m^2

$CA_{inj,2}^{flam}$ = 0.26795637 m2

C) LARGE RELEASE HOLE

$CA_{inj,3}^{flam-AIL}$ = 30.14848877 m^2

$fact^{AIT}$ = 0

$CA_{inj,3}^{AINL}$ = 4.649865845 m^2

CA_{inj3}^{flam} = 4.649865845 m^2

D) RUPTURE RELEASE HOLE

$CA_{inj,4}^{flam-AIL}$ = 504.187082 m^2

$fact^{AIT}$ = 0

$CA_{inj,4}^{AINL}$ = 94.78320583 m^2

$CA_{inj,4}^{flam}$ = 94.78320583 m^2

STEP 8.16 Determine the consequence areas (probability weighted on release hole size) for component damage and personnel injury using equations (3.59) and (3.60) based on the consequence ara from step 8.15

Equipment Type	Component Type	gff as a function of hole size (failure/yr)				gff total (failure/yr)
		Small	Medium	Large	Rupture	
Vessel/ FinFan	KODRUM	8.0E-06	2.00E-05	2.00E-06	6.00E-07	3.06E-05
	COLBTM					
	FINFAN					
	FILTER					
	DRUM					
	REACTOR					
	COLTOP					
	COLMID					

CONSEQUENCE AREA FOR COMPONENT DAMAGE

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

$$CA_{cmd}^{flam} = \left(\frac{(gff_{1} \cdot CA_{cmd,1}^{flam}) + (gff_{2} \cdot CA_{cmd,2}^{flam}) + (gff_{3} \cdot CA_{cmd,3}^{flam}) + (gff_{4} \cdot CA_{cmd,4}^{flam})}{gff_{total}} \right)$$

= 2.07 m^2

CONSEQUENCE AREA FOR PERSONNEL INJURY

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

$$CA_{inj}^{flam} = \left(\frac{\left(gff_1 \cdot CA_{inj,1}^{flam}\right) + \left(gff_2 \cdot CA_{inj,2}^{flam}\right) + \left(gff_3 \cdot CA_{inj,3}^{flam}\right) + \left(gff_4 \cdot CA_{inj,4}^{flam}\right)}{gff_{total}} \right)$$

= 2.342 m^2

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PART 9 : CALCULATE THE TOXIC CONSEQUENCES AREA

STEP 9.1 For each release hole size selected in STEP 2.2, calculate the effective duration of the toxic release using this equation below.

$$ld_n^{tox} = \min\left(3600\,,\left\{\frac{mass_n}{W_n}\right\},\left\{60.\,ld_{max,n}\right\}\right)$$

W_{n1}	=	0.00123069	kg/s	$Mass_1$	=	4.430497	kgs
W_{n2}	=	0.01969598	kg/s	$Mass_2$	=	47.27036	kgs
W_{n3}	=	0.31513574	kg/s	$Mass_3$	=	119.93446	kgs
W_{n4}	=	5.04092137	kg/s	$Mass_4$	=	826.91390	kgs

$ld_{max,1}$ = 1 hour for 1/4 inch leaks
$ld_{max,2}$ = 40 minutes for 1 inch leaks
$ld_{max,3}$ = 20 minutes for 4 inch leaks
$ld_{max,4}$ = 20 minutes for 4 inch leaks

A). SMALL RELEASE HOLE SIZE AREA

$$ld_1^{tox} = \min\left(3600\,,\left\{\frac{mass_1}{W_1}\right\},\left\{60.\,ld_{max,1}\right\}\right)$$

= 3600 s

B). MEDIUM RELEASE HOLE SIZE AREA

$$ld_2^{tox} = \min\left(3000\,,\left\{\frac{mass_2}{W_2}\right\},\left\{60.\,ld_{max,2}\right\}\right)$$

= 2400 s

C). LARGE RELEASE HOLE SIZE AREA

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

= 380.58 s

D). RUPTURE RELEASE HOLE SIZE AREA

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

= 164.04 s

STEP 9.2 Determine the toxic percentage of the toxic component, $mfrac^{tox}$, in the release material. The release fluid is a pure fluid, $mfrac^{tox}$ = 1.0. note that if there is more than one toxic component in the release fluid mixture, this procedure can be repeated for each toxic component

