SKRIPSI – ME184834

PENENTUAN *MAINTENANCE TASK* PADA *MARINE BOILER* KAPAL TANKER DENGAN METODE *RELIABILITY CENTERED MAINTENANCE* (RCM) II

Bagas Somporn Supriadi Putra
NRP 04211746000010

Dosen Pembimbing
Ir. Dwi Priyanta, M.SE
Dr. Eng. Muhammad Badrus Zaman, S.T, M.T

DEPARTEMEN TEKNIK SISTEM PERKAPALAN
FAKULTAS TEKNOLOGI KELAUTAN
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
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2020

BACHELOR THESIS – ME184834

DETERMINATION OF MAINTENANCE TASK ON TANKER VESSEL'S MARINE BOILER USING RELIABILITY CENTERED MAINTENANCE (RCM) II METHOD

Bagas Somporn Supriadi Putra
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Supervisors
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DEPARTMENT OF MARINE ENGINEERING
FACULTY OF MARINE TECHNONOLGY
SEPULUH NOPEMBER INSTITUTE OF TECHNOLOGY (ITS)
SURABAYA
2020

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PERNYATAAN BEBAS PLAGIARISME

Saya yang bertanda tangan di bawah ini:

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Program Studi	: S1 Teknik Sistem Perkapalan
Departemen	: Teknik Sistem Perkapalan
Fakultas	: Teknologi Kelautan
Perguruan Tinggi	: Institut Teknologi Sepuluh Nopember

Dengan ini menyatakan bahwa Tugas Akhir dengan judul "Penentuan *Maintenance Task* pada *Marine Boiler* Kapal Tanker dengan Metode *Reliability Centered Maintenance* (RCM) II" adalah benar karya sendiri dan bukan plagiat dari karya orang lain. Apabila di kemudian hari terbukti terdapat plagiat pada Tugas Akhir ini, maka saya bersedia menerima sanksi sesuai dengan ketentuan yang berlaku.

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Surabaya, 27 Januari 2020
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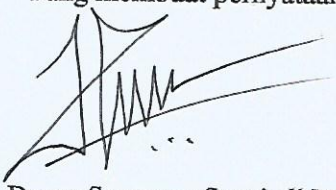

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LEMBAR PENGESAHAN

PENENTUAN *MAINTENANCE TASK* PADA *MARINE BOILER* KAPAL TANKER DENGAN METODE *RELIABILITY CENTERED MAINTENANCE* (RCM) II

TUGAS AKHIR
Diajukan Untuk Memenuhi Salah Satu Syarat
Memperoleh Gelar Sarjana Teknik
pada
Bidang Studi *Marine Operation and Maintenance* (MOM)
Program Studi S-1 Departemen Teknik Sistem Perkapalan
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LEMBAR PENGESAHAN

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Penentuan *Maintenance Task* pada *Marine Boiler* Kapal Tanker dengan Metode *Reliability Centered Maintenance* (RCM) II

Nama Mahasiswa	**: Bagas Somporn Supriadi Putra**
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Dosen Pembimbing 1	**: Ir. Dwi Priyanta, M.SE**
Dosen Pembimbing 2	**: Dr. Eng. M. Badrus Zaman, S.T, M.T**

ABSTRAK

Terdapat 3 jenis utama kecelakaan kapal tanker yaitu tabrakan (*collision*), kebakaran (*fire*) dan kandas (*grounding*). Pada salah satu jenis kecelakaan kapal yakni kebakaran, terdapat 5 penyebab utama dimana presentase terbesar yakni kebocoran minyak menjadi penyebab utama kebakaran di kapal tanker. Namun terdapat penyebab utama kecelakaan kapal yang lain yaitu ledakan pada *marine boiler* dan kerusakan pada komponen-komponen kapal. Selain faktor operasional, faktor *maintenance* (perawatan) juga menjadi penyebab kecelakaan tersebut. Berdasarkan hal tersebut, maka diperlukan pertimbangan untuk meningkatkan faktor keselamatan (*safety*) terhadap *marine boiler* selain dari sisi operasional, namun juga pengembangan dari sisi *maintenance* dengan pendekatan *Reliability Centered Maintenane* (RCM). Tujuan penelitian ini adalah untuk menentukan *maintenance task* yang sesuai terhadap sistem perawatan *marine boiler* di kapal tanker menggunakan metode RCM II serta dapat mengetahui karakteristik kegagalan aset sehingga dapat membantu dalam *assessment* level resiko terhadap operasional aset. Berdasarkan hasil analisa RCM dapat diketahui bahwa terdapat 128 kegiatan maintenance (*maintenance task*) yang terdiri dari 3 jenis kegiatan yaitu *condition monitoring* (CM), *planned maintenance* (PM) dan *One-Time Change* (OTC). Untuk *failure mode* yang memiliki *high risk* dilakukan *preventive maintenance* dengan interval setiap 1 hingga 7 hari sekali. Untuk interval *preventive maintenance* paling lama dilakukan pada *safety valve* yakni dengan interval inspeksi setiap 2 tahun sekali.

Kata Kunci: Kecelakaan Kapal, *Maintenance*, *Marine Boiler* dan RCM

Determination of Maintenance Task on Tanker Vessel's Marine Boiler using Reliability Centered Maintenance* (RCM) II *Method

Name of Student **: Bagas Somporn Supriadi Putra**
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ABSTRACT

There are 3 main types of tanker accidents, namely collision, fire and grounding. In one type of ship accident namely fire, there are 5 main causes where the largest percentage of the main cause of fire in tankers is oil leak. But there are other major causes of ship accidents, namely explosions on marine boilers and damage to ship components. In addition to operational factors, maintenance factors are also the major cause of the accident. Based on this, consideration is needed to improve the safety factor of the marine boiler in addition to the operational side, but also the development of the maintenance side with the Reliability Centered Maintenanceane (RCM) approach. The purpose of this study is to determine the appropriate maintenance task of marine boiler maintenance systems on tankers using the RCM II method and to determine the characteristics of asset failure so as to assist in assessing the level of risk to asset operations. Based on the results of the RCM analysis, it can be seen that there are 128 maintenance tasks consisting of 3 types of activities namely condition monitoring (CM), planned maintenance (PM) and One-Time Change (OTC). For failure modes that have high risk, preventive maintenance is performed at intervals every 1 to 7 days. For the longest preventive maintenance intervals carried out on the safety valve that is the inspection interval every 2 years.

Keywords: *Maintenance, Marine Boiler,* RCM *and Ship Accident*

KATA PENGANTAR

Puji syukur ke hadirat Allah *Azza Wa Jalla* yang telah memberikan rahmat serta hidayah-Nya sehingga penulis dapat menyelesaikan laporan tugas akhir (skripsi) yang berjudul "Penentuan *Maintenance Task* pada *Marine Boiler* Kapal Tanker dengan Metode *Reliability Centered Maintenance* (RCM) II" dengan baik.

Penulis menyadari bahwa laporan tugas akhir ini tidak akan terwujud tanpa kuasa dan ridho dari Allah *Ta'ala* serta bantuan dari berbagai pihak. Tidak dikatakan bersyukur kepada Allah bagi siapa yang tidak tahu berterima kasih pada manusia. Oleh karena itu, pada kesempatan ini penulis ingin menyampaikan ucapan terima kasih yang sebesar-besarnya kepada:

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7. Teman-teman mahasiswa jurusan Teknik Sistem Perkapalan ITS dan pihak-pihak lain yang tidak dapat penulis sebutkan namanya satu per satu yang telah memberikan dukungan semangat dan bantuannya baik teknis maupun non teknis dalam penyusunan laporan tugas akhir ini.

Penulis menyadari bahwa laporan tugas akhir ini masih jauh dari kata sempurna. Oleh karena itu, penulis sangat berharap segala bentuk saran dan kritik yang konstruktif guna penyempurnaan laporan tugas akhir ini. Akhirnya penulis berharap semoga laporan tugas akhir ini dapat bermanfaat bagi banyak pihak-pihak yang membutuhkan, baik sebagai referensi kegiatan penelitian maupun pengembangan ilmu pengetahuan di masa yang akan datang.

Surabaya, 20 Januari 2020

Penulis

DAFTAR ISI

DAFTAR TABEL

DAFTAR GAMBAR

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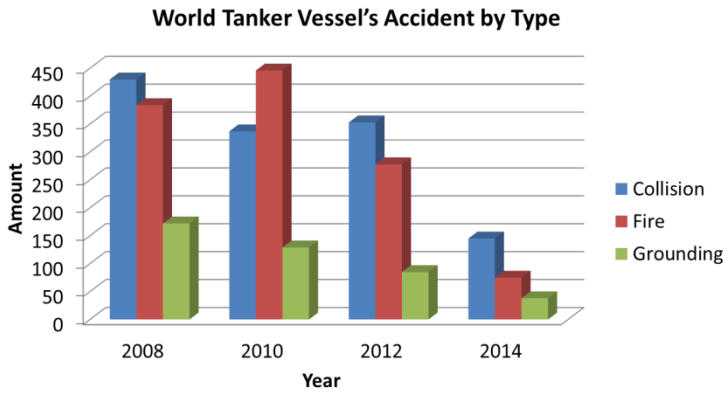
BAB I
PENDAHULUAN

Pada bab pendahuluan ini akan diberikan penjelasan mengenai latar belakang, perumusan masalah, batasan masalah, tujuan, dan manfaat dalam penelitian ini.

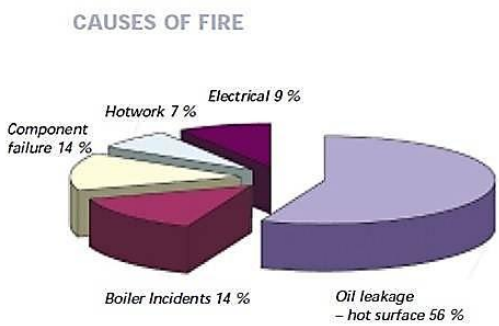
1.1 Latar Belakang

Salah satu jenis kapal yang banyak digunakan dalam sistem transportasi laut adalah kapal tanker. Sebagaimana jenis kapal yang lain, kapal tanker merupakan salah satu kapal yang memiliki resiko tinggi dalam pengoperasiannya terkait dengan masalah muatan yang dapat berdampak pada keselamatan baik bagi manusia maupun lingkungan laut di sekitarnya. Meski teknologi sudah semakin berkembang pesat dan *awareness* (kesadaran) akan pentingnya keselamatan (*safety first*) sudah semakin meningkat, namun kecelakaan kapal tanker tetap saja terjadi setiap tahunnya. Data yang dihimpun dari World Maritime News mulai dari tahun 2008 hingga tahun 2014 menunjukkan bahwa terdapat 3 jenis utama kecelakaan kapal tanker di dunia yakni tabrakan (*collision*), kebakaran (*fire*) dan kandas (*grounding*). (World Maritime News, 2017)



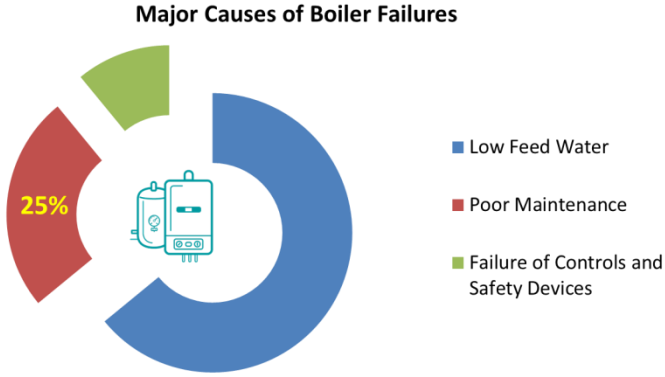
Gambar 1. 1 Jenis Utama Kecelakaan Kapal Tanker di Dunia
(World Maritime News, 2017)

Pada salah satu jenis kecelakaan yakni kebakaran, terdapat 5 penyebab utama (Officer of the Watch, 2013) yaitu kebocoran pada minyak baik muatan atau bahan bakar, ledakan pada *marine boiler*, kerusakan pada komponen-komponen kapal, masalah kelistrikan dan adanya pekerjaan yang menyebabkan panas seperti pengelasan. Presentase terbesar yakni kebocoran minyak tidak bisa dipungkiri sering menjadi penyebab utama kebakaran di kapal tanker. Namun, yang sering diabaikan adalah penyebab yang lain yaitu ledakan pada *Marine Boiler* dan kerusakan pada komponen-komponen kapal. Selain faktor operasional, faktor *maintenance* (perawatan) juga turut berperan andil dalam penyebab kegagalan (*failure*) tersebut.



Gambar 1. 2 Penyebab Kecelakaan Kapal Tanker di Dunia
(Officer of the Watch, 2013)

Menurut data statistik yang dikeluarkan oleh salah satu perusahaan inspeksi *boiler* terkemuka di dunia, The Hartford Steam Boiler Inspection and Insurrance Company pada tahun 2011 terdapat 3 penyebab utama kegagalan *(failure*) pada *boiler* yakni air pengumpan (*boiler feed water*) yang seringkali di bawah level yang diizinkan (*low feed water*), perawatan yang kurang (*poor maintenance*) dan adanya kerusakan pada peralatan keamanan dan kontrol (*failure of controls and safety devices*). (The Hartford Steam Boiler Inspection and Insurrance Corporation, 2011)



Gambar 1. 3 Penyebab Kegagalan *Boiler* pada Kapal Tanker di Dunia
(The Hartford, 2011)

Berdasarkan fakta tersebut, maka diperlukan pertimbangan untuk meningkatkan faktor keselamatan (*safety*) dari *equipment* tersebut selain dari sisi operasional, namun juga dari sisi *maintenance* (perawatan). Beberapa metode *maintenance* yang sering digunakan pada *boiler* adalah metode *Risk Based Maintenance* (RBI) dan *Condition Based Maintenance* (CBM). (Mkandawire, Ijumba, & Whitehead, 2011) Namum, beberapa metode tersebut memiliki beberapa kekurangan terutama terkait dengan analisa sistem yang ada pada *boiler*. Oleh karena itu, dipilihlah metode lain yaitu *Reliability Centered Maintenance* (RCM) untuk menganalisa fungsi sistem dan kegagalan potensial dari suatu aset fisik. (Moubray, 1997)

1.2 Rumusan Permasalahan

Berdasarkan pada penjelasan latar belakang tersebut, maka permasalahan yang akan diselesaikan dalam penelitian ini adalah:

1. Bagaimana operasional dan perawataan *marine boiler* yang ada di kapal tanker M.T Bull Kalimantan?
2. Bagaimana karakteristik kegagalan pada *marine boiler* sehingga dapat membantu dalam *assessment* level resiko terhadap operasional *marine boiler* tersebut?
3. Bagaimana menentukan *maintenance task* yang sesuai terhadap *marine boiler* di kapal tanker tersebut menggunakan metode *Reliability Centered Maintenance* (RCM) II?

1.3 Batasan Masalah

Batasan yang diberikan dalam menyelesaikan penelitian ini adalah analisa RCM pada *marine boiler* di kapal tanker M.T Bull Kalimantan yang dioperasikan oleh PT. Gemilang Bina Lintas Tirta pada periode Januari - Agustus 2019. Metode yang digunakan adalah *Reliability-Centered Maintenance* (RCM) yang mengacu pada standar *American Bureau of Shipping* (ABS) – *Guide for Surveys Based on Machinery Reliability and Maintenance Techniques* 2016.

1.4 Tujuan Penelitian

Tujuan dilakukannya penelitian ini adalah sebagai berikut:

1. Dapat mengidentifikasi operasional dan perawataan *marine boiler* yang ada di kapal tanker M.T Bull Kalimantan.
2. Dapat mengetahui karakteristik kegagalan pada *marine boiler* sehingga dapat membantu dalam *assessment* level resiko terhadap operasional *marine boiler* tersebut.
3. Dapat menentukan *maintenance task* yang sesuai terhadap sistem *marine boiler* di kapal tanker menggunakan metode *Reliability Centered Maintenance* (RCM) II.

1.5 Manfaat Penelitian

Manfaat yang dapat diambil dengan dilakukannya penelitian ini adalah sebagai berikut:

1. Sebagai sarana bagi perusahaan pelayaran terutama operator kapal tanker dalam merencanakan dan mengevaluasi kegiatan perawatan (*maintenance*) *equipment* di kapal terutama *boiler* agar dapat berjalan dengan lebih tepat, efisien dan optimal dengan memperhatikan tingkat keselamatan (*safety*) sistem pada *marine boiler* tersebut.
2. Informasi yang tersimpan dalam *work package* dapat membantu staf/pekerja baru yang kurang memiliki pengalaman atau *skill* untuk menjalankan kegiatan perawatan (*maintenance*).

BAB II
TINJAUAN PUSTAKA

Pada bab tinjauan pustaka ini akan diberikan penjelasan mengenai hasil penelitian terdahulu yang relevan untuk digunakan sebagai referensi dalam penelitian ini serta menjabarkan berbagai teori-teori yang akan digunakan untuk menyelesaikan permasalahan dalam penelitian ini.

2.1 *Maintenance*

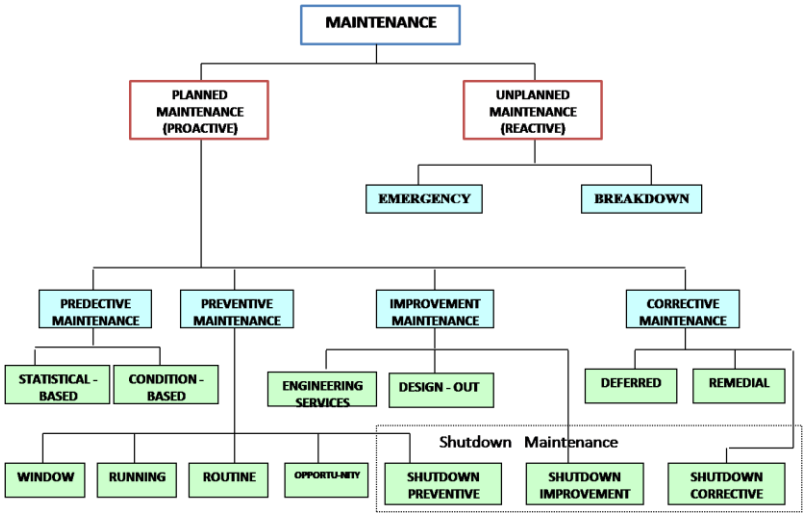
2.1.1 Definisi *Maintenance*

Kegiatan *maintenance* atau perawatan ditujukan untuk meyakinkan bahwa aset fisik yang dimiliki dapat terus berlanjut memenuhi apa yang diinginkan oleh pengguna (user) terhadap fungsi yang dijalankan oleh aset tersebut. (Moubray, 1997) Perawatan merupakan salah satu cara efektif untuk meningkatkan keandalan suatu sistem. (Aggarwal, 1993) Berdasarkan definisi tersebut, maka terdapat beberapa alasan pentingnya melakukan pekerjaan perawatan, antara lain:

1. Agar fasilitas dapat siap dipakai pada saat yang diperlukan.
2. Seiring dengan waktu, tentunya kondisi dari suatu fasilitas yang mengalami pemakaian, kemampuan kinerjanya lambat laun akan menurun karena tanpa perawatan semua fasilitas tersebut akan melemah secara bertahap tapi pasti, sehingga tidak lagi mempunyai kemampuan kerja baik secara teknis maupun ekonomis.
3. Diharapkan akan dapat memperpanjang umur pakai dari fasilitas tersebut.

2.1.2 Jenis *Maintenance*

Kegiatan *maintenance* atau perawatan sendiri terdiri dari dua jenis utama yaitu perawatan terencana (*planned maintenance*) dan perawatan tidak terencana (*unplanned maintenance*). (Bahtiar, 2019) Kedua jenis perawatan tersebut memiliki beberapa jenis diantaranya yaitu:



Gambar 2. 1 Jenis-Jenis *Maintenance*
(Asri Bahtiar, 2019)

A. Planned Maintenance

Planned maintenance (perawatan terencana) merupakan jenis perawatan yang menjadwalkan tugas perawatan berdasarkan tingkat rasio kerusakan yang pernah terjadi dan atau tingkat kerusakan yang diprediksikan. Dengan *planned maintenance*, potensi kerusakan yang terjadi secara mendadak dapat diminimalisir serta dapat lebih baik mengendalikan tingkat kerusakan komponennya. Perawatan terencana ini memiliki beberapa jenis sesuai dengan kegiatan *maintenance* yang direncanakan yaitu:

1. Preventive Maintenance

Preventive maintenance merupakan tindakan pemeliharaan yang terjadwal dan terencana. Hal ini dilakukan untuk mengantisipasi masalah-masalah yang dapat mengakibatkan kerusakan pada komponen atau *equipment* dan menjaganya selalu tetap normal selama dalam keadaan beroperasi.

2. Corrective Mainteance

Corrective maintenance merupakan pemeliharaan yang telah direncanakan didasarkan pada kelayakan waktu operasi yang telah ditentukan pada buku petunjuk suatu alat atau *equipment*. Pemeliharaan ini merupakan ”*general overhaul*” yang meliputi pemeriksaan, perbaikan dan penggantian terhadap setiap bagian-bagian alat yang tidak layak pakai lagi, baik karena rusak maupun batas maksimum waktu operasi yang telah ditentukan. Tidak hanya memperbaiki tetapi juga

mempelajari sebab-sebab terjadinya kerusakan serta cara-cara mengatasinya dengan cepat dan benar sehingga tercegah terulangnya kerusakan serupa. Untuk mencegah terjadinya kejadian kerusakan yang serupa perlu dipikirkan dengan detail dan komprehensif sesuai analisa data yang ada pada historis kerusakan komponen atau peralatan sebelumnya.

3. Predictive Maintenance

Predictive Maintenance merupakan perawatan yang bersifat prediksi, dalam hal ini merupakan evaluasi dari perawatan berkala (Preventive Maintenance). Pendeteksian ini dapat dievaluasi dari indikaktor-indikator yang terpasang pada instalasi suatu alat dan juga dapat melakukan pengecekan vibrasi dan alignment untuk menambah data dan tindakan perbaikan selanjutnya.

4. *Improvement Maintenance* (IM)

IM bertujuan untuk mengurangi atau menghilangkan sama sekali kebutuhan terhadap *maintenance*. IM terdiri dari 3 jenis yaitu:

- *Design-out maintenance*, yaitu serangkaian kegiatan untuk menghilangkan penyebab adanya *maintenance*, menyederhanakan tugas-tugas *maintenance*, atau meningkatkan kinerja mesin dari sudut *maintenance* dengan mendesain ulang mesin-mesin dan fasilitas yang rentan terhadap sering terjadinya kegagalan dan perbaikan jangka panjang atau biaya penggantian yang sangat mahal.
- *Engineering services*, meliputi modifikasi konstruksi dan konstruksi, reinstalasi, dan pengaturan ulang dari fasilitas.
- *Shutdown improvement maintenance*, serangkaian kegiatan perbaikan yang dilakukan, sementara lintas produksi berada dalam kondisi berhenti.

B. Unplanned Maintenance

Unplanned maintenance (perawatan tidak terencana) biasanya berupa *breakdown* atau *emergency maintenance*. *Breakdown* atau *emergency maintenance* (pemeliharaan darurat) adalah tindakan maintenance yang tidak dilakukan pada peralatan yang masih dapat beroperasi, sampai peralatan tersebut rusak dan tidak dapat berfungsi lagi. Melalui bentuk pelaksanaan pemeliharaan tak terencana ini, diharapkan penerapan pemeliharaan tersebut akan dapat memperpanjang umur dari perlatan dan dapat memeprkecil frekuensi kerusakan. Ciri-ciri jenis pemeliharaan ini adalah peralatan dioperasikan hingga peralatan tersebut mengalami

kerusakan. Ketika kerusakan (*failure*) terjadi, maka kegiatan peralatan akan dilakukan.

Keuntungan pemeliharaan jenis ini hanya satu yaitu mudah dalam pelaksanaannya dan tidak perlu melakukan perencanaan pemeliharaan. Namun, di sisi lain jenis perawatan ini memiliki kekurangan yang tidak sebanding yaitu sebagai berikut:

- Karena tidak bisa diketahui kapan akan terjadi breakdown, maka jika waktu breakdown adalah pada saat-saat periode produksi maksimal, maka akan mengakibatkan tidak tercapainya target produksi pada periode ini.
- Jika suku cadang untuk perbaikan ternyata sukar untuk dipenuhi berarti dibutuhkan waktu tambahan untuk membeli atau memperoleh dengan cara lain suku cadang tersebut.
- Karena kegiatan ini sifatnya mendadak, dalam tugasnya bagian pemeliharaan bekerja dibawah tekanan bagian produksi yang akan berakibat :
- Rendahnya efisiensi dan efektifias pekerja
- Tidak optimalnya mutu hasil pekerjaan perbaikan atau pemeliharaan
- Biaya relatif lebih besar.

1. *Emergency Maintenance*

   Emergency maintenance adalah pemeliharaan yang dilakukan apabila *equipment* dalam keadaan *shut down* atau mati sama sekali karena terjadinya kerusakan atau kelainan yang menyebabkan *equipment* tersebut tidak dapat dioperasikan. Perawatan ini tidak direncanakan sebelumnya dan perbaikannya dilaksanakan untuk mencegah terjadinya akibat yang lebih serius.

2. *Breakdown Maintenance*

   Breakdown maintenance adalah perawatan yang dilakukan ketika sudah terjadi kerusakan pada *equipment* sehingga *equipment* tersebut tidak dapat beroperasi secara normal atau terhentinya operasional secara total dalam kondisi mendadak. *Breakdown maintenance* ini harus dihindari karena akan terjadi kerugian akibat berhentinya *equipment* terutama yang bersifat *primary* (utama) dan vital yang dapat menyebabkan terhentinya seluruh aktifitas operasional.

2.1.3 Metode *Maintenance*

Secara umum terdapat 2 metode *maintenance* yang sering digunakan pada *boiler* yaitu metode *Risk-Based Maintenance* (RBI) dan *Condition-Based Maintenance* (CBM). (Mkandawire, Ijumba, & Whitehead, 2011)

Metode perawatan RBI sebagian besar berfokus pada industri hidrokarbon dengan aplikasi yang cukup luas. RBI sendiri merupakan *tools* yang secara sistematis dapat digunakan untuk menilai tingkat kekritisan peralatan yang bersifat statis untuk memfasilitasi pilihan metode pemantauan kondisi yang tepat. Tujuan dari penerapan RBI adalah sebagai berikut:

1. Mencari unit-unit operasi yang memiliki resiko tinggi di suatu instalasi industri atau *plant*.
2. Memperkirakan suatu nilai resiko pada setiap *equipment* dalam suatu pengoperasian instalasi
3. Membuat prioritas *equipment* berdasarkan resiko yang terukur
4. Mendesain suatu program inspeksi
5. Memanajemen resiko dari suatu kegagalan *equipment*

RBI juga merupakan sebuah proses dalam strategi *maintenance* dimana terdapat kombinasi antara kemungkinan kegagalan dari suatu *equipment* dan konsekuensinya secara kualitatif dan kuantitatif untuk menentukan suatu skala prioritas berbasiskan resiko total. Terdapat tiga buah tingkatan analisa dalam RBI yang telah dibuat oleh API (*The American Petroleum Institute*) untuk memprioritaskan tingkatan dari tiap-tiap *equipment*.

CBM adalah strategi pemeliharaan yang digunakan dalam memantau kondisi aktual suatu aset untuk memutuskan pemeliharaan apa yang perlu dilakukan. CBM menentukan bahwa pemeliharaan hanya boleh dilakukan ketika indikator tertentu menunjukkan tanda-tanda penurunan kinerja atau kegagalan yang akan datang. CBM merupakan sebuah metode penentuan waktu perawatan yang didasarkan pada data kegagalan dan kondisi dari komponen. Aset yang berjenis sama, digunakan dalam situasi yang berbeda, mungkin memerlukan perawatan dengan metode CBM untuk dapat memenuhi persyaratan pengoperasiannya yang unik. CBM memiliki tantangannya sendiri yaitu memerlukan inspeksi terjadwal untuk melakukan proses asesmen terhadap kondisi aset, yang memakan waktu saat seharusnya peralatan dapat digunakan untuk beroperasi. Selain itu, tindakan menghentikan dan membuka atau membongkar sebuah aset meningkatkan risiko kerusakan suatu komponen aset yang dapat berakibat pada kegagalan aset pada masa yang akan datang. Jika demikian, aset masih mengalami *downtime* yang tak terduga dalam jadwal *maintenance* yang secara negatif berdampak terhadap biaya operasional suatu sistem atau *plant.*

2.2 *Reliability Centered Maintenance* (RCM)

2.2.1 Definisi RCM

Reliability Centered Maintenance (RCM) adalah sebuah proses analisa yang bersifat sistematis terhadap suatu sistem rekayasa atau pemeliharaan permesinan untuk mengetahui fungsi dari masing-masing *equipment* tersebut, penyebab kegagalan fungsinya, bagaimana memilih langkah-langkah perawatan untuk mencegah penyebab kegagalan itu atau mendeteksi kegagalan itu muncul sebelum kegagalan terjadi, bagaimana untuk menentukan persyaratan dalam penyediaan suku cadang pengganti dan bagaimana menyempurnakan dan memodifikasi sistem perawatan yang telah ada seiring dengan perubahan waktu. (American Bureau of Shipping, 2016) Moubray mendefinisikan RCM dengan 2 cara (Moubray, 1997) yaitu:

a. Suatu proses yang digunakan untuk menentukan persyaratan perawatan dari setiap aset fisik dalam konteks operasinya.
b. Suatu proses yang digunakan untuk menentukan apa yang harus dilakukan untuk memastikan bahwa setiap aset fisik terus melakukan apa pun yang diinginkan penggunanya dalam konteks operasi.

Dunn menjelaskan bahwa perawatan yang efektif membantu meningkatkan pendapatan, karena meningkatkan kinerja peralatan (*equipment*) dan kapasitas produksi yang selanjutnya akan meningkatkan volume penjualan. (Dunn, 1996) Pada **Tabel 2 Perbedaan RCM dan RCM II** akan dijelaskan mengenai perbedaan di antara keduanya baik dari segi definisi, proses, *output*, fokus maupun tujuannya.

Tabel 2. 1 Perbedaan RCM dan RCM II

Aspek	RCM	RCM II
Definisi	Suatu proses yang digunakan untuk menentukan apa yang harus dilakukan untuk menjamin suatu aset dapat bekerja seperti yang diinginkan pemiliknya sesuai dengan *operating context* saat ini	Suatu proses yang digunakan untuk menentukan apa yang harus dilakukan untuk menjamin suatu aset dapat bekerja seperti yang diinginkan pemiliknya sesuai dengan *operating context*
Proses	1. Menentukan penyebab terjadinya kegagalan dan komponen kritis yang rawan 2. Mengembangkan analisa FTA 3. Mengklasifikasikan kebutuhan tingkat *maintenance* 4. Implementasi hasil RCM 5. Evaluasi	1. Mempersiapkan data-data analisa 2. Menentukan aset/sistem yang akan dianalisa 3. Mengidentifikasi fungsi dari aset/sistem 4. Mengidentifikasi kegagalan fungsi dari aset/sistem

Aspek	RCM	RCM II
		5. Mengidentifikasi kemungkinan penyebab kegagalan fungsi dari aset/sistem 6. Mengidentifikasi efek dari masing-masing fungsi dari aset/sistem 7. Penentuan *maintenance task*, eksekusi dan evaluasi
Output	1. *Reactive maintenance → run to failure* 2. *Preventive maintenance* 3. *Predictive maintenance → on condition* 4. *Proactive maintenance*	1. *Proactive maintenance → schedule restoration task, schedule discard task, on-condition task* 2. *Default task → redesign, failure finding task, no schedule maintenance*
Fokus	Pencegahan terjadinya kegagalan yang sering terjadi	Efek kegagalan yang terjadi disebabkan oleh *failure mode* sehingga dapat memperbaiki bagian yang tepat, pada saat yang tepat dan metode yang tepat
Tujuan	1. Untuk mengembangkan *design* yang bersifat *mantainability* 2. Untuk memperoleh informasi penting terkait *improvement* pada *design* awal yang kurang baik 3. Untuk mengembangkan sistem *maintenance* yang dapat mengembalikan *reliability* dan *safety* seperti awal 4. Untuk mewujudkan semua tujuan di atas dengan biaya minimum	1. Integritas keselamatan dan lingkungan lebih tinggi 2. Perbaikan kinerja operasi 3. Efektivitas biaya 4. Usia peralatan menjadi lebih panjang 5. *Database* yang lengkap 6. Motivasi pribadi yang lebih besar 7. Kerja sama yang lebih baik

2.2.2 Manfaat RCM

RCM tidak mengandung prinsip-prinsip baru untuk melakukan pemeliharaan dimana ini adalah cara yang lebih terstruktur untuk menggunakan metode dan disiplin ilmu terbaik. RCM mengatur kebijakan pemeliharaan pada tingkat jenis pabrik atau peralatan. Kekuatan RCM adalah bahwa ia menghasilkan program pemeliharaan pada tingkat berbagai sistem dalam suatu *plant* maupun peralatan (*equipment*). Kekuatan RCM adalah mampu menghasilkan program pemeliharaan terencana yang terstruktur dan

efektif bahkan dalam situasi dimana tim pengembangan memiliki akses ke sedikit atau bahkan tidak ada data historis. (Sutton, 1995)

Rausand mencatat bahwa RCM telah diterapkan dengan sukses besar selama lebih dari 20 tahun yakni yang pertama di industri pesawat terbang kemudian di pasukan militer, industri tenaga nuklir, industri minyak dan gas lepas pantai dan banyak lainnya. (Rausand, 1998) Menurut Campbell, jika RCM diterapkan dengan benar, dapat mengurangi jumlah pekerjaan pemeliharaan rutin dengan margin yang signifikan. (Campbell, 1999) Smith juga menyatakan bahwa ada beberapa manfaat dan keuntungan menggunakan RCM yang berdampak pada operasi, keselamatan, logistik, konfigurasi dan administrasi. (Smith A. M., 1992)

Berikut merupakan kelebihan/manfaat dan kekurangan dari penerapan RCM (Fore & Mispha, 2010)

- Kelebihan/manfaat RCM adalah sebagai berikut:
  1. Menjadi program pemeliharaan yang paling efisien
  2. Menurunkan biaya dengan meniadakan pemeliharaan peralatan yang tidak perlu
  3. Meminimalkan frekuensi *downtime* akibat kerusakan pada komponen peralatan (*equipment*)
  4. Mengurangi kemungkinan kegagalan peralatan mendadak
  5. Memprioritaskan kegiatan pemeliharaan pada komponen sistem kritis
  6. Meningkatkan keandalan komponen
  7. Terdapat *root cause analysis* (analisa akar masalah)
- Kekurangan RCM adalah sebagai berikut:
  1. *Initial cost* (biaya investasi awal) yang signifikan terkait dengan pelatihan dan perlengkapan kebutuhan staff/pekerja. Mengabaikan biaya ini telah banyak menyebabkan banyak kasus penarikan dukungan manajemen, sehingga membuat pengenalan tentang RCM mengalami kegagalan. (Bowler, Primrose, & Leonard, 1995)

2.2.3 Komponen RCM

Penggunaan RCM sebagai dasar dari strategi pemeliharaan keseluruhan yang efisien dan andal memerlukan beberapa *tools* dan keahlian dalam menjalankan analisa RCM sebagai bagian dari komponen pembentuknya. (American Bureau of Shipping, 2016) Poin pentingnya adalah bahwa semua teknik dalam sistem perawatan tersebut memiliki peran penting dalam filosofi *integrated maintenance* (pemeliharaan terpadu). Berikut merupakan *tools* dan keahlian yang dibutuhkan dalam analisa RCM:

a. *Failure Modes, Effects and Criticality Analysis* (FMECA)
b. RCM *decision flow diagram*
c. Pengetahuan tentang desain, rekayasa dan sistem operasional *equipment* yang akan dianalisa
d. Teknik *condition-monitoring*
e. *Risk-based decision making* (frekuensi dan dampak dari sebuah kegagalan terhadap keselamatan, lingkungan dan operasional komersialnya)

2.2.4 Tujuan RCM

Tujuan dari diterapkannya RCM ini adalah untuk mencapai tingkat keandalan untuk semua mode operasional dari sebuah sistem. (American Bureau of Shipping, 2016) Sebuah analisa RCM ketika akan dilaksanakan dengan baik terhadap suatu sistem harus dapat menjawab tujuh pertanyaan-pertanyaan dasar berikut:

a. Apa fungsi dari sistem dan hubungannya dengan standar performanya?
b. Bagaimana sistem tersebut dapat dikatakan mengalami kegagalan dalam memenuhi fungsi-fungsinya tersebut?
c. Apa yang dapat menyebabkan kegagalan fungsi pada sistem tersebut?
d. Apa yang terjadi ketika sebuah kegagalan terjadi?
e. Apa yang dampak yang mungkin terjadi ketika kegagalan tersebut terjadi?
f. Apa yang harus dilakukan untuk mendeteksi dan mencegah kegagalan fungsi tersebut?
g. Apa yang harus dilakukan jika sebuah *maintenance task* tidak bisa ditemukan?

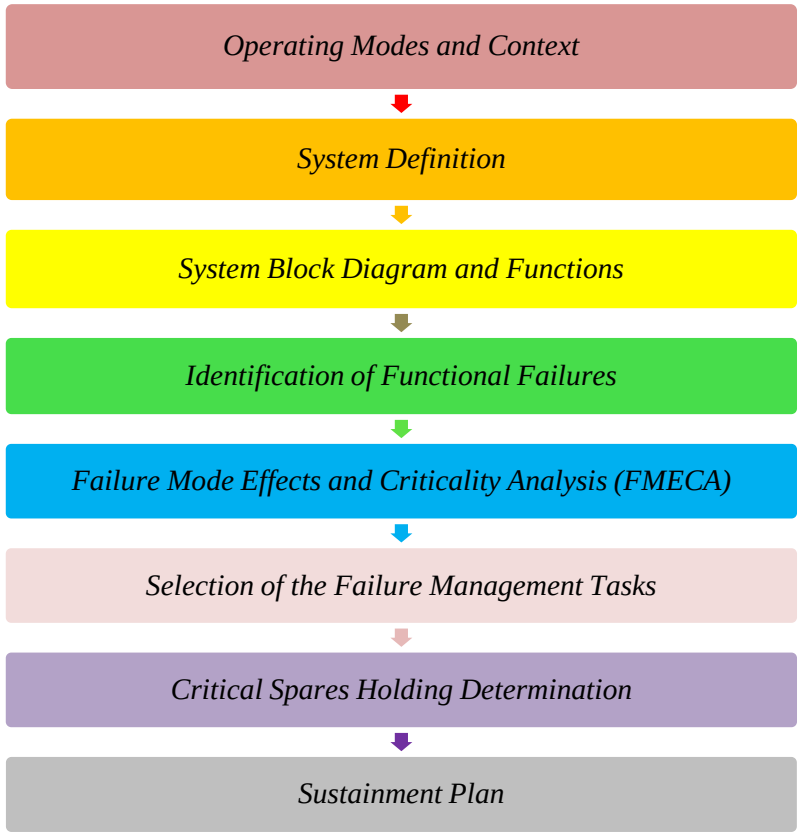
Dengan menggunakan prinsip-prinsip RCM, perawatan dievaluasi dan diterapkan secara rasional. Kegagalan fungsional dengan risiko tertinggi diidentifikasi dan kemudian difokuskan. Item peralatan dan mode kegagalannya yang akan menyebabkan kegagalan fungsional berisiko tinggi diidentifikasi untuk analisis lebih lanjut. Tugas pemeliharaan dan strategi pemeliharaan yang akan mengurangi risiko ke tingkat yang dapat diterima ditentukan. Persediaan suku cadang ditentukan berdasarkan tugas pemeliharaan yang dikembangkan dan penilaian risiko. Prosedur pelestarian RCM dilembagakan untuk terus memantau dan mengoptimalkan perawatan. Dengan demikian, peralatan yang lebih baik dan keandalan sistem dapat diharapkan.

Tujuan utama dari analisis RCM adalah untuk menyediakan investigasi yang komprehensif, sistematis dan terdokumentasi yang menetapkan kondisi kegagalan penting dari sistem permesinan, tugas pemeliharaan atau perancangan ulang sistem / peralatan yang

dipilih untuk mengurangi frekuensi kejadian seperti itu, dan alasan untuk inventaris suku cadang. Mungkin ada kondisi khusus untuk turbin uap, mesin pembakaran internal, switchgear listrik, dan panel distribusi daya dan peralatan pemantauan yang dipasang secara permanen.

2.2.5 Langkah-Langkah Utama RCM

Berikut merupakan langkah-langkah utama dalam melaksanakan proses RCM terhadap suatu *equipment* yang dapat dilihat pada **Gambar 4 Langkah-Langkah Utama RCM**



Gambar 2. 2 Langkah-Langkah Utama RCM
(ABS Guide for Surveys, 2016)

Langkah-langkah utama dalam pelaksanaan analisa RCM merupakan bentuk proses yang secara struktur dan sistematis mengidentifikasi sistem atau mesin yang akan dianalisa secara komprehensif dan menghasilkan hasil yang terintegrasi antar sistem. Berikut merupakan penjelasan dari masing-masing langkah-langkah utama RCM di atas yaitu:

a. *Operating Modes and Context*
Untuk mendefinisikan karakteristik operasi dengan benar, berbagai mode untuk aset atau peralatan harus diidentifikasi. Konteks operasi harus dikembangkan untuk setiap tingkat hirarki mesin. Contoh mode operasi, beserta konteks operasinya ditunjukkan oleh tabel di bawah ini:

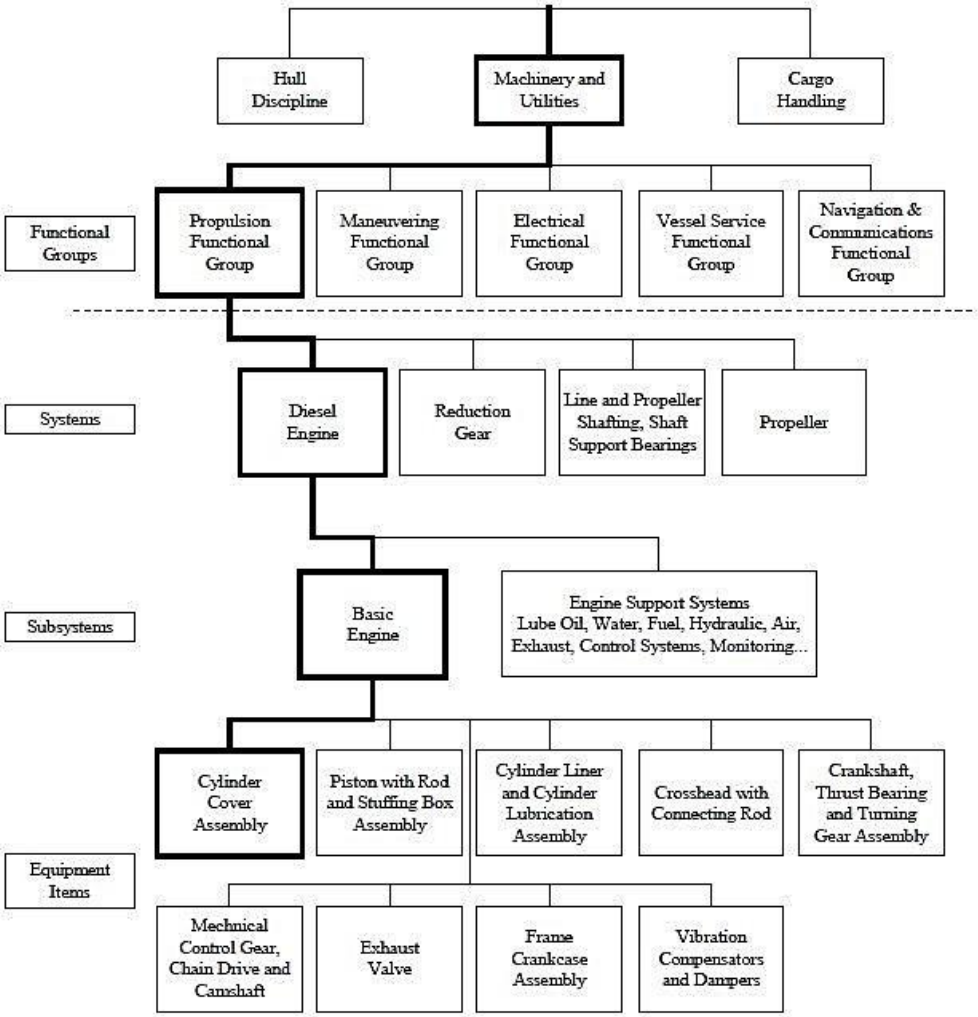
Tabel 2. 2 Contoh Mode Operasi dan Konteks Operasinya
(Sumber: ABS Guide for Surveys, 2016)

Operating Context of Diesel Engine				
The propulsion system consists of a *Manufacturer Diesel Type Model Number* low-speed diesel engine rated 16,860 kW MCR at 91 RPM, coupled directly to a shaft supported by one intermediate bearing and two stern tube bearings, and driving a fixed pitched propeller.				
Common Characteristic	*Operating Modes*			
	At Sea	*Congested Waters*	*Manoeuvring*	*Cargo Handling*
Environmental Parameters	Nominal ambient air temperature at 25°C (range from -29°C to 45°C). Barometric air pressure (dry) at 101.3 kPa (abs) Nominal sea water inlet temperature at 32°C (range from -2°C to 50°C)	Dependent on geographical location. If ports to visit are known, list environmental parameter ranges.	Dependent on geographical location. If ports to visit are known, list environmental parameter ranges.	Not used
Manner of Use	Propels vessel at 20 knots at 85% of MCR. Capable of continous operation for up to 22 days. Single-engine installation.	Propels vessel from 2 to 10 knots, with reversing and stopping capabilities.	Propels vessel from 2 to 10 knots, with reversing and stopping capabilities, and assists in mooring.	Not used
Performance Capability	To output 16,860 kW at 91 RPM; controllable from bridge, centralized control station and locally	To output 30 to 85 RPM; reversing at 63 RPM; controllable from bridge, centralized control station and locally	To output 30 to 85 RPM; reversing at 63 RPM; controllable from bridge, centralized control station and locally	Not applicable

b. *System Definition*

Setiap sistem yang dipilih untuk analisis RCM harus didefinisikan. Definisi sistem melibatkan:

1. Pembagian kelompok fungsional aset ke dalam sistem (sebagaimana diperlukan karena kompleksitas), *item* peralatan, dan komponen



Gambar 2. 3 Contoh Pembagian Kelompok Fungsional
(ABS Guide for Surveys, 2016)

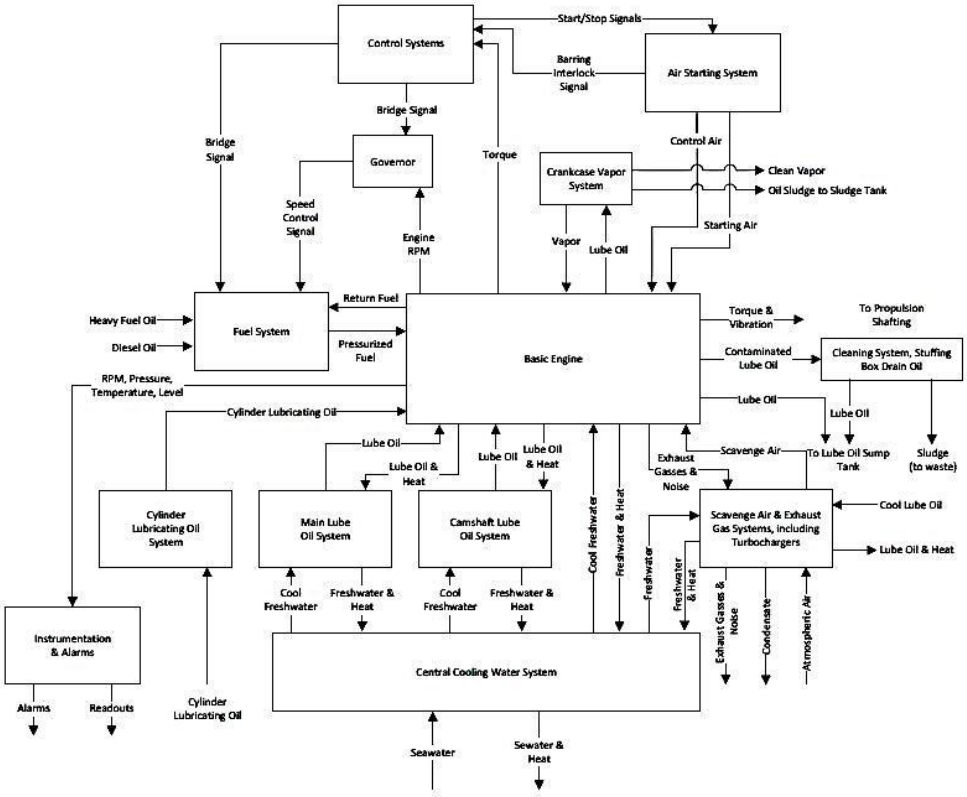
2. Pengembangan lebih lanjut dari deskripsi naratif untuk setiap kelompok fungsional, sistem, *item* peralatan dan komponen.

c. *System Block Diagrams and Functions*

Fungsi untuk kelompok fungsional, sistem, *item* peralatan, dan komponen harus diidentifikasi. Saat mengidentifikasi fungsi, mode operasi yang berlaku dan konteks operasi harus terdaftar. Semua fungsi harus diidentifikasi dengan jelas.