H_2S	=	0.74%	NH_3	=	0.037%
$mfrac^{tox}$	=	0.0074	$mfrac^{tox}$	=	0.0003704

STEP 9.3 For each release hole size, calculate the release the release rate, $rate_n^{tox}$, and release mass, $mass_n^{tox}$,to be used in the toxic analysis

$$rate_n^{tox} = mfrac^{tox}.W_n$$

$$mass_n^{tox} = mfrac^{tox}.mass_n$$

For H_2S

A) SMALL RELEASE HOLE SIZE AREA

$rate_1^{tox} = mfrac^{tox}.W_1$ = 9.09E-06 kg/s

$mass_1^{tox} = mfrac^{tox}.mass_1$ = 0.03270682 kgs

B) MEDIUM RELEASE HOLE SIZE AREA

$rate_2^{tox} = mfrac^{tox}.W_2$ = 1.45E-04 kg/s

$mass_2^{tox} = mfrac^{tox}.mass_2$ = 0.34895926 kgs

C) LARGE RELEASE HOLE SIZE AREA

$rate_3^{tox} = mfrac^{tox}.W_3$ = 2.33E-03 kg/s

$mass_3^{tox} = mfrac^{tox}.mass_3$ = 0.88538015 kgs

D) RUPTURE RELEASE HOLE SIZE AREA

$rate_4^{tox} = mfrac^{tox}.W_4$ = 3.72E-02 kg/s

$mass_4^{tox} = mfrac^{tox}.mass_4$ = 6.1044438 kgs

For NH_3

A) SMALL RELEASE HOLE SIZE AREA

$rate_1^{tox} = mfrac^{tox}.W_1$ = 4.56E-07 kg/s

$mass_1^{tox} = mfrac^{tox}.mass_1$ = 0.00164106 kgs

B) MEDIUM RELEASE HOLE SIZE AREA

$rate_2^{tox} = mfrac^{tox}.W_2$ = 7.30E-06 kg/s

$mass_2^{tox} = mfrac^{tox}.mass_2$ = 0.01750894 kgs

C) LARGE RELEASE HOLE SIZE AREA

$rate_3^{tox} = mfrac^{tox}.W_3$ = 1.17E-04 kg/s

$mass_3^{tox} = mfrac^{tox}.mass_3$ = 0.04442372 kgs

D) RUPTURE RELEASE HOLE SIZE AREA

$rate_4^{tox} = mfrac^{tox}.W_4$ = 1.87E-03 kg/s

$mass_4^{tox} = mfrac^{tox}.mass_4$ = 0.30628891 kgs

STEP 9.4 For each release hole size, calculate the toxic consequence area for each of the release hole size.

1) Calculate $CA_{inj,n}^{toxCONT}$ for HF acid and H_2S , using equation 41 for continous release or equation 42 for instantaneous releasing Table 4.11

Continous Release Duration (minutes)	HF Acid		H_2S	
	c	d	c	d
5	1.1401	3.5683	1.2411	3.9686
10	1.1031	3.8431	1.241	4.0948
20	1.0816	4.104	1.237	4.238
40	1.0942	4.3295	1.2297	4.3626
60	1.4056	4.4576	1.2266	4.4365
Instantaneous	1.4056	33606	0.9674	2.784

For continous release (equation 40) or instantaneous release (equation 41):

$$CA_{inj,n}^{toxCONT} = C_8.10^{(c.log_{10}[C_{4B}.rate_n^{tox}]+d)}$$

$$CA_{inj,n}^{toxINST} = C_8.10^{(c.log_{10}[C_{4B}.mass_n^{tox}]+d)}$$

C_8 = 0.0929 m^2.sec C_{4B} = 2.25 sec/kg

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{toxCONT} = C_8.10^{(c.log_{10}[C_{4B}.rate_1^{tox}]+d)}$$

$CA_{inj,1}^{toxCONT}$ = 0.00449 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{toxCONT} = C_8.10^{(c.log_{10}[C_{4B}.rate_2^{tox}]+d)}$$

$CA_{inj,2}^{toxCONT}$ = 0.111 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{toxCONT} = C_8.10^{(c.log_{10}[C_{4B}.rate_3^{tox}]+d)}$$

$CA_{inj,3}^{toxCONT}$ = 2.42 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{toxCONT} = C_8.10^{(c.log_{10}[C_{4B}.rate_4^{tox}]+d)}$$

$CA_{inj,4}^{toxCONT}$ = 74.75 m^2

2) Calculate $CA_{inj,n}^{toxCONT}$ for Ammonia and Chlorine, using equation 42 for continous release or equation 43 for instantaneous releasing Table 4.12M

Continous Release Duration (minutes)	Ammonia		Chlorine	
	e	f	e	f
20	1256	1.178	4191	1.089
40	2029	1.169	6860	1.072
60	2714	1.145	10994	1.026
Instantaneous	2.684	0.9011	3.528	1.177

For continous release (equation 42) or instantaneous release (equation 43):