Block diagram akan dikembangkan menunjukkan urutan aliran fungsional dari kelompok fungsional, baik untuk pemahaman teknis tentang fungsi dan operasi sistem dan untuk analisis selanjutnya. Minimal, diagram blok mengandung:

1. Partisi grup fungsional ke dalam sistem, *item* peralatan, dan komponen
2. Semua *input* dan *output* berlabel yang sesuai dan nomor identifikasi dimana setiap sistem secara konsisten menjadi referensi
3. Semua redudansi, jalur sinyal alternatif, dan fitur teknik lainnya yang menyediakan ukuran "*fail-safe*"



Gambar 2. 4 Contoh Blok Diagram Sistem
(ABS Guide for Surveys, 2016)

d. *Identification of Functional Failures*
Daftar kegagalan fungsional untuk setiap fungsi yang diidentifikasi dalam diagram blok sistem dan fungsinya harus diidentifikasi untuk masing-masing kelompok fungsional, sistem, item peralatan, dan komponen.
Setiap kegagalan fungsional harus didokumentasikan dalam pernyataan kegagalan fungsional yang berisi kata kerja, objek, dan deviasi fungsional. Contoh fungsi dan kegagalan fungsional ditunjukkan pada tabel di bawah ini:

Tabel 2. 3 Contoh Daftar Fungsi dan Kegagalannya
(ABS Guide for Surveys, 2016)

Equipment Item: Low speed diesel engine for main propulsion, drivinga controllable pitch propeller				
Function			*Functional Failure*	
Item No.	*Function Statement*	*Function Type*	*Item No.*	*Functional Failure Statement*
1	Transmit 16,860 kW of power at 91 RPM to the propulsion shafting	Primary	1.1	No transmission of power to the propulsion shafting
			1.2	Transmits less than 16,860 kW of power to propulsion shafting
			1.3	Transmits more than 16,860 kW of power to propulsion shafting
			1.4	Operates at less than 91 RPM
			1.5	Operates at more than 91 RPM
2	Exhaust engine gases after the turbochargers are to be in the range 275°C to 325°C	Secondary	2.1	Exhaust gases are less than 275°C
			2.2	Exhaust gases are more than 275°C

e. *Failure Mode Effects and Criticality Analysis* (FMECA)
FMECA harus dipertimbangkan menggunakan pendekatan *bottom-up*, mulai dari tingkat detail terendah yang diidentifikasi selama partisi sistem. Contoh format FMECA *bottom-up* ditunjukkan seperti di bawah ini:

Tabel 2. 4 Contoh Format FMECA Bottom-Up
(Sumber: ABS Guide for Surveys, 2016)

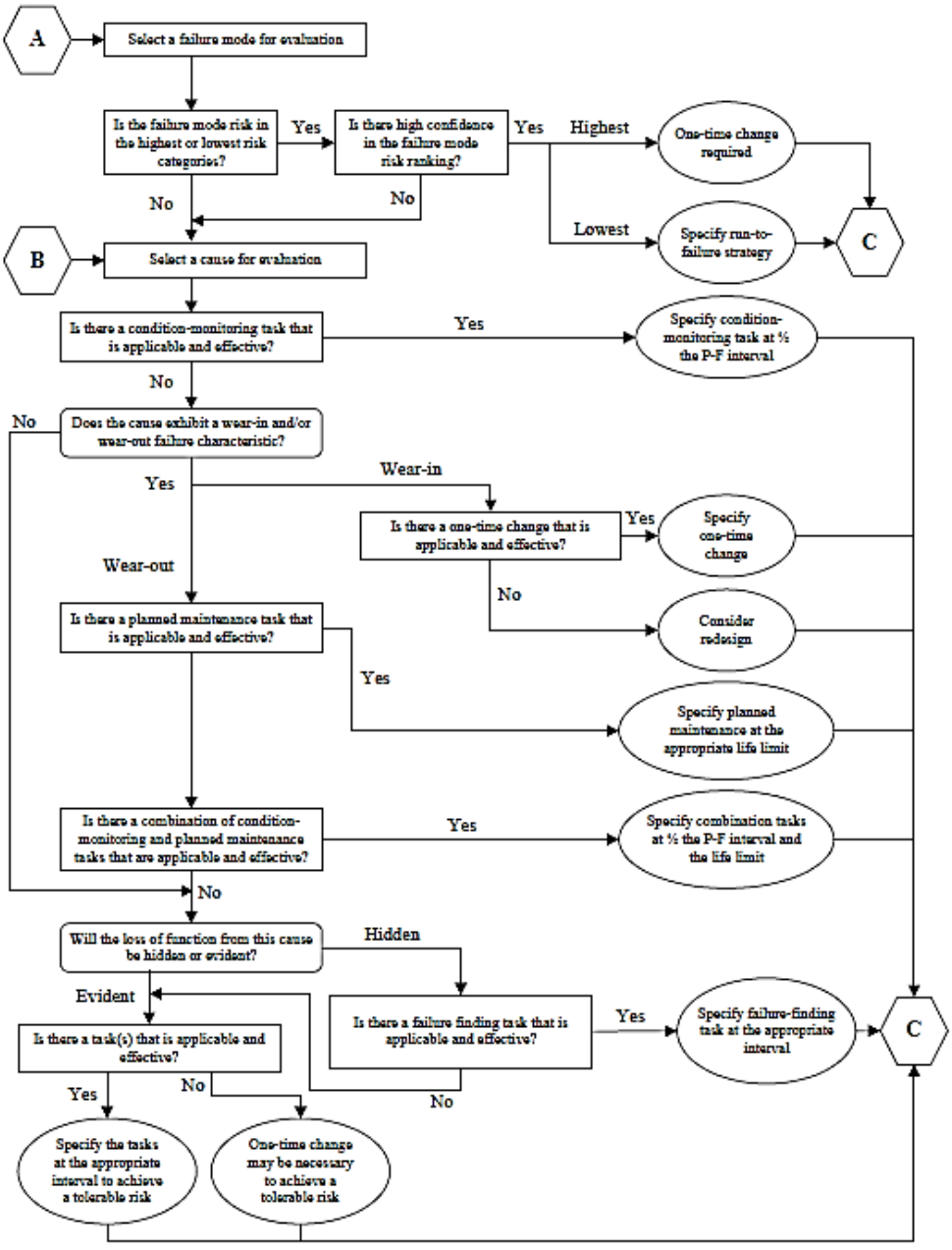
Item	Failure Mode	Causes	Failure Characteristic	Local Effects	Functional Failures	End Effects	Matrix	Severity	Current Likelihood	Current Risk	Failure Detection/ Corrective Measures
15.1	Fail off while running (on-line pump evident)	Pump motor failure Pump seizure Pump motor control failure Pump coupling failure	Random failure, Wear-out failure Random failure, Wear-out failure Random failure, Wear-out failure	Interruption of lubrication to the camshaft, repairing the standby pump to the started.	No flow of lubricant to the camshaft	Brief shut down of the engine until standby lube oil pump is started	Propulsion	Minor	Remote	Low	Upon low pressure sensor sends signal to automatic changeover controller which starts standby pump

f. *Selection of the Failure Management Tasks*
Semua penyebab setiap mode kegagalan harus dievaluasi. Tugas manajemen kegagalan yang tepat harus dipilih untuk semua tindakan korektif. Semua rekomendasi perawatan dari pabrikan (*manufacturer*) harus dipertimbangkan selama pemilihan tugas manajemen kegagalan. Jika perubahan atau penghapusan rekomendasi pabrikan dilakukan, ini harus didokumentasikan dalam analisis. Jenis tugas yang harus diidentifikasi adalah sebagai berikut:
1. *Condition Monitoring* (CM),
2. *Planned Maintenance* (PM),
3. *Combination of CM and PM* (CM/PM),
4. *Failure Finding* (FF),
5. *One-Time Change* (OTC),
6. *Run-To-Failure* (RTF), dan
7. *Any Applicable and Effective Task* (AAET).

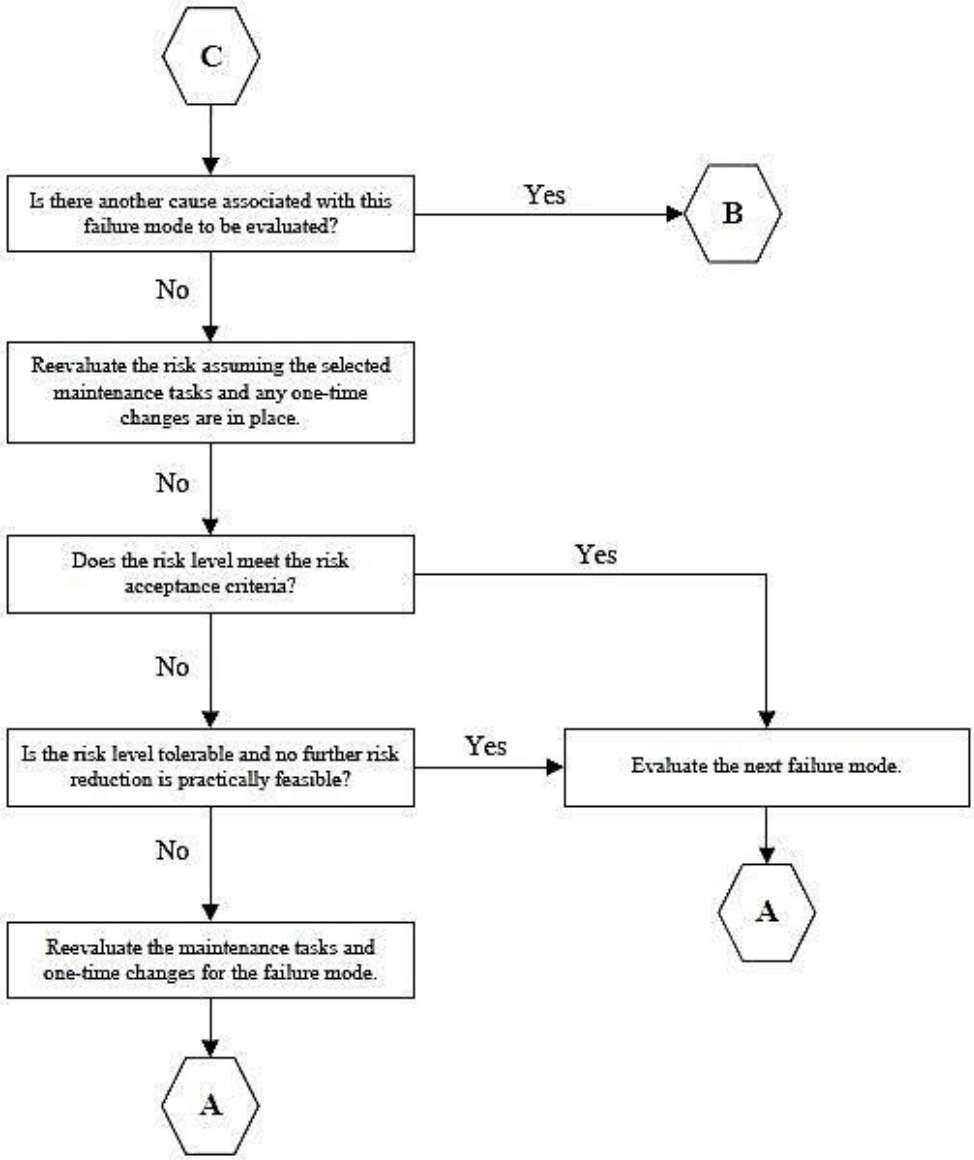
Tabel 2. 5 Contoh *Failure Management Tasks*
(ABS Guide for Surveys, 2016)

Equipment Item/Component Failure Characteristic	*Suggested Failure Management Task*
Wear-in failure	Eliminate or reduce wear-in Condition-monitoring task to detect onset of failure One-time change or redesign
Random failure	Condition-monitoring task to detect onset of failure Failure-finding task to detect hidden failure One-time change or redesign
Wear-out failure	Condition-monitoring task to detect onset of failure Planned-maintenance task Failure-finding task to detect hidden failure

Dan berikut merupakan diagram alir yang merupakan *Logic Tree Analysis* (LTA) dalam pemilihan tugas (*task selection*) untuk menetukan *failure management task* yang tepat pada analisa RCM.



Gambar 2. 5 Diagram Alir *Task Selection* RCM (1)
(ABS Guide for Surveys, 2016)



Gambar 2. 6 Diagram Alir *Task Selection* RCM (2)
(ABS Guide for Surveys, 2016)

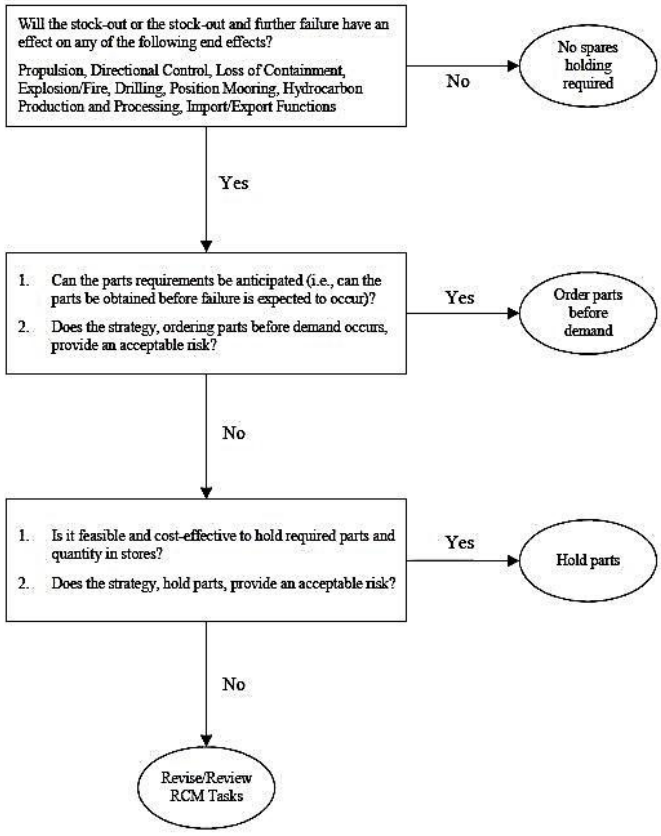
g. *Critical Spares Holding Determination*
Agar jadwal perawatan yang diusulkan dapat berjalan, penting agar suku cadang yang mendukung tugas pemeliharaan yang diidentifikasi tersedia pada waktu yang tepat.

Tabel 2. 6 Contoh *Spares Holding Determination*
(ABS Guide for Surveys, 2016)

Maintenance Category:	**Category A, B or C**
Functional Group:	**Indicate group name, e.g., Propulsion**
System:	**Indicate system name**
Equipment Item:	**Indicate equipment item name**
Component:	**Indicate component name**

Task	*Task Type*	*Item No.*	*Out-of-Stock Effect*	*Risk due to out-of-stock*			*Procedure No. or Class Reference*	*Spare Parts Identification*
				Order parts before demand	*Hold parts*	*Revise/Review RCM Tasks*		
Visual inspection of the cooling water passages with a borescope	CM	1.3, 1.5	Yes	Low			MA 901-3.1	-Cooling water connection O-rings
Removal and function testing of the cylinder puncture valve	PM	1.2	Yes		Medium		MA 911-2	-Cleaning solvent -Valve seat O-rings -Cooling water connection O-rings
Replacement of the cylinder cover O-ring	PM	1.1	Yes	Medium			MA 901-1	-Cylinder cover sealing ring -Cooling water connection O-rings
Removal and function testing of the cylinder relief valve	PM	1.2	Yes	Medium			MA 911-2	-Cleaning solvent -Valve seat O-rings -Cooling water connection O-rings

Dan berikut merupakan diagram alir untuk menentukan suku cadang yang disediakan untuk penggantian pada interval waktu tertentu.



Gambar 2. 7 Diagram Alir Penentuan *Spares Holding*
(ABS Guide for Surveys, 2016)

h. *Sustainment Plan*

Untuk perencanaan keberlanjutan (*sustainment plan*), rencana untuk perbaikan lanjutan harus diserahkan ke kantor teknik. Hasil kegiatan keberlanjutan harus dipertahankan di kapal untuk verifikasi pada survei tahunan. Untuk rencana keberlanjutan yang menerapkan item-item berikut, item tersebut harus termasuk minimal:

1. Analisis Trend: Kondisi dan tugas pemantauan kinerja ditentukan untuk analisis trend

- Identifikasi peralatan,
- Data yang akan dikumpulkan, dan
- Batas yang ditentukan sebelumnya diidentifikasi untuk data ketika tugas pemantauan kondisi dikembangkan menunjukkan tindakan pemeliharaan yang akan diambil ketika data berada di luar batas.

2. Tinjauan Rencana Perawatan

- *Maintenance Requirement Document Reviews*

Dokumen yang berisi persyaratan pemeliharaan untuk sistem, item peralatan, atau komponen harus ditinjau setidaknya setiap tahun untuk mengidentifikasi proses, teknik, atau teknologi pemeliharaan yang ketinggalan zaman, atau untuk memperhatikan alat-alat usang dan suku cadang usang.

- *Task-Packaging Reviews*

Ketika tugas-tugas pemeliharaan dimodifikasi dan diperbarui, tugas-tugas tersebut terus ditempatkan kembali ke dalam interval paket yang sama. Namun, seiring waktu, interval paket asli mungkin tidak lagi optimal. Ulasan pengemasan tugas harus dilakukan secara berkala untuk mengevaluasi interval untuk memverifikasi bahwa ketika tugas perawatan ditambahkan, dihapus atau dimodifikasi, interval paket optimal dipertahankan.

- *Age-Exploration Tasks*

Ketika data usia-ke-kegagalan tidak cukup tersedia atau data yang diasumsikan digunakan selama analisis RCM awal, tugas eksplorasi usia harus dirancang dan diimplementasikan.

3. *Failures*

Catatan harus dipelihara dari analisis kegagalan yang dilakukan, dan setiap perubahan pada tugas-tugas pemeliharaan yang terkena dampak perubahan satu kali pada *item* / komponen peralatan.

4. *Relative Ranking Analysis*

Analisis peringkat relatif dapat dikembangkan untuk item-item yang memiliki biaya operasional tertinggi atau dampak biaya.

5. *Sustainment Result Implementation*

- Catatan harus disimpan dari hasil kegiatan lain yang dilakukan yang menghasilkan perubahan pada analisis keandalan dan / atau tugas pemeliharaan. Surveyor yang hadir harus diberitahu tentang perubahan ini. Surveyor mungkin memerlukan analisis atau perubahan tugas untuk diserahkan ke kantor teknik yang bertanggung jawab yang melakukan tinjauan awal.
- Dapat ditentukan bahwa tugas pemeliharaan yang ada tidak dilakukan pada interval yang paling efektif. Dengan mengumpulkan informasi melalui upaya berkelanjutan, data yang diperlukan untuk memperbaiki asumsi yang digunakan untuk menetapkan interval selama analisis RCM awal dapat digunakan untuk menyesuaikan interval tugas sehingga meningkatkan efektivitas interval.
- Upaya mempertahankan juga dapat mengidentifikasi tugas pemeliharaan yang perlu ditambahkan, dihapus, atau dimodifikasi.
- Upaya mempertahankan juga dapat menghasilkan persyaratan untuk memodifikasi tugas eksplorasi usia yang sedang berlangsung
- Perubahan lain yang mungkin terjadi sebagai hasil dari upaya berkelanjutan termasuk desain ulang sistem atau peralatan, atau perubahan atau batasan operasional.

Analisis akan dilakukan untuk semua peralatan dan sistem yang diusulkan untuk pendaftaran dalam program RCM. Selanjutnya, laporan RCM tahunan harus disiapkan untuk ditinjau oleh surveyor yang hadir pada survei konfirmasi tahunan. Studi terperinci tentang sistem atau mesin yang menjadi subjek analisis RCM harus dilakukan melalui penggunaan gambar sistem, gambar item peralatan, dokumen yang berisi persyaratan perawatan untuk sistem, *item* atau komponen peralatan, dan pengalaman operator.

Dokumentasi analisis RCM terdiri dari beberapa langkah dimana untuk setiap langkahnya terdiri topik-topik berikut yang harus didokumentasikan yakni:

1. Hasil langkah analisis
2. *Tools* dalam pengambilan keputusan yang digunakan
3. Informasi terkait lainnya yang terkait dengan langkah (asumsi, peralatan dikecualikan dari analisis)

Berdasarkan tugas pemeliharaan yang diidentifikasi dalam analisis RCM, rencana pemeliharaan harus dikembangkan dan didokumentasikan sesuai dengan program pemeliharaan preventif.

2.3 *Marine Boiler*

2.3.1 Definisi

Pada dasarnya, *boiler* atau ketel uap adalah suatu bejana tertutup yang di dalamnya berisi air untuk dipanaskan. Energi panas dari uap air keluaran *boiler* tersebut selanjutnya digunakan untuk berbagai macam keperluan, seperti untuk turbin uap, pemanas ruangan/kargo, mesin uap, dan lain sebagainya. Secara proses konversi energi, *boiler* memiliki fungsi untuk mengkonversi energi kimia yang tersimpan di dalam bahan bakar menjadi energi panas yang tertransfer ke fluida kerja. (Harrington, 1992)

Proses perubahan air menjadi uap pada *boiler* terjadi dengan memanaskan air yang berada didalam pipa-pipa dengan memanfaatkan panas dari hasil pembakaran bahan bakar. Pembakaran dilakukan secara terus menerus di dalam ruang bakar dengan mengalirkan bahan bakar dan udara dari luar. Uap yang dihasilkan *boiler* adalah uap panas super dengan tekanan dan temperatur yang tinggi. Jumlah produksi uap tergantung pada luas permukaan perindahan panas, laju aliran fluida, dan panas pembakaran yang diberikan.

Gambar 2. 8 *Marine Boiler* di Kapal Tanker
(Nauticexpo.com)

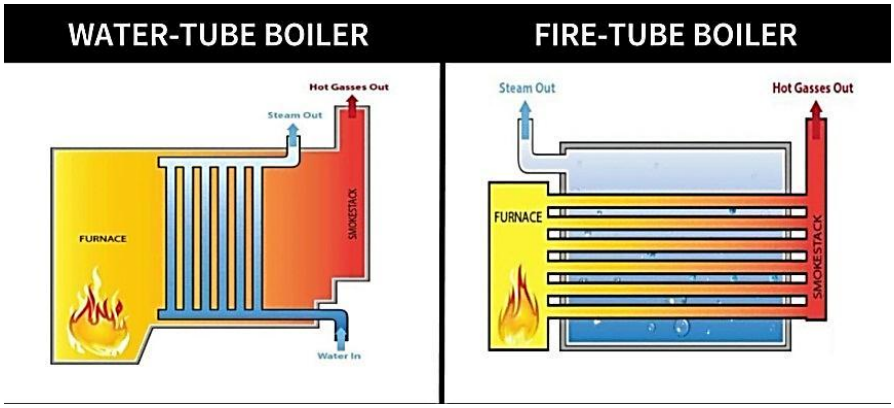
Boiler yang digunakan di kapal sering disebut sebagai *marine boiler* merupakan alat pemanas utama di kapal. Hal tersebut dikarenakan karakteristik *boiler* di kapal berbeda dengan *boiler* industri pada umunya karena beberapa persyaratan komponen yang harus memenuhi kualifikasi *marine use* yakni mulai dari material yang digunakan dan fungsi dari masing-masing komponen tersebut.

2.3.2 Jenis-Jenis *Boiler*

Berdasarkan tipe *tube* (pipa), *boiler* terbagi menjadi 2 jenis yaitu *fire tube boiler* dan *water tube boiler*. (Kusnarjo, 2012) *Fire tube boiler* juga sering disebut *boiler* pipa api. *Fire tube boiler* biasanya digunakan untuk kapasitas *steam* yang relatif kecil dengan tekanan rendah hingga sedang. Hal tersebut dikarenakan sesuai dengan karakteristik dari *fire tube boiler* itu sendiri, yang dimana karakteristinya ialah menghasilkan kapasitas *steam* dan tekanan rendah. *Fire tube boiler* kompetitif untuk kecepatan *steam* sampai 12.000 kg/jam dengan tekanan sampai dengan 18 kg/cm^2. *Fire tube boiler* dalam operasinya menggunakan bahan bakar minyak bakar, gas atau bahan bakar padat. Sebagian besar *fire tube boiler* dirakit oleh pabrik untuk semua jenis bahan bakar. Cara kerja *fire tube boiler* cukup mudah dipahami yaitu dikarenakan pada saat proses pengapian yang terjadi di dalam pipa, panas yang dihasilkan dari pengapian tersebut akan dihantarkan langsung kedalam *boiler* yang berisi air.

Water tube boiler atau biasa disebut sebagai *boiler* pipa air. *Water tube boiler* memiliki karakteristik yang hampir sama dengan *fire tube boiler*, jika pada *fire tube boiler* itu hanya mampu menyimpan tekanan *steam* rendah sedangkan pada *water tube boiler* mampu menghasilkan kapasitas dan tekanan *steam* yang tinggi. Bukan hanya itu saja, karakteristik dari *water tube boiler* diantaranya kurang toleran terhadap kualitas air yang dihasilkan dari *plant* pengolahan air. *Water tube boiler* dirancang dengan kapasitas *steam* antara 4.500 – 12.000 kg/jam, dengan tekanan sangat tinggi mencapai 63 kg/cm^2. Cara kerja *water tube boiler* yakni proses pengapian terjadi diluar pipa, kemudian panas yang dihasilkan memanaskan pipa yang berisi air dan sebelumnya air tersebut dikondisikan terlebih dahulu melalui *economizer*, kemudian *steam* yang dihasilkan terlebih dahulu dikumpulkan di dalam sebuah *steam drum*. Sampai tekanan dan temperatur sesuai, melalui tahap *secondary superheater* dan *primary superheater* baru *steam* dilepaskan ke pipa utama distribusi. Di dalam pipa air, air yang mengalir harus dikondisikan terhadap mineral atau kandungan lainnya yang larut di dalam air tesebut. Hal ini merupakan faktor utama yang harus diperhatikan terhadap tipe *boiler* ini.

Water tube boiler mempunyai efisiensi lebih tinggi dari pada *fire tube boiler*, khususnya untuk sistem yang membutuhkan panas tinggi dan tekanan tinggi. (Kusnarjo, 2012) Oleh karena itu, *boiler* jenis ini banyak digunakan oleh industri besar yang dalam prosesnya membutuhkan tekanan tinggi. Adapun di dalam dunia *marine* penggunaan *water tube boiler* sangat jarang bahkan tidak digunakan karena instalasi *water tube boiler* membutuhkan ruang (*space*) yang cukup besar untuk berbagai utilitas yang terkait dimana ruang (*space*) tersebut sangat terbatas di kapal. Oleh karena itu, pertimbangan dalam pemilihan jenis boiler yang akan digunakan harus mempertimbangkan dari berbagai aspek penggunaan boiler tersebut.



Gambar 2. 9 Perbedaan *Water Tube Boiler* dengan *Fire Tube Boiler*
(Midwestmachinery.net, 2019)

Sedangkan berdasarkan jenis bahan bakar yang digunakan, *boiler* dibagi menjadi 4 yaitu *solid fuel, oil fuel, gaseous fuel* dan *electric*.

1. *Solid Fuel* (Bahan Bakar Padat)

   Tipe boiler ini menggunakan bahan bakar padat seperti kayu, batu bara, dengan karakteristik seperti harga bahan bakar relatif lebih murah dan lebih efesien bila dibandingkan dengan boiler tipe *electric*.

   - Prinsip kerja : Pemanasan bersumber dari pembakaran bahan bakar padat atau bisa juga campuran dari beberapa bahan bakar padat (batu bara dan kayu) yang dibantu dengan oksigen.
   - Kelebihan : Bahan bakar mudah untuk didapatkan dan lebih murah.
   - Kekurangan : Sisa pembakaran sulit untuk dibersihkan.

2. *Oil Fuel* (Bahan Bakar Minyak)

   Jenis ini memiliki bahan bakar dari fraksi minyak bumi, biasanya jenis minyak solar yang sering digunakan sebagai bahan bakar *boiler*. Dengan karakteristik yaitu memiliki bahan baku pembakaran yang lebih mahal, tetapi memiliki nilai efesiensi yang lebih baik jika dibandingkan dengan tipe boiler yang lainnya.

   - Prinsip kerja : Pemanasan yang bersumber dari hasil pembakaran antara campuran bahan bakar cair (kerosen, *diesel oil*, residu) dengan oksigen dan sumber panas.
   - Kelebihan : Memiliki sisa pembakaran yang sedikit sehingga mudah dibersihkan dan bahan baku yang mudah didapatkan.
   - Kekurangan : Memiliki harga bahan baku yang mahal serta memiliki kontruksi yang mahal.

3. *Gas Fuel* (Bahan Bakar Gas)

   Memiliki jenis bahan bakar gas baik LPG (*Liquified Petroleum Gas*) atau LNG (*Liquified Natural Gas*) dengan karakteristik bahan baku yang lebih murah dan nilai efesiensi lebih baik jika dibandingkan dengan jenis tipe bahan bakar lain.

   - Prinsip kerja : Pembakaran yang terjadi akibat campuran dari bahan bakar gas dengan oksigen serta sumber panas.
   - Kelebihan : Memiliki bahan bakar yang paling murah dan nilai efesiensi yang lebih baik serta lebih ramah lingkungan.
   - Kekurangan : Kontruksi yang mahal dan sumber bahan bakar yang sulit didapatkan serta harus melalui jalur distribusi tertentu.

4. Electric (Sumber Energi Listrik)

   Dari namanya saja kita tentu sudah mengetahu bahwa sumber panas alat ini berasal dari listrik, dengan karakteristik bahan bakar yang lebih murah akan tetapi memiliki tingkat efesiensi yang rendah.

   - Prinsip kerja : Pemanas bersumber dari energi listrik yang menyuplai panas melalui elemen pemanas.
   - Kelebihan : Memiliki perewatan yang sederhana dan sumber pemanas sangat mudah untuk didapatkan.
   - Kekurangan : Nilai efesiensi yang buruk dan memiliki temperatur pembakaran yang rendah.

2.3.3 Komponen-Komponen Boiler

Marine boiler merupakan peralatan yang cukup *complex* dan *compact* yang terdiri dari beberapa item komponen yang saling berkaitan. (Aalborg Industries, 2014). Berikut ini adalah uraian singkat tentang item terpenting dari *boiler*:

1. *Burner*

   Fungsi dari *equipment* ini adalah untuk mengabutkan bahan bakar berupa minyak dan mencampurnya dengan udara kemudian membakar bahan bakar tersebut.

2. *Air Heater*

   Equipment ini berfungsi untuk memanaskan udara yang digunakan untuk menghembus atau meniup bahan bakar agar dapat terbakar dengan lebih sempurna (*air atomizing*).

3. *Steam Drum*

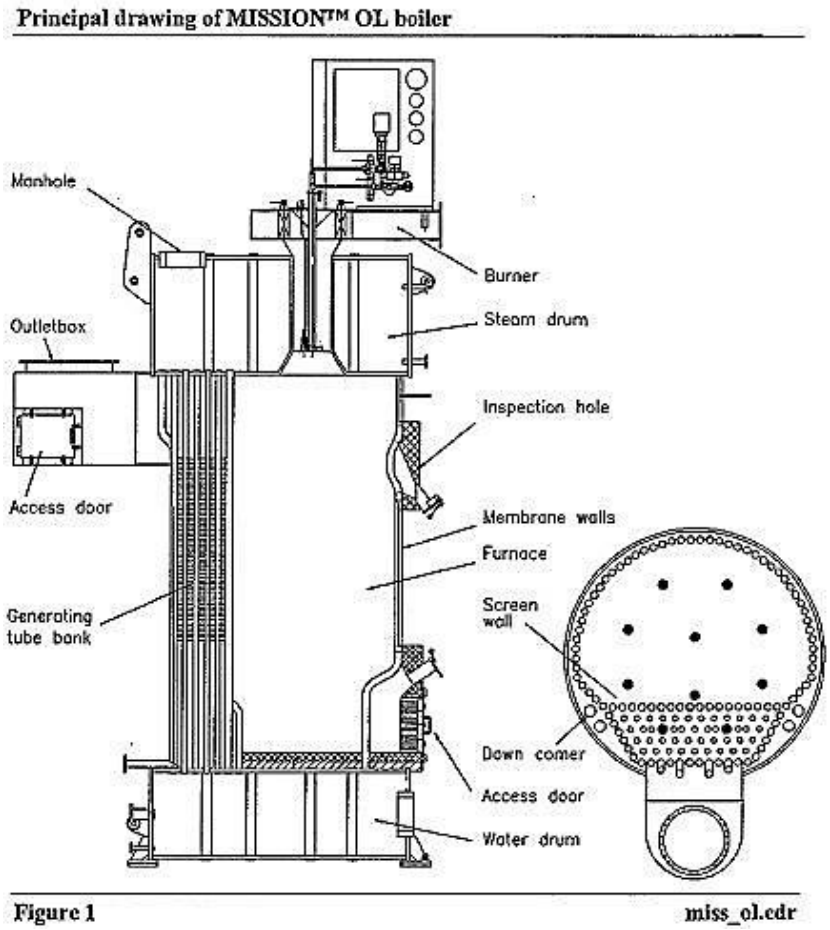
   Salah satu komponen pada *boiler* pipa air (*water* tube) yang berfungsi sebagai *reservoir* campuran air dan uap air, dan juga berfungsi untuk memisahkan uap air dengan air pada proses pembentukan uap *superheater*.

4. *Membrane Wall*
   Merupakan bagian dari *boiler* berupa dinding yang terdiri dari *tubes* (pipa-pipa) yang disatukan oleh membran. Di dalam *membrane wall* tersebut mengalir air yang akan dididihkan.
5. *Furnace*
   Furnace (ruang bakar) berfungsi sebagai tempat pembakaran bahan bakar. Bahan bakar dan udara dimasukkan ke dalam ruang bakar sehingga terjadi pembakaran. Dari pembakaran bahan bakar dihasilkan sejumlah panas dan nyala api/gas asap. Dinding ruang bakar umumnya dilapisi dengan pipa-pipa. Semakin cepat laju peredaran air, pendinginan dinding pipa bertambah baik dan kapasitas steam yang dihasilkan bertambah besar.
6. *Generating Tube Bank*
   Generating tube bank adalah rangkaian pipa-pipa yang disusun sedemikian rupa untuk membangkitkan uap di dalam *boiler*.
7. *Outletbox*
   Merupakan saluran buang dari hasil pembakaran bahan bakar pada *furnace* yang dihubungkan dengan sistem *ducting* di kapal.
8. *Safety Valve*
   Terdapat dua *safety valve* (katup-katup pengaman) yang dipasang ke bejana tekan pada *boiler*. Kedua katup tersebut dipasang untuk alasan keamanan dan dirancang untuk menngantisipasi terjadinya *overpressure* (tekanan berlebih) di atas nilai standar pada *boiler.*
9. *Main Steam Valve*
   Main steam valve (katup utama saluran uap) merupakan sebuah katup *non-return* atau katup *shut off* dimana ketika katup itu tertutup, katup tersebut mengisolasi boiler dari jalur uap utama. Namun, ketika katup tersebut terbuka, katup tersebut mencegah uap dari tekanan balik menuju *boiler*. Jalur uap utama harus dilengkapi dengan sebuah sambungan ekspansi yang berada di dekat katup ini.
10. *By-pass Valve*
    By-pass valve (katup *by-pass*) merupakan katup *shut off*. Tujuan dari dipasangnya katup ini adalah untuk menyamakan tekanan antara boiler dengan sistem uap ketika katup utama saluran uap ditutup. Perlu diperhatikan bahwa *by-pass valve* hanya digunakan untuk *boiler* dengan kapasitas besar (sekitar 6500 kg/jam).
11. *Feed Water Valve*
    Dua kelompok dari *feed water valve* (katup air pengumpan) terdapat di dalam *boiler*. Tiap kelompok terdiri dari sebuah katup *shut-off* dan sebuah katup *non-return*. Katup *shut-off* harus dibuka ketika *boiler* dioperasikan atau jika *boiler* digunakan sebagai *steam drum.* Namun, katup *shut-off* harus ditutup jika *boiler* tidak digunakan.

12. *Water Level Gauge*
    Dua *water level gauge* (alat pengukur ketinggian air) pada *boiler* terhubung dengan bagian dari *boiler* dimana masing-masing *water level gauge* ini dilengkapi dengan dua katup *shut-off* dan sebuah katup pembuangan (*drain*). Katup *shut-off* dipasang di bagian atas dan bawah dari *sight glass* (kaca pengelihatan) yang memiliki mekanisme penutupan dengan sangat cepat untuk mengantisipasi apabila *sight glass* mengalami kerusakan (retak atau pecah). Pipa-pipa dari katup pengurasan pada pengukur ketinggian air yang harus mengarah ke saluran pembuangan terbuka dan dapat dilihat secara visual untuk diperiksa.
13. *Blow Down Valve*
    Dua *blow down valve* (katup pembuangan) merupakan katup jenis *shut-off* atau *non-return* yang berada pada bagian paling bawah dari konstruksi *boiler*. Fungsi dari *shut-off* adalah untuk alasan keamanan sedangkan fungsi dari *non-return* adalah untuk mencegah air atau uap mengalir ke dalam boiler yang kosong akibat adanya kesalah operasional.
14. *Air Valve*
    Katup ventilasi udara (*air valve*) yang terletak di bagian atas *boiler* adalah sebuah katup *shut off*. Katup tersebut tertutup pada kondisi normal kecuali apabila *boiler* sedang dalam keadaan diisi atau telah dikuras sepenuhnya. Bagian ujung pipa pengurasan dari *air valve* harus dapat dilihat secara visual agar dapat ditentukan kapan air atau uap yang sedang keluar.
15. *Scum Valve*
    Scum valve (katup buih) adalah sebuah katup kombinasi antara katup jenis *shut-off* dan katup *non-return*. Ketika terjadi buih atau busa yang timbul pada *boiler* maka buih atau busa tersebut dapat dikeluarkan dari permukaan air dengan membuka katup ini.
16. *Sample Valve*
    Sebuah *sample valve* (katup sampel) merupakan sebuah jenis katup yang digunakan untuk proses pengambilan bagian representatif dari air yang ada di dalam *boiler* untuk keperluan identifikasi sampel air dan mengontrol kualitas air yang ada di dalam *boiler* serta menganalisa air *boiler* tersebut.
17. *Inspection Hole*
    Dua lubang inspeksi berukuran kecil yang ada di dinding tungku pembakaran digunakan untuk memeriksa api pada *burner*. Sebagian suplai udara dikeluarkan dari *burner fan* (kipas *burner*) untuk mendinginkan jendela lubang inspeksi dan mencegah endapan jelaga.

18. *Manhole*
    Dua lubang akses manusia (*manhole*) diletakkan di bagian atas dan bagian bawah *boiler* untuk memudahkan pemeriksaan terhadap bagian dalam *boiler* oleh petugas inspeksi (surveyor).
19. *Access Doors*
    Akses ke *furnace* dan *outlet box* asap memungkinkan melewati *access door* (pintu akses) yang terletak di bagian bawah masing-masing pada *furnace* dan di *outlet box* asap. Kedua pintu akses tersebut dapat digunakan untuk memeriksa *generating tube bank.*
20. *Drain for Furnace*
    Pada bagian bawah *furnace* terdapat sebuah *socket* untuk menguras air pencuci *boiler*.

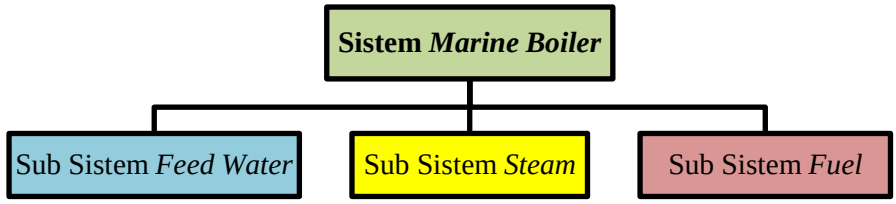
Tata letak dan bentuk dari komponen-komponen *marine boiler* di kapal dapat dilihat pada **Gambar 2.10 Konstruksi dan Komponen *Marine Boiler*.**



Gambar 2. 10 Konstruksi dan Komponen *Marine Boiler*
(Aalborg Marine Boiler Product Guide, 2004)

2.3.4 Sistem Kerja *Marine Boiler*

Perlu diketahui bahwa secara umum, sistem kerja pada *marine boiler* terdiri dari tiga sub sistem (Rachman, Garside, & Kholik, 2017) yaitu sub sistem air pengumpan (*feed water*), sub sistem uap (*steam*), dan sub sistem bahan bakar (*fuel*).



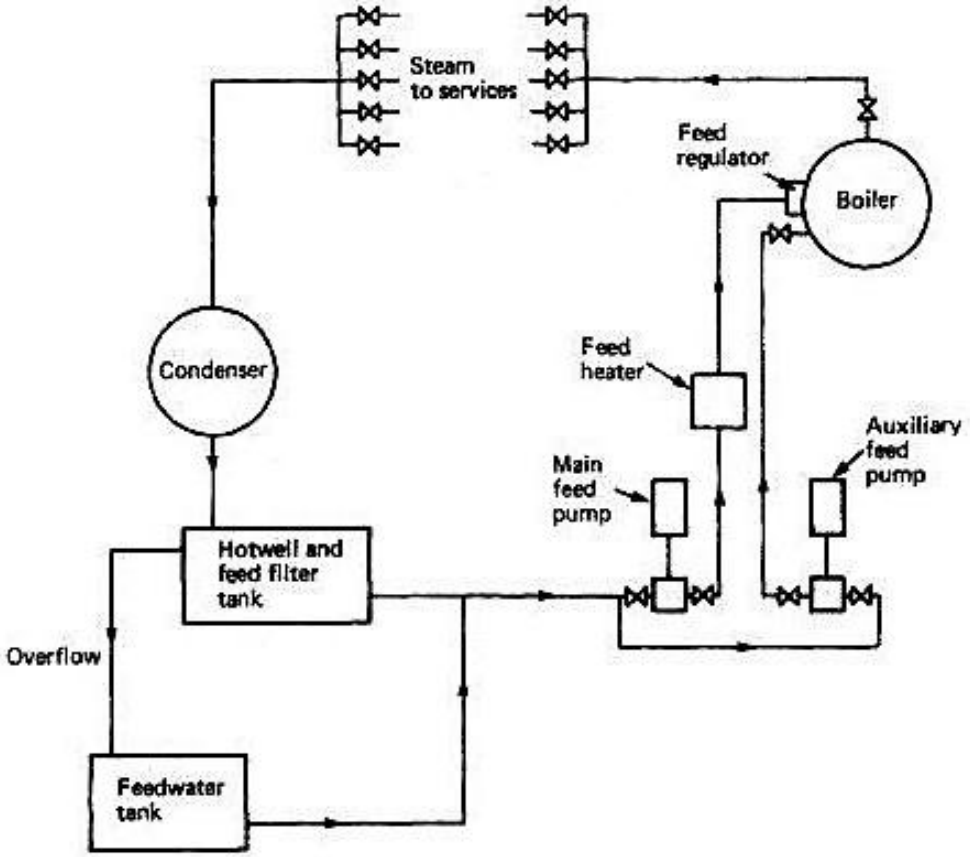
Gambar 2. 11 Sistem *Marine Boiler*
(Rachman, Garside, & Kholik, 2017)

Sub sistem air pengumpan (*feed water*) memiliki fungsi menyediakan dan memastikan kelancaran pasokan bahan baku utama dalam pembentukan uap yakni air yang biasa disebut sebagai air pengumpan (*feed water*) *boiler*. Sub sistem ini terdiri dari enam *equipment* utama yaitu *feedwater tank, hotwell, feed pump, feed heater, feed regulator*, dan *condenser*.

1. *Feedwater Tank*
   Berfungsi menyimpan kelebihan air pengumpan boiler (*overflow*) yang terjadi pada *hotwell*, sebagai tempat mengisi air pengumpan (*feed water*) untuk *marine boiler* dan sebagai tempat pengurasan serta penggantian air pengumpan (*feed water*) untuk *marine boiler.*
2. *Hotwell and Feed Filter Tank*
   Berfungsi sebagai tempat menampung dan menyaring air dari *condenser* untuk didistribusikan kembali menuju *marine boiler* dengan menggunakan *feed pump*.
3. *Main and Auxiliary Feed Pump*
   Berfungsi untuk mengalirkan air pengumpan (*feed water*) dari *hotwell* atau *feed water tank* menuju *marine boiler*.
4. *Feed Heater*
   Berfungsi sebagai pemanas air mula (*preheater*) agar tidak terjadi perubahan suhu secara mendadak (*thermal shock*) akibat perbedaan temperatur yang sangat tinggi ketika *feed water* dimasukkan ke dalam *marine boiler*.
5. *Feed Regulator*
   Sebagai *device* yang mengatur jumlah *feed water* yang masuk ke dalam *marine boiler* agar pada kondisi standar pengoperasian yakni pada kisaran NOWL (*Normal Operational Water Level*) dan sebagai sensor otomatis bagi *feed pump* dan *feed heater* untuk nyala dan mati (ON/OFF).

6. *Condenser*

Sebagai *equipment* yang berfungsi mengubah fase fluida berupa uap (*steam*) yang berasal dari sistem pemakaian *steam* untuk pemanas *cargo oil* maupun kebutuhan pemanas lainnya (*steam services*) menjadi fase air (*liquid*) untuk digunakan kembali sebagai air pengumpan (*feed water*) pada *marine boiler.*



Gambar 2. 12 Sub Sistem *Feed Water*
(Aalborg Marine Boiler Product Guide, 2004)

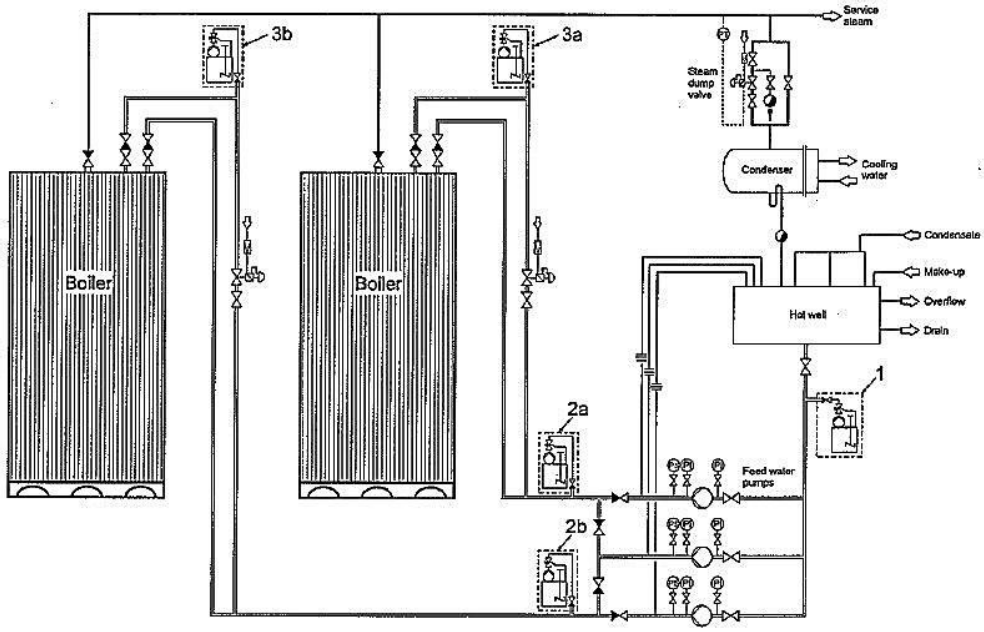
Sub sistem air pengumpan (*feed water*) menyediakan air untuk *boiler* secara otomatis sesuai dengan kebutuhan steam. Berbagai kran disediakan untuk keperluan perawatan dan perbaikan dari sub sistem *feed water* ini dimana penanganannya sangat diperlukan sebagai bentuk pemeliharaan untuk mencegah terjadi kerusakan dari sub sistem *steam.*

Sub sistem *steam* (uap) berfungsi mengumpulkan dan mengontrol produksi *steam* dalam *boiler*. *Steam* dialirkan melalui sistem perpipaan ke titik pengguna. Pada keseluruhan sistem, tekanan *steam* diatur menggunakan katup pengatur tekanan (*by-pass*) dan dipantau dengan alat pemantau tekanan (*pressure gauge*).

Sub sistem bahan bakar adalah semua perlatan yang digunakan untuk menyediakan bahan bakar untuk menghasilkan panas yang dibutuhkan pada *boiler*. Peralatan yang diperlukan pada sub sistem bahan bakar tergantung pada jenis bahan bakar yang digunakan pada sistem.