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

$$CA_{inj,n}^{toxINST} = e(Mass_n^{tox})^f$$

A) SMALL RELEASE HOLE SIZE AREA

$$CA_{inj,1}^{toxCONT} = e(Rate_1^{tox})^f$$

$CA_{inj,1}^{toxCONT}$ = 0.00014892 m^2

B) MEDIUM RELEASE HOLE SIZE AREA

$$CA_{inj,2}^{toxCONT} = e(Rate_2^{tox})^f$$

$CA_{inj,2}^{toxCONT}$ = 0.00200533 m^2

C) LARGE RELEASE HOLE SIZE AREA

$$CA_{inj,3}^{toxCONT} = e(Rate_3^{tox})^f$$

$CA_{inj,3}^{toxCONT}$ = 0.02924922 m^2

D) RUPTURE RELEASE HOLE SIZE AREA

$$CA_{inj,4}^{toxCONT} = e(Rate_4^{tox})^f$$

$CA_{inj,4}^{toxCONT}$ = 0.7663740 m^2

STEP 9.5 If there are additional toxic component in the released fluid mixture, the STEP 9.2 througt 9.4 should be repeated for each toxic component.

There are no additional toxic components.

STEP 9.6 Determine the final toxic consequence areas for personnel injury in accordance with equation 44.

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

Equipment Type	Component Type	gff as a function of hole size (failure/yr)				gff total (failure/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

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

$$CA_{inj}^{tox} = \left(\frac{\left(gff_1 \ . CA_{inj,1}^{tox}\right) + \left(gff_2 \ . CA_{inj,2}^{tox}\right) + \left(gff_3 \ . CA_{inj,3}^{tox}\right) + \left(gff_4 \ . CA_{inj,4}^{tox}\right)}{gff_{total}} \right)$$

= 1.72 m^2

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PART 10 : CALCULATE THE NON-FLAMMABLE, NON-TOXIC CA

Step 10.1 For each release hole size, calculate the non-flammable , non-toxic consequence

1). FOR STEAM

Steam represents a hazard to personnel who are exposed to it at high temperatures. In general, steam is at 100°C (212°F) immediately after exiting a hole in an equipment item. Within a few feet, the steam will begin to mix with air cool, and condensed. The approach used here is that injury occurs above 60°C (140°F). In this case of Steam ejector, the temperatur inside the presssure vessel is working around 26.5°C. So, in this case step 10 can be skipped.

2). FOR ACIDS AND CAUSTIC

No acid or caustic, thus value are 0.

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PART 11 : CALCULATION OF FINAL CONSEQUENCE AREA

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, $CAcmd^{flam}$.

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

$$= 2.07 \ m^2$$

Step 11.2 Calculate the final personnel injury consequence area, CA_{inj}

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

$$CA_{inj}^{flam} = 2.3421349 \ m^2$$

$$CA_{inj}^{tox} = 1.715956 \ m^2$$

$$CA_{inj}^{nfnt} = 0 \ m^2$$

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

$$= 2.342135 \ m^2$$

Step 11.3 Calculate the final consequence area, CA, using equation below:

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

$$= 2.342135 \ m^2$$

$$= 25.21053 \ ft^2$$

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BIODATA PENULIS

Penulis lahir di Jambi pada tanggal 5 Agustus 1997 dengan nama Pradnya Sasmitha Andaka dan merupakan anak pertama dari 2 bersaudara pasangan (adik beliau meninggal diusia belia). Penulis pindah ke Kota Cimahi pada usia 1 tahun dan menempuh pendidikan 9 tahun di kota tersebut. Mulai dari SDN Mandiri 5 Cimahi, Kota Cimahi (2003-2009), SMPN 3 Cimahi (2010-2012), dan SMA Negeri 2 Cimahi (2013-2015). Setelah lulus dari bangku SMA, penulis memutuskan untuk kuliah di luar kota dan diterima di Departemen Teknik Sistem Perkapalan, Fakultas Teknologi Kelautam, Institut Teknologi Sepuluh Nopember melalui jalur Seleksi Bersama Masuk Perguruan Tinggi Negeri (SBMPTN). Selama menempuh masa studi penulis aktif di kepanitiaan kegiatan jurusan dan institut. Diantaranya menjadi wakil kepala biro kajian strategis HIMASISKAL FTK-ITS, staff mahkamah mahasiswa ITS. Selama berkutat di lingkup kajian strategis, penulis pernah mengkaji kebijakan impor garam Indonesia. Selama masa perkuliahan, penulis melaksanakan kerja praktik di PT. Janata Marina Indah, Semarang dan PT. Pertamina Shipping, Jakarta.

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