Boiler pada umumnya dapat membentuk uap dengan tekanan lebih besar dari tekanan rata-rata atmosfer. Sebuah *boiler* atau ketel uap harus di lengkapi peralatan (*equipment*) yang dapat membantu kinerjanya sehingga operasional *boiler* berjalan dengan aman. *Boiler* atau ketel uap harus mempunyai persyaratan (Putri, 2008) sebagai berikut:

1. Dapat menghasilkan uap dengan berat tertentu dalam waktu tertentu pula, dan tekanannya lebih besar dari satu atmosfer.
2. Kadar air yang di hasilkan pada uap panas harus sedikit mungkin.
3. Jika menggunakan alat pemanas lanjut uap (*superheater*), maka suhu uap pada pemakaian uap yang terakhir tidak boleh berubah terlalu besar.
4. Uap harus dibentuk dengan jumlah bahan bakar sehemat mungkin.
5. Jika pemakaian uap berubah-ubah (fluktuatif), maka tekanan uap tidak boleh berubah terlalu besar.



Gambar 2. 13 Sistem Kerja *Marine Boiler*
(Sumber: Aalborg Marine Boiler Product Guide)

Kegiatan pengoperasian boiler dimulai dari proses *commisioning* untuk boiler baru, *start* awal, operasi normal, sampai dengan *shut down* baik pada saat normal operasi maupun pada saat terjadi gangguan operasi.

Commissioning adalah proses pengujian operasional suatu pekerjaan secara nyata maupun secara simulasi untuk memastikan bahwa pekerjaan tersebut telah dilaksanakan dan memenuhi semua peraturan yang yang berlaku, regulasi, kode dan sesuai dengan standar yang telah ditetapkan antara kontraktor dan pengguna. (Sugiharto, 2015) Kegiatan inti *commissioning* pada boiler ini antara lain :

1. *Air Leakage Test* (uji kebocoran)
2. *Hydro Testing of Boiler* (uji hidrodinamis pada boiler)
3. *Readiness of Boiler Auxilliary* (uji kesiapan perlengkapan boiler)
4. *Gas Distribution Test* (uji distribusi gas)
5. *Boiler Light Up* (uji penyalaan boiler)
6. *Safety Valve Floating* (uji fungsi pada katup pengaman)
7. *Fuel Firing* (uji pembakaran pada tungku boiler)

Dalam pengoperasian boiler, ada beberapa parameter yang harus diperhatikan (Putri, 2008) yaitu:

1. Aliran Uap (*Steam Flow*)

Yaitu banyaknya uap yang harus dihasilkan boiler pada tingkat pengoperasian tertentu. Pengoperasian pada MCR (*Maximum Continous Rating*) merupakan pengoperasian *boiler* pada tingkat aliran uap maksimum yang bisa dijalankan secara berkelanjutan. Jika melebihi tingkat ini bisa merusak peralatan ataupun meningkatkan biaya perawatan. *Control load* untuk beban penuh aliran uap sekitar 48% dan sekitar 47 % untuk aliran uap pada tingkat MCR. *Control load* merupakan titik dimana suhu uap utama maupun uap pemanasan ulang telah mencapai titik desain kerjanya (kondisi stabil).

2. Tekanan Uap

Peningkatan temperatur pada air pengumpan (*feed water*) berdasarkan persamaan gas ideal, maka akan menyebabkan peningkatan tekanan (*pressure*) pada air hingga berubah fase menjadi uap. Hal ini tentu saja harus diperhatikan agar tekanan yang terjadi tidak melebihi ambang batas yang diizinkan sehingga menyebabkan *overpressure* (kelebihan tekanan) yang dapat menyebabkan kecelakaan.

3. Temperatur Uap

Dalam proses konversi wujud dari cair menjadi uap, air perlu dipanaskan di dalam *furnace*. Panas yang dihasilkan dari proses pembakaran di dalam *furnace* tersebut juga harus diperhatikan agar suhu uap yang dihasilkan memenuhi standar yang ditentukan. Karena jika suhu uap kurang dari standar tersebut, maka efisiensi kerja *boiler* akan turun namun jika terlalu tinggi akan berpengaruh pada gas buangnya dan bisa menyebabkan kenaikan tekanan (*pressure*) yang berlebih sehingga menyebabkan kecelakaan.

4. Efisiensi *Boiler*

Untuk melihat apakah desain suatu *boiler* telah tepat ditentukan oleh beberapa faktor yang mempengaruhi,yakni diantaranya kegunaan unit *boiler* itu sendiri yaitu apakah uap yang harus dihasilkan konstan atau bervariasi sesuai kebutuhan. Selanjutnya yang menentukan juga adalah jenis dan kualitas bahan bakar yang akan dibakar : apakah padat, cair atau gas. Seberapa banyak uap harus dihasilkan tiap jamnya apakah ratusan atau bahkan jutaan kg tiap jamnya juga perlu dipertimbangkan dalam desain.

5. Fuel Analysis

Analisa ini dilakukan untuk mengetahui kandungan gas (oksigen, hidrogen dan karbon) yang terdapat dalam bahan bakar yang digunakan. Karena kualitas bahan bakar seiring waktu dapat sangat berbeda. Perbedaan ini berpengaruh terhadap kebutuhan udara dan panas yang dilepaskan di ruang bakar, begitu juga dengan massa aliran gas buang yang meninggalkan ruang bakar.

6. Feedwater Temperature

Perubahan suhu air yang masuk ke *boiler* menentukan tingkat pembakaran yang diperlukan di *furnace*, lebih lanjut lagi hal tersebut akan mempengaruhi panas yang dihasilkan oleh *boiler* dan banyaknya massa aliran yang keluar dari *boiler*.

7. Excess Air

Banyaknya udara yang masuk ruang bakar berpengaruh terhadap jumlah panas yang dibawa dari *furnace (dry gas loss*) , banyaknya udara yang keluar merupakan faktor penting yang menentukan tingkat efisiensi dari *boiler*.

Pemakaian dan perawatan boiler yang baik akan membuat efisiensi boiler semakin tinggi dan menghemat biaya operasional secara umum. Berbagai usaha dapat dilakukan untuk menghemat biaya produksi uap diantaranya dengan penambahan peralatan guna memperbesar efisiensi dan bahkan adanya penggantian jenis bahan bakar yang digunakan.

Pengoperasian dan pemeliharaan yang baik akan bisa meningkatkan efisiensi boiler secara signifikan apabila dilakukan secara rutin dan sesuai dengan aturan maupun prosedur yang berlaku. Untuk menjaga kualitas dan keandalan boiler, diperlukan pemeliharaan secara terjadwal agar boiler dapat bekerja dengan baik pada saat beroperasi. Perawatan dan pemeliharaan yang terjadwal dengan baik dapat meminimalisasi gangguan dan kerusakan serta dapat meningkatkan kinerja dari boiler.

2.4 *State of the Art* (SOTA)

State of the Art (SOTA) menunjukkan landasan teori yang dapat menjadi rujukan dalam penyusunan karya tulis ilmiah. Berikut merupakan daftar rujukan literatur ilmiah dari penelitian-penelitian sebelumnya tentang *Reliability Centered Maintenance* (RCM) yang ditunjukkan pada **Tabel 2.7 *State of the Art* (SOTA).**

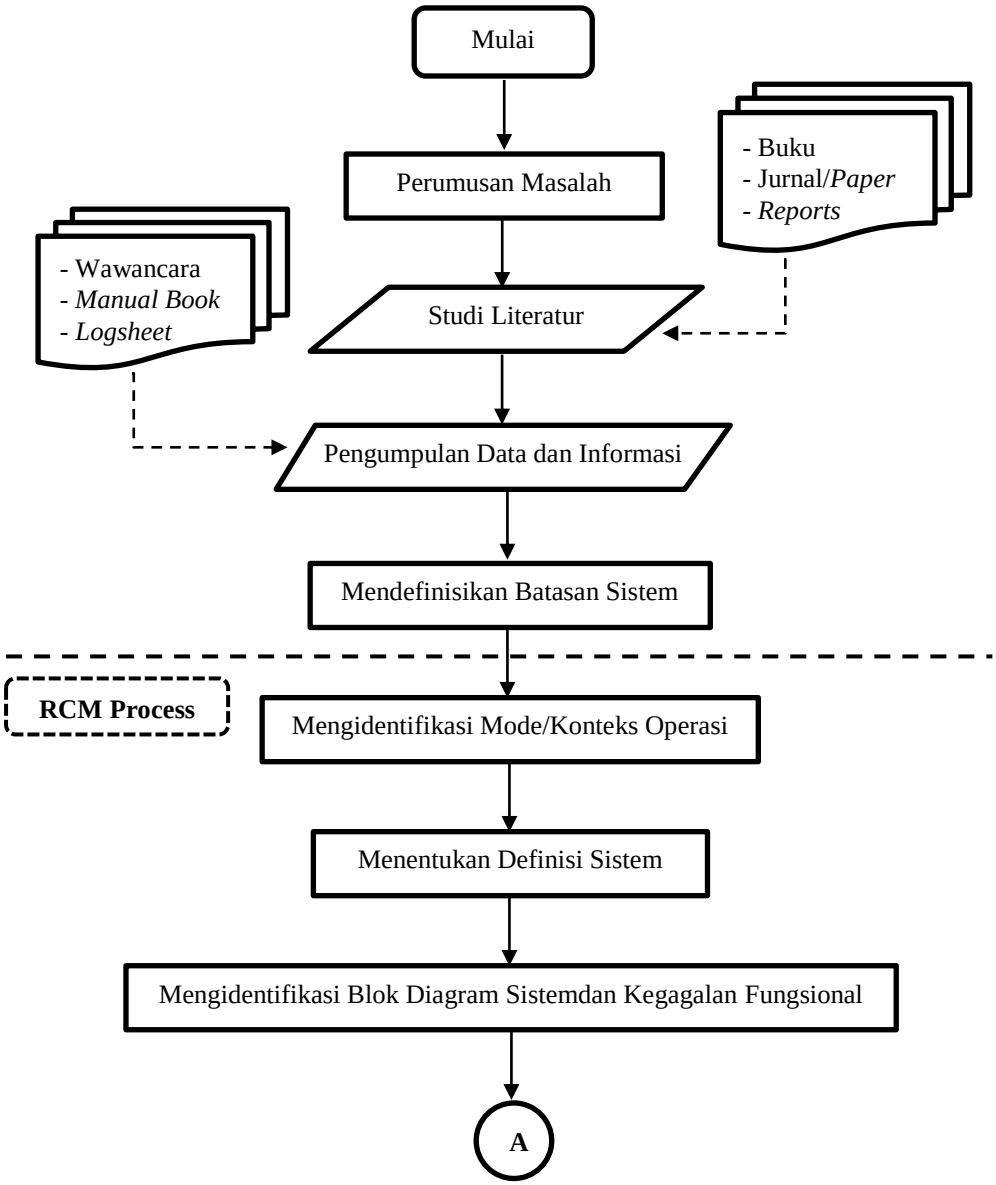
Tabel 2. 7 *State of the Art* (SOTA)

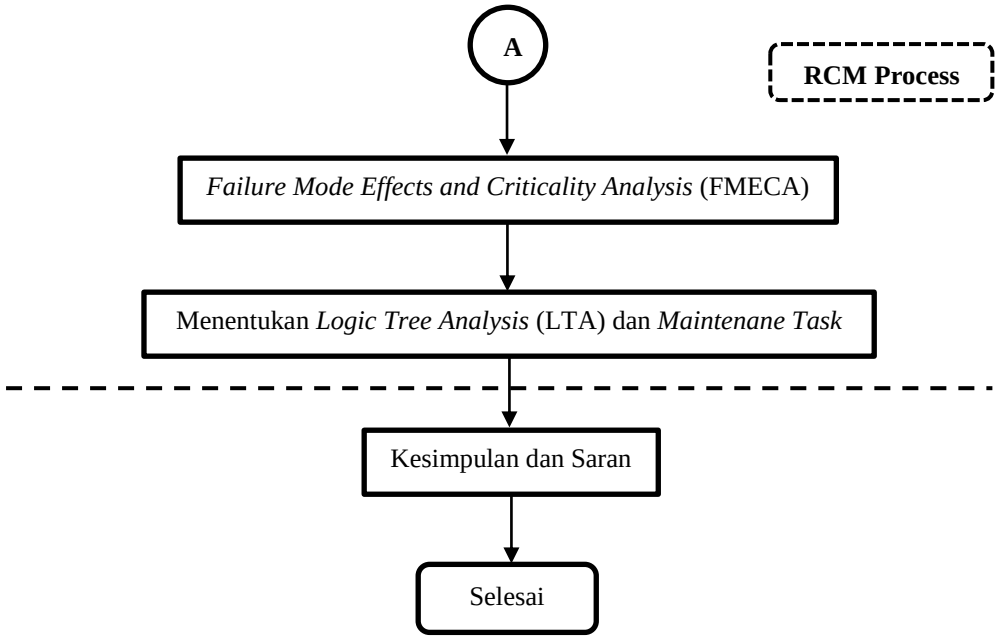
Tahun	Peneliti	Judul	Hasil
2000	N. Cotaina, F. Matos adn J. Carretero	*Study of Existing Reliability Centered Maintenance (RCM) Approaches Used in Different Industries*	Di beberapa industri penggunaan RCM dapat meningkatkan keandalan dan efektifitas biaya dari sistem pada beberapa industri tersebut.
2006	A. K. Alghofari, M. Djunaidi and A. Fauzan	Perencanaan Pemeliharaan Mesin Ballmill dengan Basis RCM (*Reliability Centered Maintenance*)	Implementasi RCM untuk menentukan pemeliharaan yang optimal serta dapat memprediksikan langkah untuk mengatasi kerusakan yang mungkin terjadi pada periode berikutnya berdasarkan data-data yang ada.
2008	Sulistiyono, Rachmad Tri, Juniani, Anda Iviana dan Setyana, Iva	*Implementation of RCM II (Reliability Centered Maintenance) and RPN (Risk Priority Number) in Risk Assessment and Scheduling Maintenance Task at HPB (High Pressure Boiler) Based on JSA (Job Safety Analysis)*	Tugas pemeliharaan yang terjadwal di HPB dengan menerapkan metode RCM II dan RPN dalam penilaian risiko dan mengamati potensi bahaya berdasarkan tugas perawatan yang telah dijadwalkan.
2009	D. Sarchiz, D. Bica and O. Georgescu	*Mathematical Model of Reliability Centered Maintenance (RCM) Power Transmission and Distribution Networks Applications*	Mengembangkan model matematika intervensi eksternal pada sistem yang selanjutnya disebut *Renewal Processes.*
2010	Lazakis, Iraklis, Turan, Osman and Aksu, Seref	*Increasing Ship Operational Reliability Through the Implementation of A*	Strategi pemeliharaan prediktif dengan menggabungkan tugas operasional dan

Tahun	Peneliti	Judul	Hasil
		Holistic Maintenance Management Strategy	pemeliharaan kapal yang ada dengan kemajuan yang berasal dari teknik baru yang diterapkan.
2014	V. Chaturvidani and A. Singh	*Reliability-Centered Maintenance (RCM) of Quenching Car Used in Coke Oven Plants*	Analisis RCM diterapkan untuk pemeliharaan mobil pendinginan untuk fokus pada komponen yang sering gagal.
2016	Ayre, Timothy and Jenkins, Derrick	*Life Cycle Reliability and Maintenance Analyses of Fire-Tube Boilers*	Menganalisis keandalan siklus hidup dan pemeliharaan boiler pipa-api dengan menerapkan konsep analisis FMEA dan pemodelan grafik ikatan untuk mensimulasikan efek strategi pemeliharaan pada biaya siklus hidup boiler.
2017	Rachman, Hamim, Garside, Annisa Kesy dan Kholik, Heri Mujayin	Usulan Perawatan Sistem Boiler dengan Metode Reliability Centered Maintenance (RCM)	Usulan perawatan metode RCM dapat menurunkan *down time* sebesar 11,33% dari metode yang dilakukan oleh PLTU PT Indo Pusaka Berau pada sistem boiler.
2018	Adumene, Sidum and Nitonye, Samson	*Application of Probabilistic Model for Marine Steam System Failure Analysis under Uncertainity*	Mengaitkan risiko dan kegagalan boiler uap laut untuk mencegah bahaya operasional berdasarkan kegagalan fungsional yang umumnya terjadi.

BAB III
METODOLOGI PENELITIAN

Pada bab metodologi penelitian ini akan diberikan penjelasan mengenai metode yang digunakan dan urutan pelaksanaan percobaan dalam penelitian ini. Suatu metode penelitian harus disusun secara sistematis dan terarah untuk mendapatkan hasil penelitian yang tepat sesuai dengan rumusan masalah dan tujuan penelitian. Adapun langkah-langkah dalam proses penelitian ini dapat dilihat pada **Gambar 3.1** ***Flow Chart Diagram*** sebagai berikut:





Gambar 3. 1 *Flow Chart Diagram*

3.1 Perumusan Masalah

Tahap ini bertujuan untuk memaparkan latar belakang masalah yang diangkat dalam penelitian, merumuskan masalah sebagai bahan yang akan dibahas dalam penelitian, menetapkan tujuan yang akan dicapai, serta menentukan asumsi dan batasan yang akan membantu dalam penyelesaian masalah dalam penelitian. Dalam prosesnya, aktifitas yang dilakukan bisa beragam, seperti diskusi dengan para ahli di bidangnya, mencari beberapa referensi buku, jurnal/*paper* dan *proceeding* yang berkaitan dengan tema penelitian yang akan dilakukan atau dengan kata lain merupakan studi literatur serta melakukan observasi kegiatan serta mengidentifikasi studi kasus yang berkaitan dengan tema penelitian yang akan dilakukan pada kondisi yang sebenarnya di lapangan.

3.2 Studi Literatur

Studi literatur akan digunakan untuk mendapatkan kajian secara teoritis, mengetahui metode yang dapat digunakan untuk menyelesaikan permasalahan dalam penelitian ini. Teori yang digunakan yaitu teori-teori tentang *Reliability Centered Maintenance* (RCM) II, standar yang digunakan dan teori-teori mengenai sistem atau *equipment* yang akan menjadi objek penelitian yakni *marine boiler* di kapal. Selain itu juga dilakukan studi terhadap penelitian-penelitian yang telah ada sebelumnya yang dapat dijadikan sebagai pertimbangan dan acuan bagi penelitian yang akan dilakukan.

Hasil studi literatur akan dijadikan bahan acuan dalam menentukan *step-by-step* penelitian yang akan dilakukan dan sebagai rujukan dalam pengambilan keputusan dalam memutuskan serta memecahkan berbagai rumusan masalah yang telah dirumuskan sebelumnya. Data yang diperoleh dari kegiatan studi literatur ini adalah berupa data sekunder.

3.3 Pengumpulan Data dan Informasi

Data-data serta informasi yang dibutuhkan sebagai bahan utama dalam penelitian ini dikumpulkan dari hasil observasi lapangan, studi literatur dan wawancara. Pada penelititan ini dilakukan obervasi lapangan di PT Gemilang Bina Lintas Tirta yakni lebih tepatnya di kapal tanker MT Bull Kalimantan. Pada proses pengumpulan data, ada dua proses yakni dengan melakukan wawancara ke pihak-pihak yang secara langsung menangani atau bekerja di bagian *maintenance* atau mengambil data informasi dari *manual book, logsheet* dan dokumen-dokumen lain yang berkaitan dengan *maintenance* dan operasional kapal tanker MT Bull Kalimantan milik PT Gemilang Bina Lintas Tirta.

- Data yang didapat melalui wawancara:
  1. *Work Order* (WO)
  2. Penyebab umum kerusakan
  3. Data historis kerusakan
  4. Dokumen gambar sistem
  5. Rekomendasi solusi untuk mengatasi dan mencegah *failure*
  6. Dampak kerusakan terhadap sistem lainnya
  7. Kerugian materi apabila terjadi kerusakan
  8. Fungsi primer dan sekunder pada *marine boiler*
- Data yang didapat dari *manual book, logsheet* dan dokumen lainnya:
  1. Data waktu operasional
  2. Spesifikasi *marine boiler*
  3. Data *shut down*
  4. Data waktu perbaikan (*downtime*)
  5. Data komponen yang sering mengalami kerusakan (*failure*)
  6. PID dan PFD dari sistem *marine boiler*
  7. Data *corrective maintenance* yang dilakukan

3.4 Mendefinisikan Batasan Sistem

Marine boiler di kapal merupakan sistem pemanas utama di kapal tanker. Berdasarkan sistem kerjanya, *marine boiler* terdiri dari tiga sub sistem yakni diantaranya adalah sub sistem bahan bakar (*fuel system*), sub sistem air pengumpann (*feed water system*) dan sub sistem uap (*steam system*). Beberapa sub sistem tersebut saling terintegrasi satu sama lain sehingga ketika terjadi kegagalan pada satu sub sistem maka akan berpengaruh pada sub sistem lainnya dan sistem *marine boiler* secara umum.

3.5 Mengidentifikasi Mode/Konteks Operasi

Untuk mendefinisikan karakteristik operasi dengan benar, berbagai mode operasi untuk aset atau peralatan harus diidentifikasi. Mode operasi digunakan untuk menentukan konteks operasi untuk setiap item yang diidentifikasi dalam daftar mesin sebagai berikut:

- Lingkungan fisik di mana kelompok fungsional dioperasikan
- Deskripsi yang tepat tentang cara di mana kelompok fungsional digunakan
- Persyaratan kinerja yang ditentukan dari grup fungsional serta kinerja yang diperlukan dari setiap grup tambahan di mana grup fungsional dihubungkan

Pengembangan konteks operasi adalah untuk mempertimbangkan pengaturan sistem, kinerja atau standar kualitas, standar lingkungan, standar keselamatan dan cara operasi. Konteks operasi harus dikembangkan untuk setiap tingkat hierarki mesin.

Semua mode operasi, sebagaimana berlaku, dalam kondisi lingkungan desain normal harus dipertimbangkan. Mode operasi berikut adalah biasa diterapkan untuk kapal:

i) Kondisi berlayar normal dengan kecepatan penuh
ii) Kecepatan operasi maksimum yang diizinkan di perairan yang padat
iii) Bermanuver menyamping
iv) Penanganan kargo pada saat bongkar muat

Saling ketergantungan fungsional dari sistem yang dipilih dalam kelompok fungsional akan dijelaskan melalui penggunaan diagram blok atau diagram *fault-tree* atau dalam format naratif untuk memungkinkan efek kegagalan dapat dipahami dengan lebih komprehensif. Daftar mode kegagalan untuk masing-masing sistem yang dianalisis akan dikembangkan.

3.6 Menentukan Definisi Sistem

Setiap sistem yang dipilih untuk analisis RCM harus didefinisikan. Definisi sistem melibatkan:

1. Membagi grup fungsional di kapal ke dalam sistem, subsistem (sesuai kebutuhan karena kompleksitas), *item* peralatan, dan komponen.
2. Pengembangan lebih lanjut dari deskripsi naratif untuk setiap kelompok fungsional, sistem, item peralatan dan komponen.

Deskripsi naratif untuk setiap tingkat hierarki dan persyaratan fungsional yang sesuai akan dikembangkan, memberikan informasi berikut:

i) Gambaran umum operasi dan struktur
ii) Hubungan fungsional antara sistem atau peralatan item atau komponen
iii) Batas kinerja fungsional yang dapat diterima dari item sistem atau peralatan atau komponen untuk setiap mode operasi dipertimbangkan
iv) Kendala yang dihadapi dalam operasional

Pembagian fungsional sistem harus dilakukan dengan menggunakan pendekatan *top-down* sampai tingkat rincian yang dicapai fungsinya yang diidentifikasi dengan item peralatan atau komponen. Tingkat detail harus sedemikian rupa sehingga item atau komponen peralatan:

i) Dapat diidentifikasi karena kontribusinya terhadap fungsi keseluruhan kelompok fungsional
ii) Dapat diidentifikasi untuk mode kegagalannya
iii) Adalah unit fisik paling mudah untuk pemeliharaan yang dapat ditentukan

3.7 Mengidentifikasi Blok Diagram Sistem dan Kegagalan Fungsi

Fungsi untuk grup fungsional, sistem, item peralatan, dan komponen harus diidentifikasi. Saat mengidentifikasi fungsi, mode operasi yang berlaku dan konteks operasi harus tercatat dengan baik. Semua fungsi harus diidentifikasi.

3.7.1 Diagram Blok

Diagram blok yang dikembangkan menunjukkan urutan aliran fungsional dari kelompok fungsional, baik untuk pemahaman teknis tentang fungsi dan operasi sistem dan untuk analisis selanjutnya. Minimal diagram blok berisi:

i) Pembagian grup fungsional menjadi sistem, item peralatan, dan komponen.
ii) Semua input dan output berlabel yang sesuai dan nomor identifikasi dimana setiap sistem direferensikan secara konsisten.
iii) Semua redudansi, jalur sinyal alternatif, dan fitur teknik lainnya yang menunjukkan ukuran tindakan *"fail-safe"*.

3.7.2 Fungsi Sistem

Ketika mengidentifikasi fungsi, standar kinerja adalah untuk menggambarkan persyaratan minimum yang dapat diterima untuk konteks operasi dibandingkan kemampuan desain sistem atau komponen. Standar kinerja harus didefinisikan dengan jelas atau dikuantifikasi karena digunakan untuk menentukan kegagalan. Fungsi harus dikategorikan sebagai berikut:

i) *Primary Functions*. Fungsi-fungsi ini adalah alasan mengapa ada kelompok fungsional atau item sistem atau peralatan atau komponen. Pada sistem *marine boiler* fungsi utamanya adalah menjadi sistem pemanas bagi muatan kapal tanker yaitu berupa *crude oil* di ruang muat untuk menjaga karakteristik fluidanya.
ii) *Secondary Functions*. Fungsi-fungsi ini adalah merupakan tambahan dari fungsi utama. Pada sistem *marine boiler* fungsi tambahannya yakni merupakan sistem pemanas pada sistem-sistem lainnya yang ada di kapal yang memerlukan pemanas misalnya sistem bahan bakar kapal, sistem pelumas mesin kapal, sistem pendingin mesin kapal dan lain-lain.

Daftar kategori fungsional berikut dengan beberapa contoh sebagai acuan dalam menentukan fungsi sekunder untuk sistem yang akan dianalisis yaitu sebagai berikut:

i. *Environment Integrity*. Fluida dari peralatan atau batas gas emisi harus tunduk pada MARPOL atau peraturan lainnya
ii. *Safety, Structural Integrity*. Getaran, kerusakan atau defleksi pada struktur, batasan-batasan keselamatan terhadap operator manusia atau petugas perawatan.
iii. *Control, Containment, Comfort.* Kendali peralatan, pengurungan terhadap fluida atau gas dalam suatu sistem, kenyamanan pribadi personel yang bekerja.
iv. *Appearance.* Visibilitas peralatan yang dapat dengan mudah dilihat oleh operator atau khalayak umum.
v. *Protection.* Alat-alat yang digunakan untuk melindungi peralatan (*equipment*) dari kecepatan berlebih (*overspeed*), tekanan tinggi atau temperatur tinggi.
vi. *Economy, Efficiency.* Efisiensi bahan bakar, konsumsi minyak pelumas.
vii. *Supplementary Functions.* Fungsi unik lainnya di dalam kelompok fungsional atau sistem atau item peralatan atau komponen.

3.7.3 Kegagalan Fungsi

Daftar kegagalan fungsional untuk setiap fungsi harus diidentifikasi untuk masing-masing kelompok fungsional, sistem, item peralatan dan komponen. Kegagalan fungsional harus diidentifikasi menggunakan kegagalan yang disarankan berikut ini:

i) Tidak berfungsi atau tidak ada fungsi
ii) Kurang dari *output* fungsi yang ditentukan
iii) Lebih dari *output* fungsi yang ditentukan
iv) Operasi fungsi yang terputus-putus
v) Operasi fungsi yang prematur
vi) Gagal mengoperasikan fungsi pada waktu yang ditentukan
vii) Gagal menghentikan pengoperasian fungsi pada waktu yang ditentukan
viii) Kegagalan fungsional lain yang sesuai untuk kelompok fungsional

Setiap kegagalan fungsional harus didokumentasikan dalam pernyataan kegagalan fungsional yang berisi kata kerja, objek, dan deviasi fungsional.

3.8 *Failure Modes, Effect and Criticality Analysis* (FMECA)

FMECA harus dipertimbangkan menggunakan pendekatan *bottom-up*, mulai dari tingkat detail terendah yang diidentifikasi selama partisi sistem. Contoh format FMECA bottom-up seperti di bawah ini:

Tabel 3. 1 Format Lembar Kerja FMECA *Bottom-Up*

Item	Failure Mode	Causes	Failure Characteristic	Local Effects	Functional Failures	End Effects	Matrix	Severity	Current Likelihood	Current Risk	Failure Detection/ Corrective Measures

Prosedur analisa FMECA dibagi menjadi beberapa langkah berikut:

Gambar 3. 2 Langkah-Langkah Prosedur Analisa FMECA

3.8.1 Mengidentifikasi Mode Kegagalan

Mode kegagalan adalah cara dimana kegagalan diamati. Secara umum mode kegagalan menggambarkan cara kegagalan terjadi dan dampaknya pada peralatan atau sistem. Semua item peralatan atau penyebab terkait komponen dari mode kegagalan yang diidentifikasi harus diidentifikasi.

Daftar mode kegagalan untuk berbagai item peralatan dan komponen ditampilkan seperti tabel di bawah ini:

Tabel 3. 2 Contoh Identifikasi Mode Kegagalan

Equipment Item	***Failure Modes***
Boiler	• *External leak/lupture* • *Tube leak/lupture* • *Tube plugged/choked* • *Tube fouled* • *Overfired* • *Underfired* • *Exhaust emissions exced limits*
Burner	• *External leak/lupture* • *Plugged/choked* • *Fouled* • *Overfired* • *Underfired* • *Exhaust emissions exced limits*
Exhaust Valve	• *External leak/lupture* • *Plugged/choked* • *Fails to open on demand* • *Fails to close on demand* • *Fails to reseat* • *Opens prematurely* • *Closes prematurely*

Perlu diperhatikan bahwa mode kegagalan lain mungkin ada yang tidak tercantum dalam ABS Guide. Mode kegagalan yang tercantum dalam ABS Guide dapat digunakan untuk menggambarkan kegagalan setiap item peralatan atau komponen dalam istilah yang cukup spesifik. Ketika digunakan bersama dengan spesifikasi kinerja yang mengatur *input* dan *output* pada diagram blok sistem, semua mode kegagalan potensial dapat diidentifikasi dan dijelaskan secara lebih detail dan komprehensif. Kegagalan harus diasumsikan oleh satu mode kegagalan yang mungkin pada suatu waktu dengan pengecualian "kegagalan tersembunyi" di mana yang kedua harus terjadi untuk mengekspos "kegagalan tersembunyi" tersebut.

Mode kegagalan pada item atau komponen peralatan juga bisa menjadi penyebab kegagalan sistem. Karena mode kegagalan mungkin memiliki lebih dari satu penyebab, semua penyebab independen potensial untuk setiap mode kegagalan harus diidentifikasi. Karakteristik kegagalan untuk mode kegagalan harus diidentifikasi sebagai berikut:

i) *Wear-in Failure.* Kegagalan *wear-in* digunakan untuk kegagalan yang terkait dengan cacat fabrikasi dan kesalahan pada pemasangan, pemeliharaan, atau produk cacat/gagal di awal.
ii) *Random Failure*. Kegagalan acak harus digunakan untuk kegagalan yang terkait dengan kegagalan acak yang disebabkan oleh tekanan mendadak, kondisi ekstrem, kesalahan manusia yang tidak menentu atau kegagalan apa pun yang tidak dapat diprediksi oleh waktu.
iii) *Wear-out Failure.* Kegagalan *wear-out* harus digunakan untuk kegagalan yang terkait dengan masalah akhir masa manfaat peralatan.

3.8.2 Dampak Kegagalan

Dampak dari kegagalan pada tiap mode kegagalan dijabarkan pada penjelasan berikut ini:

i) *The Local Effect.* Efek lokal adalah untuk menggambarkan perubahan awal dalam item peralatan atau operasi komponen ketika mode kegagalan terjadi. Metode deteksi kegagalan (jika ada) harus diidentifikasi dan ketersediaan sistem atau peralatan siaga untuk menyediakan fungsi yang sama.
ii) *The Functional Failure.* Kegagalan fungsional adalah untuk menggambarkan efek dari mode kegagalan pada sistem atau kelompok fungsional, seperti potensi kerusakan fisik pada sistem atau item peralatan atau potensi kerusakan sekunder baik untuk item peralatan dalam sistem atau item peralatan yang tidak terkait di sekitarnya.
iii) *The End Effect.* Efek akhir adalah untuk menggambarkan efek keseluruhan pada sistem di kapal, kontrol arah, lingkungan, kebakaran dan atau ledakan. Satu mode kegagalan dapat menghasilkan beberapa efek akhir tersebut.

Untuk kegagalan dalam sistem dengan tindakan korektif, hal tersebut terbukti segera efektif atau dijadikan *online* dengan penundaan waktu yang dapat diabaikan. Jika tindakan operator diperlukan untuk membawa langkah-langkah perbaikan *online*, efek penundaan operator dapat dipertimbangkan. Diasumsikan untuk analisis bahwa tindakan korektif berhasil.

Jika deteksi kegagalan tidak jelas (misalnya tersembunyi) dan sistem dapat melanjutkan dengan operasi spesifiknya, analisis diperluas untuk menentukan efek dari kegagalan kedua, yang dikombinasikan dengan kegagalan pertama yang tidak terdeteksi dapat menghasilkan efek yang lebih parah. Harus diasumsikan untuk analisis bahwa setiap tindakan korektif yang diberikan berhasil kecuali jika tindakan korektif adalah kegagalan kedua yang pengaruhnya dianalisis.

Tindakan yang diperlukan untuk memperbaiki komponen atau *item* peralatan yang rusak ditunjukkan pada efek akhirnya. Informasi ini termasuk perbaikan barang atau komponen peralatan, perbaikan peralatan lain yang dipengaruhi oleh mode kegagalan, personel yang dibutuhkan, fasilitas perbaikan khusus dan waktu untuk melakukan perbaikan.

3.8.3 Deteksi Kegagalan

Informasi berikut akan dimasukkan dalam kolom *Failure Detection/ Corrective Measures* pada lembar kerja FMECA *bottom-up* yaitu:

i) Sarana deteksi kegagalan, seperti perangkat peringatan visual atau yang dapat terdengar, perangkat penginderaan otomatis, instrumentasi penginderaan atau indikasi unik lainnya jika diterapkan. Istilah "jelas" harus ditunjukkan.
ii) Ketika deteksi kegagalan tidak jelas, maka istilah “tersembunyi” harus ditunjukkan.

3.8.4 Tindakan Korektif

Informasi berikut akan dimasukkan dalam kolom *Failure Detection/ Corrective Measures* pada lembar kerja FMECA *bottom-up* yaitu:

i) Ketentuan yang merupakan fitur desain pada tingkat apa pun untuk membatalkan efek dari mode kegagalan (misalnya, sistem *standby* yang memungkinkan pengoperasian yang berkelanjutan dan aman, perangkat keselamatan, ketentuan pemantauan atau alarm yang memungkinkan operasi terbatas atau membatasi kerusakan dan mode operasional alternatif).
ii) Ketentuan yang mengharuskan tindakan operator untuk menghindari atau mengurangi efek dari mode kegagalan harus disediakan. Kemungkinan dan efek yang dihasilkan dari kesalahan operator harus dipertimbangkan jika tindakan korektif atau inisiasi item peralatan yang berlebihan memerlukan *input* operator ketika mengevaluasi cara untuk menghilangkan efek kegagalan lokal.

3.8.5 Analisa Tingkat Kekritisan

Analisis kekritisan digunakan untuk menentukan peringkat risiko yang terkait dengan masing-masing mode kegagalan yang diidentifikasi selama analisa FMECA dengan menilai tingkat keparahan Efek Akhir dan kemungkinan kegagalan berdasarkan data terbaik yang tersedia. Ini memungkinkan perbandingan setiap mode kegagalan dengan semua mode kegagalan lainnya sehubungan dengan risiko. Kemungkinan kegagalan dapat ditentukan dengan menggunakan salah satu dari dua pendekatan ini:

a. Kuantitatif. Pendekatan ini digunakan jika data keandalan tersedia. Ketika pendekatan ini digunakan, sumber data dan konteks operasi harus tersedia.
b. Kualitatif. Ketika data kuantitatif tidak tersedia untuk menentukan kemungkinan kegagalan, pertimbangan teknis bisa dilakukan berdasarkan pengalaman sebelumnya.

Probabilitas kegagalan didasarkan pada data tingkat kegagalan yang masih terjadi untuk item peralatan atau komponen yang beroperasi dalam mode operasi yang sama dan konteks operasi untuk tugas pemeliharaan yang telah ada (*existing maintenance*). Jika data ini tidak tersedia, maka tingkat kegagalan diperkirakan berdasarkan pada asumsi bahwa tidak ada pemeliharaan yang dilakukan.

Tingkat keparahan (*severity*) untuk konsekuensi yang disebabkan oleh kehilangan fungsional (sebagaimana yang berlaku), kebocoran (*loss of containment*), ledakan atau kebakaran dan keselamatan, harus dijelaskan dan didefinisikan. Deskriptor digunakan untuk mendefinisikan setiap tingkat keparahan (*severity*). Empat tingkat keparahan direkomendasikan untuk didefinisikan menggunakan format seperti yang ditunjukkan di bawah ini:

Tabel 3. 3 Format Definisi Tingkat Keparahan (*Severity*) atau Konsekuensi

Severity Level	*Descriptions for Severity Level*	*Definition for Severity Level*	*Applicable for Functional Groups for*
1	*Minor, Neglible*	*Little or no response necessary*	*Loss of Containment*
2	*Major, Marginal, Moderate*	*Limited response of short duration*	
3	*Critical, Hazardous, Significant*	*Serious/significant commitment of resources and personnel*	
4	*Catastropic, Critical*	*Complete loss of containment. Full scale response of extended duration to mitigate effects on environment.*	

Severity Level	*Descriptions for Severity Level*	*Definition for Severity Level*	*Applicable for Functional Groups for*
1	*Minor, Neglible*	*Minor impact on personnel / No impact on public*	*Safety*
2	*Major, Marginal, Moderate*	*Professional medical treatment for personnel / No impact on public*	
3	*Critical, Hazardous, Significant*	*Serious injury to personnel / Limited impact on public*	
4	*Catastropic, Critical*	*Fatalities to personnel / Serious impact on public*	

Severity Level	*Descriptions for Severity Level*	*Definition for Severity Level*	*Applicable for Functional Groups for*
1	*Minor, Neglible*	*No damage to affected equipment or compartment, no significant operational delays.*	*Explosion*
2	*Major, Marginal, Moderate*	*Affected equipment is damaged, operational delays*	
3	*Critical, Hazardous, Significant*	*An occurence adversely affecting the vessel's seaworthiness or fitness for service or route*	
4	*Catastropic, Critical*	*Loss of vessel or results in total constructive loss*	

Untuk kemungkinan kegagalan (*likelihood of failure*), terdapat lima kemungkinan kegagalan yang direkomendasikan untuk dijelaskan dan didefinisikan. *Range* berdasarkan jumlah kegiatan per tahun harus disediakan. Namun, frekuensi lain yang menggunakan kegiatan per jam operasi atau unit praktis lainnya dapat diterapkan. Contoh format yang menggambarkan deskriptor dan definisi ditunjukkan seperti di bawah ini:

Tabel 3. 4 Format Kriteria Kemungkinan Kegagalan

Kemungkinan Kegagalan	Deskripsi
Improbable	Kurang dari 0.001 kejadian per tahun
Remote	0.001 hingga 0.01 kejadian per tahun
Occasional	0.01 hingga 0.1 kejadian per tahun
Probable	0.1 hingga 1 kejadian per tahun
Frequent	1 atau lebih kejadian per tahun

Matriks risiko dikembangkan di mana setiap sel dalam matriks risiko harus ditetapkan sebagai deskriptor prioritas (tinggi, sedang, rendah, dll.). Pemeringkatan risiko lainnya seperti nomor prioritas atau angka kritis juga dapat digunakan. Minimal tiga peringkat harus disediakan. Peringkat terendah adalah untuk menandakan risiko yang dapat diterima dan peringkat risiko tertinggi adalah untuk menandakan risiko yang tidak dapat diterima. Matriks risiko harus dikembangkan untuk kelompok fungsional dan kategori konsekuensi. Selama pengembangan matriks risiko, peringkat risiko untuk kemungkinan dan tingkat keparahan (*severity*) tertentu dapat bervariasi ketika membandingkan kelompok fungsional dan kategori konsekuensi. Untuk kasus seperti itu, matriks risiko terpisah untuk kelompok fungsional / kategori konsekuensi harus dibuat. Contoh format matriks risiko ditunjukkan sebagai berikut:

Tabel 3. 5 Format Matriks Resiko

Severity Level	*Likelihood of Failure*				
	Improbable	*Remote*	*Occasional*	*Probable*	*Frequent*
4	Medium	Medium	High	High	High
3	Low	Medium	Medium	High	High
2	Low	Low	Medium	Medium	High
1	Low	Low	Low	Medium	Medium

Untuk setiap mode kegagalan, analisa FMECA adalah untuk menunjukkan semua kehilangan fungsi, mengidentifikasi tingkat keparahan, probabilitas kegagalan dan risiko yang dihasilkannya. Kategori konsekuensi (misalnya kebocoran (*loss of containment*), ledakan atau kebakaran, keselamatan, dan lain-lain) harus dipertimbangkan dalam analisa FMECA ketika mode kegagalan secara langsung mulai menyebabkan konsekuensi terhadap kegagalan.

Kepercayaan dalam karakterisasi risiko harus dinilai melaui proses *assessment*. Kepercayaan yang tinggi pada karakterisasi risiko menunjukkan risiko dikarakterisasi dengan benar dan dapat digunakan tanpa diskusi lebih lanjut. Kepercayaan yang rendah menunjukkan ketidakpastian dan bahwa data tambahan tentang frekuensi kejadian atau tingkat keparahan Efek Akhir diperlukan sebelum risiko dapat digunakan dalam strategi manajemen kegagalan. Kepercayaan yang rendah tersebut harus dicatat dalam laporan untuk mode kegagalan yang terpengaruh oleh hal tersebut.

3.9 Penentuan *Logic Tree Analysis* (LTA) dan *Maintenance Task*

Setelah mengidentifikasi FMECA, kemudian dilakukan *Logic Tree Analysis* (LTA) yang merupakan metode yang digunakan untuk menganalisa dampak yang ditimbulkan oleh masing-masing mode kegagalan (*failure mode*) yang terjadi. Tujuan dari dilakukannya LTA ini adalah untuk mengklasifikasikan mode kegagalan ke dalam beberapa kategori sehingga dapat menentukan tingkat prioritas penanganannya.

Semua mode kegagalan yang dinilai harus dievaluasi sesuai dengan diagram alir *task selection* dari RCM pada **Gambar 2.5** dan **Gambar 2.6**. Tujuan diagram alir tersebut adalah untuk membantu dalam memilih strategi tugas perawatan yang paling tepat untuk mencegah atau mendeteksi mode kegagalan tertentu. Semua penyebab setiap mode kegagalan harus dievaluasi. Tugas manajemen kegagalan yang tepat harus dipilih untuk semua tindakan korektif dengan menerapkan metode itu.

Semua rekomendasi perawatan dari *manufacturer* (pabrik) harus dipertimbangkan selama pemilihan tugas manajemen kegagalan. Jika perubahan atau penghapusan terhadap rekomendasi pabrikan dibuat, ini harus didokumentasikan dalam analisis berikut:

3.9.1 *Maintenance Task Allocation and Planning*

Tugas pemeliharaan yang diidentifikasi dalam setiap langkah harus diatur sesuai dengan kategori yang disarankan berikut:

- Kategori A - Dapat dilakukan di lokasi (di laut atau lepas pantai) oleh personel kapal
- Kategori B - Harus dilakukan bersama oleh vendor peralatan atau dengan menggunakan fasilitas dermaga
- Kategori C - Harus dilakukan di fasilitas *dry dock*

Kategori alternatif untuk yang disarankan harus sepenuhnya dijelaskan dengan cara yang sesuai dengan uraian di atas.

Jenis tugas yang harus diidentifikasi adalah sebagai berikut:

1. *Condition Monitoring* (CM),
2. *Planned Maintenance* (PM),
3. *Combination of CM and PM* (CM/PM),
4. *Failure Finding* (FF),
5. *One-Time Change* (OTC),
6. *Run-To-Failure* (RTF), dan
7. *Any Applicable and Effective Task* (AAET).

Analisis RCM dapat mengidentifikasi tugas perawatan yang sama yang membahas mode kegagalan dengan interval berbeda pada item peralatan atau komponen yang sama. Interval tugas yang dikembangkan mungkin tidak sejalan dengan jadwal pemeliharaan berbasis kalender yang digunakan saat ini. Dengan demikian, interval tugas dapat diintegrasikan ke dalam jadwal pemeliharaan umum sebagai bantuan untuk efisiensi penjadwalan personil. Jika tugas terintegrasi, interval tugas RCM hanya dapat disesuaikan dengan interval yang lebih pendek untuk menghindari kompromi efek akhir (*end effect*).

Setelah melakukan semua rangkaian kegiatan *task selection*, kemudian membuat *work package* sebagai *output* dari proses analisa penelitian tersebut. *Work package* merupakan rangkaian *maintenance task* yang akan menggambarkan strategi maintenance yang akan dilaksanakan berdasarkan metode RCM II. Pembuatan *work package* dalam format *spreadsheet* yang hasilnya akan diserahkan kepada pihak perusahaan sebagai bentuk rekomendasi kepada pihak perusahaan terkait dengan hal *maintenance* pada sistem *marine boiler* yang ada di kapal tanker tersebut.

3.10 Kesimpulan dan Saran

Tahap ini merupakan tahapan akhir dalam proses penelitian yang dilakukan. Kesimpulan yang tersusun harus bisa sesuai dengan tujuan penelitian yang telah ditetapkan. Selain penarikan kesimpulan, pemberian saran atas penelitian yang telah selesai dilakukan dapat dilakukan. Pengemukaan saran dalam hal ini biasanya berupa kesempatan penelitian lanjutan ataupun koreksi atas kekurangan atau ketidaksempurnaan pada penelitian yang sudah dilakukan.

BAB IV
ANALISA DATA DAN PEMBAHASAN

Pada bab ini dijelaskan tentang bagaimana pengumpulan data dan pengolahan data dimana pengumpulan data tersebut merupakan data sekunder dari perusahaan.

4.1 Pengumpulan Data dan Informasi

Pada proses pengumpulan data, ada dua proses yakni dengan mencari data yang dikumpulkan dari hasil observasi lapangan, studi literatur dan wawancara. Pada penelititan ini dilakukan obervasi lapangan di PT Gemilang Bina Lintas Tirta yakni lebih tepatnya pada departemen atau bagian operasional dan *maintenance*. Pada proses pengumpulan data, ada dua proses yakni dengan melakukan wawancara ke pihak-pihak yang secara langsung menangani atau bekerja di bagian *maintenance* atau mengambil data informasi dari *manual book, logsheet* dan dokumen-dokumen lain yang berkaitan dengan *maintenance* dan operasional kapal tanker MT Bull Kalimantan milik PT Gemilang Bina Lintas Tirta.

- Data yang didapat melalui wawancara:
  1. Penyebab umum kerusakan
  2. Data historis kerusakan
  3. Dokumen gambar sistem
  4. Rekomendasi solusi untuk mengatasi dan mencegah *failure*
  5. Dampak kerusakan terhadap sistem lainnya
- Data yang didapat dari *manual book, logsheet* dan dokumen lainnya:
  1. Data waktu operasional
  2. Spesifikasi *marine boiler*
  3. Data waktu perbaikan (*downtime*)
  4. Data komponen yang sering mengalami kerusakan (*failure*)
  5. PID dan PFD dari sistem *marine boiler*
  6. Data *corrective maintenance* yang dilakukan

Berikut merupakan data dari kapal tanker MT Bull Kalimantan:

Gambar 4. 1 Kapal Tanker MT Bull Kalimantan
(Bull.co.id, 2019)

IMO *Number*	: 9223318	
Length Overall (LOA)	: 240	m
Breadth (B)	: 42	m
Depth (H)	: 12	m
Draught (T)	: 9	m
Service Speed (Vs)	: 13	knots
Dead Weight (DWT)	: 106548	ton
Gross Tonage (GT)	: 57683	
Year Built	: 2002	
Year Launched	: 2004	
Flag	: Indonesia	
Classification Society	: DNV-GL	

Berikut merupakan data spesifikasi *marine boiler* pada kapal tanker MT Bull Kalimantan:

Gambar 4. 2 Marine Boiler MT Bull Kalimantan
(Alfalaval.com, 2019)

- *Two cylindrical water tube boiler*
- *Standard preassembled modules*
- *Innovative PLC-based control system*
- *Top-fired compact design*
- *Membrane wall design*
- *Made of mild carbon steel with elevated temperature properties*
- *Integrated steam atomizing burner*
- *Refractory is reduced to a protective layer at the bottom of the furnace*

Design Data

Thermal Output	6 – 24 MW
Water Volume	10 ton
Pressure	7 – 16 bar (g)

Operational Data

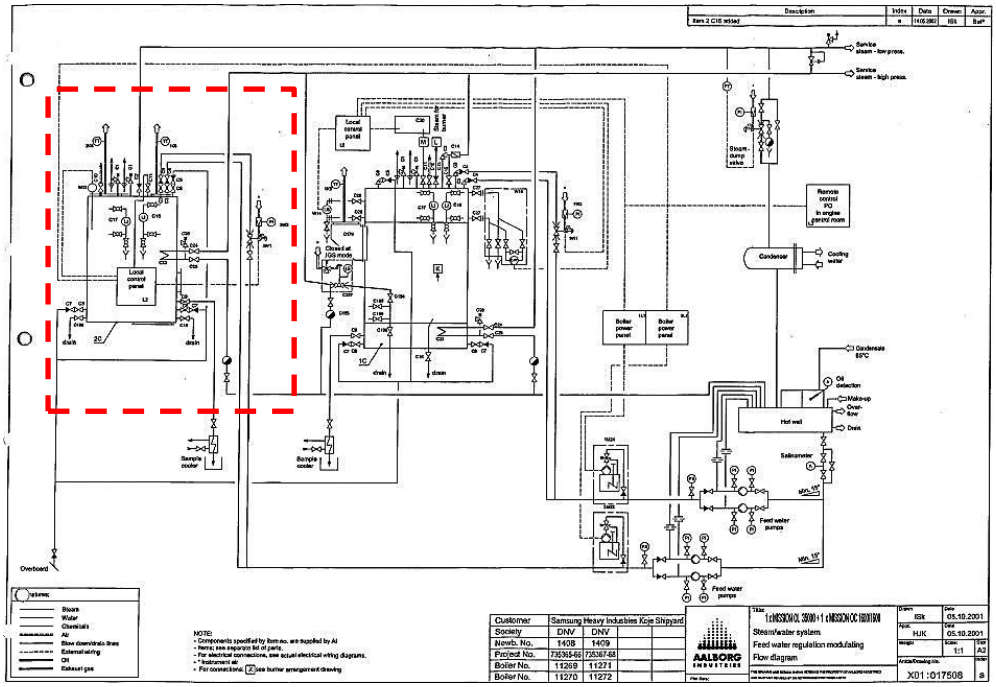
Thermal Output	8 – 38.8 MW
Steam Capacity	35 ton/hour
Design Pressure	9 – 18 bar (g)

Data dan spesifikasi lebih detail mengenai kapal tanker MT Bull Kalimantan dan *marine boiler* beserta sistem dan komponen-komponennya dapat dilihat pada **Lampiran 1.**

4.2 Mendefinisikan Batasan Sistem

Berdasarkan pada *manual book, marine boiler* pada kapal tanker MT Bull Kalimantan terdiri dari dua sistem yaitu *main system* dan *supporting system*. *Main system* merupakan sistem yang bekerja pada *boiler* itu sendiri beserta aksesorisnya, sedangkan *supporting system* merupakan *equipment* yang mendukung kinerja dari *boiler* tersebut. Terdapat dua *marine* boiler yaitu tipe Aalborg MISSION™ OL 35000 dan MISSION™ OC 1600.

Batasan sistem yang akan dianalisa di sini adalah *main system* dari *marine boiler* tipe Aalborg MISSION™ OL 35000 pada kapal tanker MT Bull Kalimantan. Adapun daftar komponen beserta fungsinya dapat diketahui berdasarkan data-data pada *marine boiler* tersebut. Data yang diperlukan yakni daftar komponen dan fungsinya berdasarkan diagram PFD dan P&ID pada sistem *marine boiler*. Untuk gambar PFD yang lebih jelas dapat dilihat pada **Lampiran 2.** Berikut merupakan PFD pada sistem *marine boiler* yang aka dilakukan analisa RCM:



Gambar 4. 3 PFD Sistem *Marine Boiler* pada Kapal Tanker MT Bull Kalimantan
(Aalborg Marine Boiler Product Guide, 2004)

4.3 Mengidentifikasi Mode/Konteks Operasi

Identifikasi mode atau konteks operasi pada sistem *marine boiler* dilakukan untuk mengetahui karakteristik operasional dengan berbagai mode operasi yang tentu saja akan menentukan kondisi operasional *equipment* pada sistem tersebut. Identifikasi mode/konteks operasi pada *marine boiler* kapal tanker MT Bull Kalimantan ditunjukkan pada tabel di bawah ini:

Tabel 4. 1 Identifikasi Konteks Operasi dan Mode Operasi *Marine Boiler*

Operating Context of Marine Boiler			
The heating system on a tanker vessel called MT Bull Kalimantan using marine boiler: Aalborg MISSION^{TM} OL 35000, large oil-fired with 35000 kg/h steam capacity working on low pressure at 16 kg/cm². All fully automatic operation of the boiler system and the steam atomising burner.			
Common Characteristic	***Operating Modes***		
	Tropical/Summer	***Subtropical/Winter***	***Cargo Handling***
Environmental Parameters	Nominal ambient air temperature: 30-45°C. Barometric air press (dry) 101.3 kPa (abs) Sea water temperature: 20-27°C	Nominal ambient air temperature: 4-17°C. Barometric air press (dry) 101.3 kPa (abs) Sea water temperature: 6-10°C	Not used

Common Characteristic	***Operating Modes***		
	Tropical/Summer	***Subtropical/Winter***	***Cargo Handling***
Manner of Use	Air supply to the burner must be monitored at 41,303 kg/h and the steam pressure at 16 kg/cm².	Air heater must be checked to make the inlet burner air at 45°C and feed water preheater is also monitored at 60°C.	Not used
Performance Capability	To output 35000 kg/hour steam at 203.35°C in an hour; the local control panel an all relevant boiler mountings are mounted on top of the boiler, this can be easily be operated and monitored from the burner platform.	To output 35000 kg/hour steam at 203.35°C in 2 hours; the local control panel an all relevant boiler mountings are mounted on top of the boiler, this can be easily be operated and monitored from the burner platform.	Not applicable

Berdasarkan tabel 4.1 di atas dapat diketahui bahwa konteks operasi *marine boiler* tipe Aalborg MISSION^{TM} OL 35000 menggunakan bahan bakar berupa minyak dengan kapasitas uap yang dihasilkan yaitu sebesar 35000 kg/jam. Boiler tipe ini bekerja pada tekanan rendah yakni 16 kg/cm² dimana semua operasionalnya dijalankan secara otomatis melalui sebuah sistem kontrol.

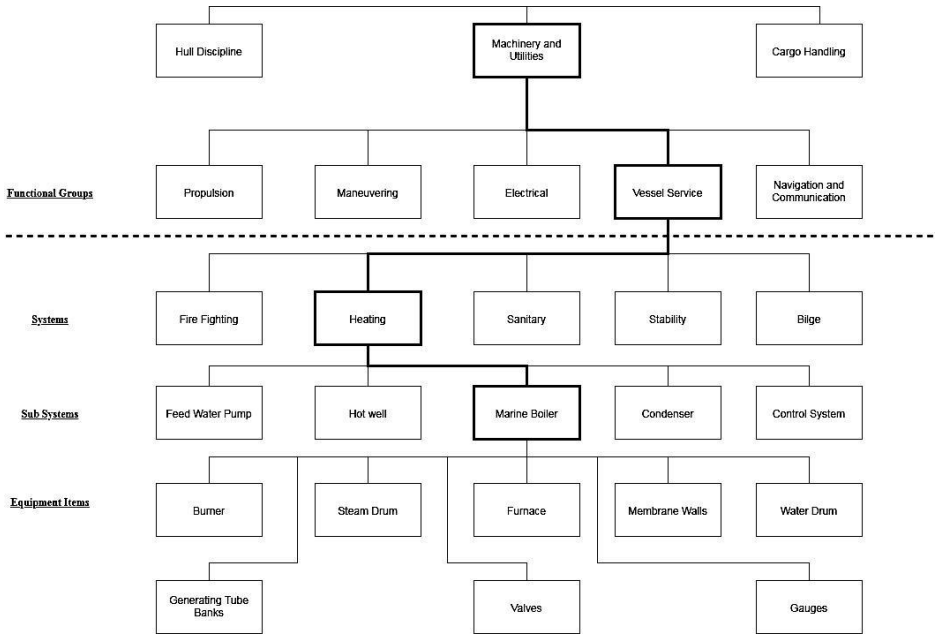
Identifikasi untuk mode operasi *marine boiler* terdiri dari 2 mode utama yaitu untuk mode *tropical/summer* dan mode *subtropical/winter*. Mode *tropical/summer* merupakan mode dimana *marine boiler* dioperasikan pada saat musim panas atau ketika kapal berada pada perairan tropis selama lebih dari 24 jam. Sedangkan mode *subtropical/winter* merupakan mode operasi dimana *marine boiler* dioperasikan pada saat musim dingin atau ketika kapal berada pada perairan subtropis selama lebih dari 24 jam. Parameter lingkungan untuk mengidentifikasi mode operasi adalah pada temperatur udara dan temperatur air laut. *Marine boiler* akan dioperasikan pada mode *tropical/summer* jika temperatur udara normal berkisar antara 30-45°C dan temperatur air laut sekitar yaitu berkisar antar 20-27°C. Sedangkan mode *subtropical/winter* dilaksanakan jika jika temperatur udara normal berkisar antara 4-17°C dan temperatur air laut sekitar yaitu berkisar antar 6-10°C.

Cara pengoperasian dari kedua mode operasi tersebut memiliki sedikit perbedaan diantaranya yang terkait dengan air pengumpan *boiler*. Untuk mode operasi *tropical/summer* dapat dilakukan dengan memeriksa dan memastikan sistem kendali level air pengumpan pada *steam drum* di dalam *boiler* selalu dalam keadaan NOWL (*Normal Operational Water Level*) atau tingkat ketinggian air normal sesuai dengan petunjuk operasional standar yakni pada titik 0 dengan batas atas pada +135 mm dan batas bawah pada -145 mm. Sedangkan pada metode *subtropical/winter* dapat dilakukan dengan memeriksa apakah pemanas air pengumpan *boiler* (*feed heater*) dapat menyala dan menghasilkan keluaran air pengumpan pada suhu 60°C. Perhatikan juga tegangan listrik pada *feed heater* agar tidak lebih dari 380 V. Periksa juga fungsi *burner* agar bekerja sesuai dengan fungsinya yaitu menghasilkan pembakaran bahan bakar untuk memanaskan air pengumpan boiler.

Kemampuan kinerja dari 2 mode operasi *marine boiler* juga kinerja kemampuan yang sedikit berbeda namun dengan parameter yang sama berdasarkan syarat operasional standar. Pada mode operasi *tropical/summer*, *marine boiler* harus dapat menghasilkan keluaran berupa uap (*steam*) dengan kapasitas 35000 kg/jam dengan temperatur kerja mencapai 203,35°C selama 1 jam operasional sejak sistem *marine boiler* mulai bekerja. Sedangkan pada mode operasi *tropical/summer*, *marine boiler* harus dapat menghasilkan keluaran berupa uap (*steam*) dengan kapasitas 35000 kg/jam dengan temperatur kerja mencapai 203,35°C selama 2 jam operasional sejak sistem *marine boiler* mulai bekerja. Panel kontrol lokal dan semua perlengkapan boiler yang relevan dipasang di atas boiler. Hal tersebut dapat dengan mudah dioperasikan dan dipantau dari atas platform burner.

4.4 Menentukan Definisi Sistem

Setiap sistem yang dipilih untuk analisis RCM harus didefinisikan. Definisi sistem di sini melibatkan pembagian kelompok fungsional aset ke dalam sistem (sebagaimana diperlukan karena adanya tingkat kompleksitas), item peralatan, dan komponen. Berikut merupakan definisi sistem *marine boiler* pada kapal tanker M.T. Bull Kalimantan:



Gambar 4. 4 Definisi Sistem *Marine Boiler*

Berdasarkan gambar 4.4 di atas dapat diketahui bahwa definisi sistem *marine boiler* dapat diidentifikasi dari hierarki paling tinggi yakni pada level kelompok fungsional (*functional group*).

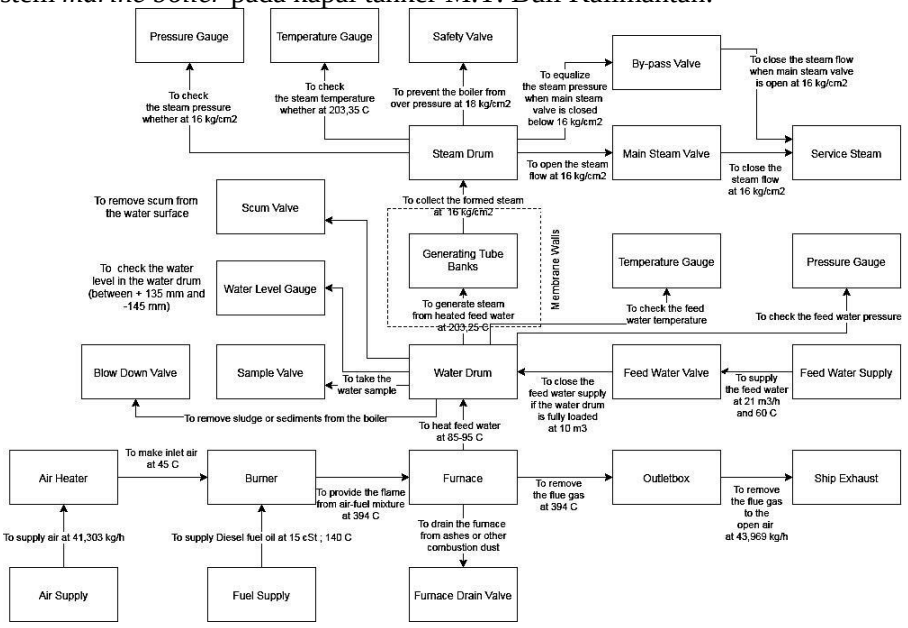
Pengelompokan aset berdasarkan 3 fungsi utama di kapal yaitu lambung kapal (*hull discipline*), permesinan utilitas (*machinery and utility*) dan peralatan bongkar muat (*cargo handling*). Fungsi utama yang akan diambil adalah permesinan utilitas yang memiliki 5 kelompok fungsional yaitu fungsi propulsi, fungsi manuver, fungsi kelistrikan, fungsi pelayanan kapal (*vessel service*), dan fungsi navigasi serta komunikasi. Kelompok fungsional yang diambil adalah fungsi pelayanan kapal yang memiliki 5 sistem utama yaitu sistem pemadam kebakaran, sistem pemanas, sistem sanitasi, sistem stabilitas dan sistem bilga. Sistem yang diambil adalah sistem pemanas yang memiliki 5 sub sistem yaitu sub sistem pompa air pengumpan, penyimpan air pengumpan (*hotwell*), *marine boiler*, kondenser dan sistem kontrol.

Berdasarkan batasan sistem yang telah ditentukan, maka dipilih sub sistem *marine boiler* untuk dilakukan analisa RCM. Sub sistem *marine boiler* sendiri terdiri dari 8 peralatan utama yaitu *burner, steam drum, furnace, membrane walls, water drum, generating tube banks,* katup (*valve*) dan alat ukut (*gauges*).

4.5 Mengidentifikasi Blok Diagram Sistem dan Kegagalan Fungsi

Setelah mengetahui definisi sistem *marine boiler* yang ada di kapal tanker M.T. Bull Kalimantan, kemudian dilakukan identifikasi hubungan antara masing-masing sub sistem yang ada pada *marine boiler* beserta fungsi masing-masing item peralatan.

Block diagram akan dikembangkan menunjukkan urutan aliran fungsional dari kelompok fungsional, baik untuk pemahaman teknis tentang fungsi dan operasi sistem dan untuk analisis selanjutnya. Berikut merupakan blok diagram sistem *marine boiler* pada kapal tanker M.T. Bull Kalimantan:



Gambar 4. 5 Blok Diagram Sistem *Marine Boiler*

Berdasarkan gambar 4.5 di atas dapat diketahui bahwa blok diagram tersebut menggambarkan secara umum bagaimana sistem *marine boiler* ini bekerja untuk menjalankan fungsinya yaitu menjadi sistem pemanas utama di kapal tanker. Blok diagram sistem *marine boiler* memiliki beberapa tingkat kompleksitas hubungan antar sub sistem yang juga terdiri dari beberapa peralatan (*equipment*) utama. Hubungan antara satu *equipment* dengan *equipment* lainnya tersebut dapat berupa aliran fluida. Untuk fluida yang terdapat pada sistem ini yaitu berupa air, uap (*steam*), udara dan bahan bakar minyak (*fuel oil*). Kondisi fluida pada masing-masing *equipment* tentu saja akan berpengaruh pada kinerja masing-masing *equipment* maupun potensi kerusakan yang dapat terjadi baik yang bersifat acak (*random*) maupun berdasarkan usia pemakaian *equipment* tersebut (*age-related*).

4.6 *Failure Mode Effects and Criticality Analysis* (FMECA)

Setelah mengetahui fungsi dan kegagalan fungsi dari masing-masing *equipment* yang ada pada sistem *marine boiler*, kemudian dilakukan identifikasi terhadap kegagalan (*failure*) yang terjadi pada masing-masing *equipment* beserta komponen-komponennya. Berikut merupakan bentuk kegagalan fungsional dari salah satu *equipment* dari sistem *marine boiler*:

Tabel 4. 2 Fungsi dan Kegagalan Fungsional *Feed Water Tank*

Equipment Item: Burner				
Function			*Functional Failure*	
Item No.	*Function Statement*	*Function Type*	*Item No.*	*Functional Failure Statement*
1	To provide the flame from air-fuel mixture at 394°C	Primary	1.1	No flame appeared
			1.2	Unstable flame
			1.3	Flame temperature above 394°C
			1.4	Flame temperature below 394°C

Berdasarkan tabel 4.2 di atas dapat diketahui fungsi dari salah satu *equipment* pada sistem *marine boiler* yaitu *burner*. Fungsi utama (*primary*) dari *equipment* tersebut adalah menyediakan panas dari hasil pembakaran antara campuran udara dan bahan bakar pada temperatur 394°C. Fungsi utama dari *equipment* tersebut memiliki kegagalan fungsional (*functional failure*) yakni tidak ada nyala api, nyala api yang tidak stabil, temperatur api di atas 394°C dan temperatur api di bawah 394°C.

Identifikasi fungsi dan kegagalan fungsi tersebut merupakan salah satu dari enam *equipment* yang diidentifikasi pada sub sistem *burner*. Fungsi dan kegagalan fungsional peralatan (*equipment*) kemudian akan dijadikan acuan dalam melakukan analisa FMECA. Adapun identifikasi lengkap fungsi dan kegagalan fungsi dari *equipment* lainnya dapat dilihat pada **Lampiran 3**.

Setelah melakukan identifikasi terhadap fungsi dari masing-masing *equipment* dan kegagalan fungsionalnya, kemudian lanjutan analisa terhadap penyebab kegagalan fungsional tersebut (*failure mode*), penyebab dari *failure mode* (*causes*) karakteristik kegagalan (*failure characteristic*) dan dampaknya baik secara lokal maupun terhadap sistem lainnya (*local and end effect*). Pengklasifikasian jenis kerusakan (*failure*) dapat ditentukan berdasarkan *matrix* sebagaimana yang dapat dilihat pada **Tabel 3.3**. Kemudian analisa dilanjutkan dengan penentuan tingkat keparahan (*severity*) dari *failure* yang terjadi beserta penilaian frekuensi kemungkinan kegagalan (*current likelihood*) berdasarkan kegagalan fungsional tersebut yang dapat dilihat pada **Tabel 3.4**.

Selain pengelompokan matriks berdasarkan tingkat keparahan *failure*, matriks resiko (*current risk*) juga diperlukan untuk megidentifikasi berdasarkan analisa terhadap kegagalan fungsional yang terjadi mengenai dampak terhadap kegagalan tersebut. Pengelompokan matriks resiko berdasarkan tingkat *severity* dan *current likelihood* kegagalan fungsional tersebut dan dapat dilihat pada **Tabel 3.5**. Setelah itu diperlukan identifikasi terhadap deteksi kegagalan fungsional atau langkah-langkah penanggulangan (*failure detection/corrective measures*) terhadap kegagalan fungsional yang terjadi agar dampak yang ditimbulkan tidak sampai menimbulkan resiko yang lebih besar.

Maka berdasarkan fungsi dan kegagalan fungsional dari *equipment* pada sistem *marine boiler* sebagaimana terlihat pada **Tabel 4.2** maka dapat dilakukan analisa FMECA sebagai berikut:

Tabel 4. 3 Analisa FMECA pada *Burner*

Equipment	Function	No. Item	Functional Failure	Failure Mode	Causes	Failure Characteristic	Local Effect
Burner	To provide the flame from air-fuel mixture at 394°C	1.1	No flame appeared	1. No fuel and air supply	1. Not working fuel pump	Random failure, Wear-out failure	Difficulties on boiler start
					2. Not working air fan	Random failure	Difficulties on boiler start
				2. No fire generated from stoker	1. Broken lighter	Random failure, Wear-out failure	Boiler fails to start
					2. Electrical problems	Random failure, Wear-out failure	Boiler fails to start

End Effect	Matrix	Severity	Current Likelihood	Current Risk	Failure Detection/Corrective Measures
System shut down	Explosion	Catastrophic	Remote	Medium	Flow meter and pressure gauges indicate no flow of fuel oil. Fuel indicator on panel switch on. Fuel inlet valve is automatically closed. Burner fails to start
System shut down	Explosion	Catastrophic	Remote	Medium	Flow meter and pressure gauges indicate no flow of intake air. Air supply indicator on the panel switch on. Air heater is switched off. Burner fails to start.
System shut down	Explosion	Critical	Frequent	High	No flame detected on flame eye sensor. Air and fuel supply are closed. Burner fails to start.
System shut down	Explosion	Critical	Occasional	Medium	No flame detected on flame eye sensor. Air and fuel supply are closed. Burner fails to start.

Berdasarkan analisa FMECA pada **Tabel 4.3** dapat diketahui bahwa pada nomor item kegagalan 1.1 yakni jenis kegagalan fungsional berupa tidak adanya api pada *burner* yang menjadi *equipment* yang memanaskan *feed water* pada *marine boiler*. Penyebab dari kegagalan fungsional tersebut (*failure mode*) yang pertama adalah tidak adanya suplai bahan bakar dan udara sedangkan yang kedua adalah tidak munculnya api yang berasal dari pemantik api pada *burner* tersebut. Pada *failure mode* yang pertama, penyebab kegagalan tersebut terjadi karena tidak berfungsinya *fuel pump* dan *air fan* yang menyuplai bahan bakar dan udara sebagai pemicu timbulnya api pembakaran pada *burner*. Karakteristik dari kegagalan fungsional pada item 1.1 tersebut ada yang bersifat *random failure* artinya kegagalan yang tidak bisa diperkirakan kapan terjadinya berdasarkan satuan waktu atau lama penggunaan (*lifetime*) dari *equipment* tersebut. Selain itu, karakteristik lainnya yakni *wear-out failure*, yakni kegagalan yang dapat diperkirakan kapan terjadinya berdasarkan satuan waktu atau lama penggunaan (*lifetime*) dari *equipment* tersebut. Efek lokal yang terjadi yakni adanya gangguan atau kesulitan dalam proses *starting* pada *marine boiler*. Efek akhir yang timbul akibat efek lokal tersebut adalah berhentinya seluruh operasional dari sistem *marine boiler* tersebut (*system shut down*).

Kegagalan fungsional pada nomor item 1.1 termasuk dalam matriks *explosion* yang memiliki tingkat keparahan (*severity*) yang tergolong besar (*catastrophic*). Penilaian frekuensi kemungkinan kegagalan (*current likelihood*) berdasarkan kegagalan fungsional tersebut masuk ke dalam tingkat *remote* yakni kemungkinan terjadinya kegagalan tersebut berkisar antara 0.001 hingga 0.01 kali kejadian per tahun berdasarkan perhitungan *probability of failure* (PoF). Hal tersebut menyebabkan penilaian terhadap resiko pada kegagalan fungsional tersebut masuk ke dalam kategori resiko menengah (*medium*).

Deteksi kegagalan pada kegagalan fungsional tersebut adalah adanya indikator pada alat ukur yang terpasang pada sistem *marine boiler* tersebut yakni alat ukur aliran fluida (*flow meter*) dan alat ukur tekanan fluida (*pressure gauge/manometer*) yang menunjukkan tidak adanya fluida yang mengalir pada saluran fluida tersebut baik untuk bahan bakar maupun udara. Hal ini kemudian dideteksi oleh sistem kontrol pada panel yang tersedia yang kemudian diproses untuk menyalakan alarm penanda bahwa adanya kegagalan pada salah satu proses operasional. Sinyal tersebut kemudian akan diteruskan melalui sistem *programmable logic control* (PLC) untuk menutup aktuator berupa katup maupun *equipment* yang berhubungan dengan suplai kedua fluida tersebut.

Adapun analisa FMECA dari nomor item kegagalan fungsional *equipment* lainnya dapat dilihat pada **Lampiran 4**.

4.7 Penentuan *Logic Tree Analysis* (LTA) dan *Maintenance Task*

Setelah mengidentifikasi FMECA, kemudian dilakukan *Logic Tree Analysis* (LTA) untuk menganalisa dampak yang ditimbulkan oleh masing-masing mode kegagalan (*failure mode*) yang terjadi serta mengklasifikasikan mode kegagalan tersebut ke dalam beberapa kategori sehingga dapat menentukan tingkat prioritas penanganannya. Hasil dari analisa LTA tersebut kemudian dimasukkan ke dalam rangkaian lembar kerja pemilihan *maintenance task* sesuai dengan petunjuk dari ABS Guide. **Tabel 4.4** menunjukkan *template* yang digunakan untuk *maintenance task selection* berdasarkan ABS *Guide*. Untuk hasil *maintenance task selection* secara keseluruhan dapat dilihat pada **Lampiran 5**.

Tabel 4. 4 ***Maintenance Task Selection Worksheet***

Functional Failure	***Failure Mode***	***Failure Char.***	***Hidden/ Evident***	***Effects***		***Risk Characterization***		
				Local	***End***	***Severity***	***Current Likelihood***	***Current Risk***
No flame appeared	1. No fuel and air supply	Random failure, Wear-out failure	Evident	Difficulties on boiler start	System shut down	Catastrophic	Remote	Medium
Task Selection								
Proposed Action(s)					***Projected Likelihood***	***Projected Risk***	***Disposition***	
1. Check fuel pipe work for any leakage 2. Check flanges, joints and connections for leakages 3. Check the manual valves are operating properly 4. Check there is no leakage from any part of the valve 5. Ensure the fuel supply pump is changed to standby and all parameters are in normal operating range					Remote	Medium		

Berdasarkan analisa *task selection* tersebut dapat diketahui bahwa sebagian besar *failure mode* merupakan *evident failure* dimana untuk kegagalan fungsional yang *evident* dapat dideteksi oleh anggota staf pekerja, dan memiliki tingkat kepentingan yang berbeda-beda, dimana keselamatan manusia dan lingkungan menjadi yang utama. Sedangkan untuk kegagalan fungsional *hidden*, penyebab kegagalan tersebut tidak langsung terlihat dan tidak dapat dideteksi oleh anggota staf pekerja. Ini biasanya terlihat dalam perangkat keselamatan atau proteksi. Kegagalan fungsional *hidden* jauh lebih kompleks untuk dihadapi, membuat analisis RCM lebih sulit dan aset biasanya mencakup perangkat keselamatan dan proteksi untuk meminimalkan konsekuensi dari kegagalan yang berbeda.

Setelah menyusun *task selection*, maka hasilnya dapat dibuat ringkasan dalam bentuk *summary of maintenance tasks* sesuai dengan petunjuk dari ABS Guide.**Tabel 4.5** berikut merupakan salah satu contoh *summary of maintenance tasks* pada *burner*. Untuk *summary of maintenance tasks* secara keseluruhan dapat dilihat pada **Lampiran 6**.

Tabel 4. 5 ***Summary of Maintenance Tasks***

Maintenance Category	:	A
Functional Group	:	Vessel Service
System	:	Heating
Sub System	:	Marine Boiler
Equipment Item	:	Burner

Task	***Task Type***	***Item No.***	***Risk***		***Frequency***	***Reference***	***Comments***
			Unmitigated	***Mitigated***			
Check the condition of nozzle for clogging	CM	1.1	Medium	Medium	Monthly	Anish Wankhede (2015)	If a blockage is found, clean it with a soft brush or scrubbing paper. Chemical liquids are not allowed in this case.
Clean all filters related to the burner	PM	1.2	Medium	Low	Every 2 weeks	Anish Wankhede (2015)	No chemical liquid allowed
Reset all set point for boiler supplies control system	OTC	1.3, 1.4	Medium	Low	Every 3 months	Anish Wankhede (2015)	Set to the default.

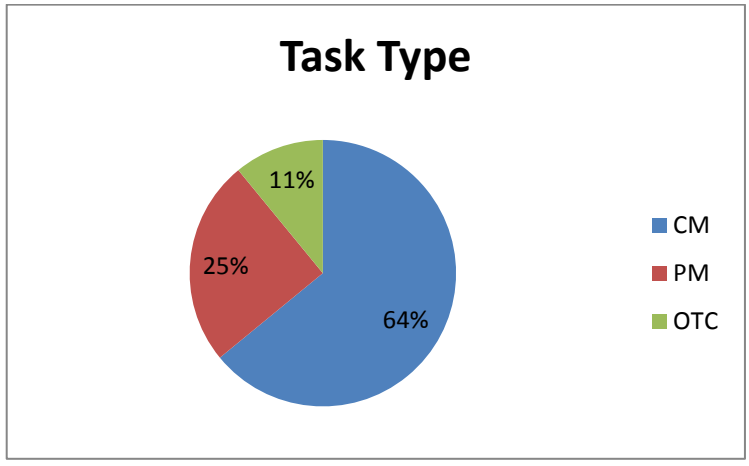
Pada *summary of maintenance tasks* yang ditunjukkan oleh **Tabel 4.5** di atas dapat diketahui bahwa *maintenance* pada *burner* yang merupakan salah satu *equipment* dari *marine boiler* pada sistem *heating* yang merupakan bagian dari sistem pelayanan kapal (*vessel* service) masuk dalam kategori A, yang artinya bahwa seluruh kegiatan maintenance pada burner tersebut dapat dilakukan di lokasi (di laut atau lepas pantai) oleh personel kapal.

Pada nomor item 1.1 jenis *maintenance task* yang dilakukan adalah *condition monitoring* (CM) artinya proses pemantauan parameter kondisi dalam sistem untuk mengidentifikasi perubahan signifikan yang mengindikasikan kesalahan atau kegagalan yang sedang berlangsung. Hal tersebut dilakukan untuk menanggulangi resiko yang semula bersifat *medium* menjadi *medium* dengan interval waktu *maintenance* yakni bulanan (*monthly*).

Pada nomor item 1.2 jenis *maintenance task* yang dilakukan adalah *planned maintenance* (PM) artinya setiap kegiatan pemeliharaan yang direncanakan, didokumentasikan dan dijadwalkan. Tujuan dari PM ini adalah untuk mengurangi *down time* dengan memiliki semua sumber daya yang diperlukan, seperti tenaga kerja dan suku cadang, dan strategi untuk menggunakan sumber daya ini. Hal tersebut dilakukan untuk menanggulangi resiko yang semula bersifat *medium* menjadi *low* dengan interval waktu *maintenance* yakni setiap 2 minggu sekali (*every 2 weeks*).

Pada nomor item 1.3 jenis *maintenance task* yang dilakukan adalah *One-Time Change* (OTC) artinya kegiatan *maintenance* tersebut dilakukan sekali penggantian dalam satu satuan waktu. Hal tersebut dilakukan untuk menanggulangi resiko yang semula bersifat *medium* menjadi *low* dengan interval waktu *maintenance* yakni setiap 3 bulan sekali (*every 3 months*).

Berdasarkan keseluruhan dari *summary of maintenance tasks* tersebut, didapatkan sebanyak 28 kegiatan *maintenance* yang dibagi menjadi 3 jenis kegiatan dengan presentase sebagai berikut:



Gambar 4. 6 Persentase Jenis Kegiatan *Maintenance*

Berdasarkan *summary of maintenance tasks* kemudian dapat disusun *workpackage* yang dibuat per *equipment* yang terdiri dari interval perawatan, pelaksana perawatan dan perawatan apa saja yang harus dilakukan. Penyusunan *workpackage* berdasarkan pada *manual guide book* dan *maintenance* yang sudah dilaksanakan dalam menyusun *workpackage* ini. **Tabel 4.6** berikut merupakan salah satu contoh *workpackage* pada *burner*. Untuk *workpackage* secara keseluruhan dapat dilihat pada **Lampiran 7**.

Tabel 4. 6 *Workpackage*

MAINTENANCE SCHEDULE	
Burner	
Interval	**Done by**
Monthly	*Mechanic*
Following these recommended steps should help operators reduce problems with boiler burner. Here is a brief check list: 1. Check the condition of nozzle for clogging 2. Check the atomization of fuel in the workshop	
Interval	**Done by**
Annual	*Mechanic*
Following these recommended steps should help operators reduce problems with boiler burner. Here is a brief check list: 1. Replace ceramic insulation of the electrodes 2. Check the solenoid valve controlling the fuel in the main burner	
Interval	**Done by**
Every 3 Month	*Mechanic*
Following these recommended steps should help operators reduce problems with boiler burner. Here is a brief check list: 1. Clean the electrodes with electro-cleaner solution 2. Check and clean the cup for hard deposits in rotary cup burner 3. Reset all set point for boiler supplies control system	
Interval	**Done by**
Every 2 Weeks	*Mechanic*
Following these recommended steps should help operators reduce problems with boiler burner. Here is a brief check list: 1. Clean all filters related to the burner	

BAB V
KESIMPULAN DAN SARAN

Pada bab ini dibahas tentang hasil penelitian yang telah dilakukan yang dirangkum dalam penarikan kesimpulan yang menjawab rumusan masalah dan pencapaian tujuan penelitian. Selain penarikan kesimpulan, pemberian saran atas penelitian yang telah selesai dilakukan dapat dilakukan.

5.1 Kesimpulan

Berdasarkan hasil analisa di atas dapat diketahui bahwa terdapat 28 kegiatan maintenance (*maintenance task*) yang terdiri dari 3 jenis kegiatan yaitu *condition monitoring* (CM), *planned maintenance* (PM) dan *One-Time Change* (OTC). Masing masing jenis kegiatan *maintenance* tersebut memiliki *task* sebanyak:

a. CM = 18 (64%)
b. PM = 7 (25%)
c. OTC = 3 (11%)

Setelah dilakukan analisa RCM, penyusunan *preventive maintenance* dilakukan pada tiap *equipment* berdasarkan tingkat resikonya dalam bentuk *workpackage*. Untuk *failure mode* yang memiliki *high risk* dilakukan *preventive maintenance* dengan interval setiap 1 hingga 7 hari sekali. Untuk interval *preventive maintenance* paling lama dilakukan pada *safety valve* yakni dengan interval inspeksi 2 tahun.

5.2 Saran

Adapun saran berdasarkan analisa di atas adalah sebagai berikut:

a. Pembuatan analisa RCM dapat dilakukan sampai *level parts* untuk memperoleh hasil analisa yang lebih terperinci dan komprehensif.
b. Analisa terhadap sub sistem lainnya pada sistem *marine boiler* agar diperoleh hasil yang lebih objektif dan faktual.
c. Perhitungan analisa tentang biaya dapat ditambahkan untuk dijadikan pertimbangan dalam analisa RCM untuk memperoleh hasil yang lebih efektif dan efisien serta aplikatif.

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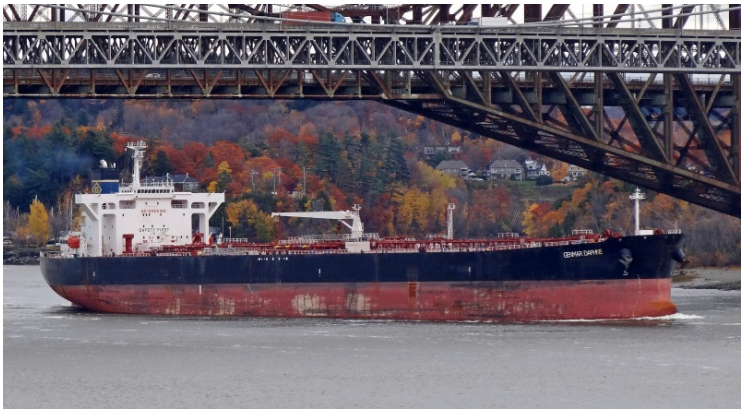
LAMPIRAN

LAMPIRAN 1

DATA DAN SPESIFIKASI KAPAL TANKER MT BULL KALIMANTAN DAN MARINE BOILER AALBORG MISSION™ OL

BULL KALIMANTAN



IMO number	9223318
MMSI	525107004
Name of the ship	BULL KALIMANTAN
Former names	GENMAR DAPHNE (2016) FIDELITY (2008) 7ENMAR DAPHNE 7ENMAR_DAPHNE
Vessel type	Crude oil tanker
Operating status	Active
Flag	Indonesia
Gross tonnage	57683 tons
Deadweight	106548 tons
Breadth	42 m
Engine type	MAN-B&W
Engine power	12268 KW
Year of build	2002
Builder	TSUNEISHI TADOTSU FACTORY - TADOTSU, JAPAN
Class society	DET NORSKE VERITAS
Home port	JAKARTA
Owner	GENERAL MARITIME MANAGEMENT - NEW YORK NY, United States (USA)
Manager	GENERAL MARITIME MANAGEMENT - NEW YORK NY, United States (USA)

LAMPIRAN 2

PROCESS FLOW DIAGRAM (PFD) DAN P&ID (PIPING & INSTRUMENTATION DIAGRAM)

Technical data for boiler unit

1 General data

- Project No.: 735365, 735367
- Hull No.: 1408, 1409
- Classification society: ..... DNV
- Pressure gauge calibration: ..... kg/cm^2
- Thermometer calibration: ..... °C
- Language for signs: ..... UK

2 Dimensions for boiler unit

- Height excl. of mountings: ..... 7,010 mm
- Diameter incl. insulation: ..... 3,870 mm
- Total height incl. retraction of burner lance: ..... 10,050 mm
- Weight of boiler unit excl. water: ..... 39700 kg
- Weight of boiler unit incl. water: ..... 55100 kg

3 Water/steam process data

- Steam output: ..... 35,000 kg/h
- Working pressure: ..... 16.0 kg/cm^2
- Max. allowable working pressure: ..... 18.0 kg/cm^2
- Working temperature: ..... 203.35°C
- Feed water operation: ..... Modulating
- Feed water temperature, operation: ..... 85-95°C
- Feed water temperature, layout: ..... 60°C

4 Combustion process data

- Min. calorific value of diesel oil: ..... 42,200 kJ/kg
- Min./max. viscosity of diesel oil: ..... 3-12 cSt at 50°C
- Density of diesel oil: ..... 890 kg/m^3

- Min. calorific value of fuel oil: ..... 40,200 kJ/kg
- Min./max. viscosity of fuel oil: ..... 600 cSt at 50°C
- Density of fuel oil: ..... 990 kg/m^3
- Fuel oil temperature before pre-heater: ..... 45°C
- Fuel oil viscosity at burner inlet: ..... 15 cSt
- Fuel oil temperature at burner inlet: ..... 140°C
- Ambient air temperature: ..... 45°C
- Air excess No. at 100% load: 1.15
- Flue gas temperature (clean boiler): ..... 394°C
- Air consumption at 100% load: ..... 41,303 kg/h
- Flue gas flow (approx.): ..... 43,969 kg/h
- Pressure loss across pin elements: ..... 271 mmWC
- Expected back pressure from stack at full load: ..... 15 mmWC

5 Data for atomising steam

- Atomising steam pressure at burner, max.: ..... 6.0 kg/cm^2
- Atomising steam consumption.: ..... 120 kg/h
- Atomising air pressure at burner, max.: ..... 7.0 kg/cm^2
- Atomising air consumption, max.: ..... 210 kg/h

6 Data for electric systems

- Power supply: ..... 3 x 690 V, 50 Hz
- *Control voltage: ..... 1 x 230 V, 50 Hz
- Pilot voltage: ..... 24 V
- Insulation class: ..... F
- Degree of protection: ..... IP 44
- Colour of boiler control panel: ..... Munsell 7.5 BG 7/2
- Colour of boiler power panel: ..... Munsell 7.5 BG 7/2

7 Data for pressure part

- Boiler type: ..... Large oil fired boiler
- Model: ..... MISSION™ OL
- Test pressure: ..... 27.0 kg/cm^2
- Max. allowable shrink: ..... 0.650 m^3

- Max. allowable swell: ..... 1.350 m^3
- Number of pin tubes: 140
- Protection of boiler body: ..... trapezoid plate
- Colour of insulation plates: ..... hot dip galvanized

8 Data for burner

- Burner type: ..... Steam atomising, modulating
- Model: ..... KBSD 2650
- Burner capacity on diesel oil, min./max.: ..... 260/2,445 kg/h
- Burner capacity on fuel oil, min./max.: ..... 260/2,566 kg/h
- Colour of burner ..... red (RAL 3000)

9 Data for water level operation

- Too high water level alarm: ..... +165 mm
- High water level warning: ..... +135 mm
- Normal water level 0
- Start stand-by feed water pump: ..... not AI supply
- Low water level warning: ..... -145 mm
- Too low water level alarm and burner off: ..... -190 mm

10 Data for steam pressure operation

- Safety valve: ..... 18.0 kg/cm^2
- Safety valve: ..... 18.0 kg/cm^2
- High steam pressure alarm and burner off: ..... 17.8 kg/cm^2
- High steam pressure warning: ..... 17.5 kg/cm^2
- Burner start/stop: ..... 16.2/17.2 kg/cm^2
- Burner operation: ..... 16.0 kg/cm^2
- Low steam pressure warning: ..... 4.0 kg/cm^2

11 Manuals

- Language for manuals: ..... UK
- Set of instruction manuals: 6
- Document revision date: ..... 24 JAN 2003

MISSION™ OL boiler

1 Description

The MISSION™ OL boiler is a vertical two-drum boiler, insulated and pre-assembled with boiler mountings for easy installation and operation.
The boiler is top-fired and equipped with a steam atomising burner. As the burner, the local control panel and all relevant boiler mountings are mounted on top of the boiler, this can easily be operated and monitored from the burner platform. Most of the cabling for instrumentation and drain are pre-wired before delivery.
The control system supplied with the MISSION™ OL boiler unit provides fully automatic operation of the boiler and the steam atomising burner.

1.1 Boiler pressure part

The principal drawing of the MISSION™ OL boiler is shown in Figure 1. The steam drum is cylindrical with two flat plates of equal thickness. Because of the internal pressure, the flat plates are mutually connected by vertical solid stays. The steam drum is furnished with the necessary internal fittings to ensure an even distribution of the feed water, of the circulation water from the exhaust boiler and to ensure a sufficient dryness of steam.
The burner cone in the furnace opening are an integrated part and accordingly no refractory are provided in the top of the furnace room.
Manholes are conveniently placed in both drums and inside the drums enough space is available for inspection and maintenance.
The water drum is designed similar to the steam drum. The drum size gives optimal space for the heating coil and easy access for inspection.
For the foundation the boiler is provided with four supports, one as fixed foot and the others designed with possibility of thermal expansions. Counter plates are provided for welding to deck.
Both the furnace and the generating tube bank are located asymmetrically and are separated by the screen wall. Besides the screen wall the furnace consists of gas tight polygon shaped membrane walls. The generating tube bank consists of vertical pin-tubes arranged in a staggered configuration. To avoid any risk of vibration problems supports are arranged.
The flue gas passes through the deflected tubes at the bottom of the screen wall, up through the generating tube bank and out through the smoke outlet box.
An effective circulation in the boiler is achieved bye means of down comers.
The bottom tube plate is first covered with coat of insulation refractory and above with castable refractory.
Access to the furnace is possible through the access door at the bottom of the furnace. Inspection of the generating tubes is also possible through the inspection door at the bottom of the furnace.
Inspection of the burner flame is possible through the two inspection holes arranged in two heights on the furnace panel wall.

Principal drawing of MISSION™ OL boiler

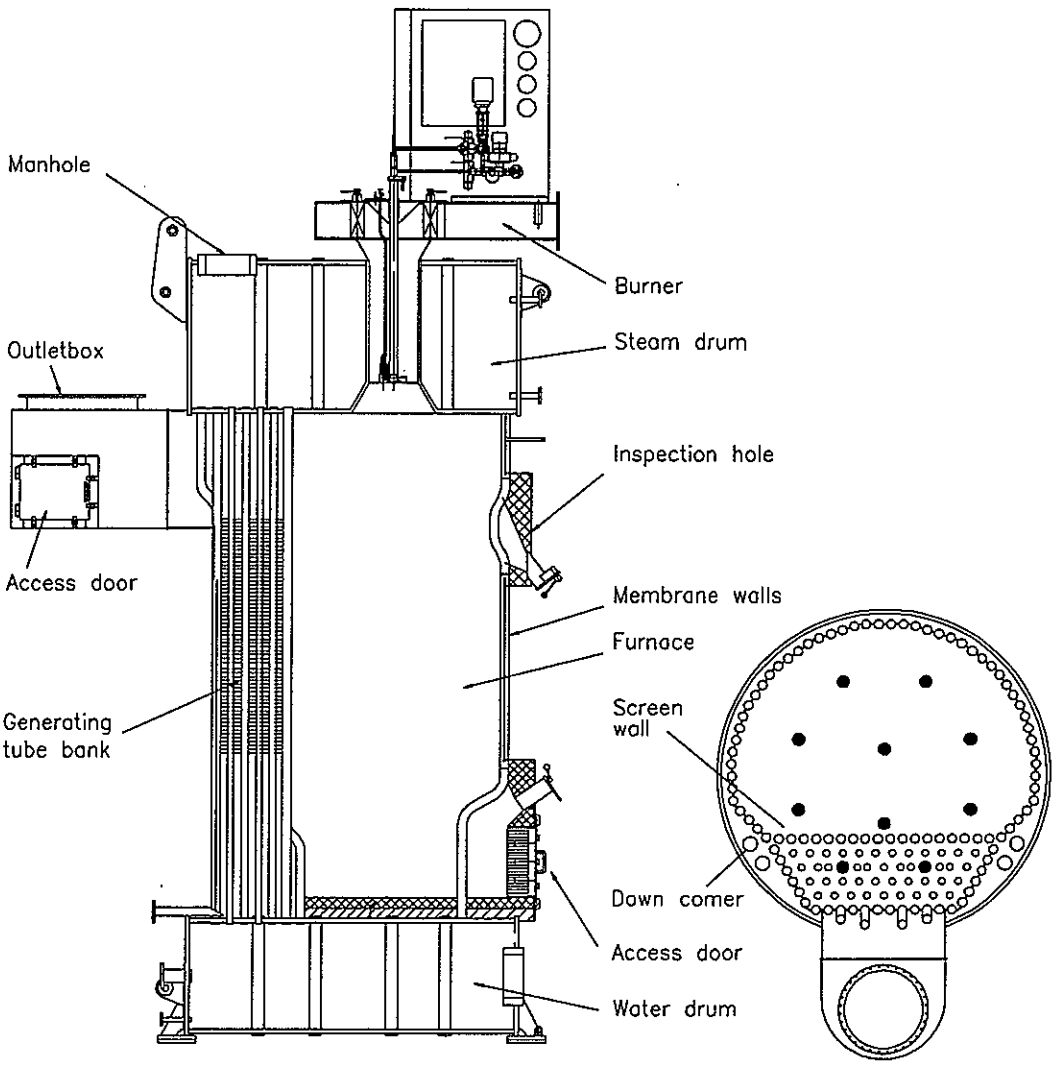


Figure 1 **miss_ol.cdr**

Boiler mountings

1 Mountings

The following is a brief description of the most important items of the boiler mountings. The components mentioned in this section are referring to the general arrangement drawing of the boiler.

Safety valves

Two safety valves are fitted to the pressure vessel of the boiler. They are installed for security reasons, and designed to prevent the boiler pressure from rising above the design value.
The safety valves must be supplied with waste steam pipes and either expansion devices, or bellows.

Main steam valve

The main steam valve is a shut off/non-return valve. When closed, it isolates the boiler from the main steam line. When open, it prevents steam from flowing backwards into the boiler.
The main steam line should be equipped with an expansion joint next or close to the valve.

By-pass valve

The by-pass valve is a shut off valve. The purpose of the valve is to equalise the pressure between the boiler and the steam system when the main steam valve is closed. Please note that the by-pass valve is only supplied for larger boilers.

Feed water valve / feed water valve (sdnr)

Two groups of feed water valves are provided in the boiler. Each group comprises a shut-off valve and a non-return valve.
The shut-off valve in the ordinary group must be open when the boiler is in operation, or if the boiler is used as a steam drum.
The shut-off valves should be closed when the boiler is not in use.

Water level gauges

Two local water level gauges are connected to the front of the boiler, each gauge being provided with two shut-off valves and a drain valve.
The shut-off valves, fitted at the top and bottom of the sight glass, have a quick-closing mechanism to be used in case of broken glass.
The pipes from the drain cocks on the water level gauge must lead to an open drain, visible for inspection.

Blow-down valve

Two blow-down valves of the shut-off/non-return type are mounted at the bottom of the boiler body.
The shut-off function is for security and the non-return function prevents steam/water from flowing into an empty boiler by mistake.

Air valve

The air/ventilation valve located on top of the boiler is a shut-off valve. It is normally closed except when the boiler is being filled or completely drained. The end of the drain pipe from the air valve must be visible in order to determine when water or steam is coming out.

Scum valve

The scum valve is a combined shut-off/non-return valve. In the event of scum in the boiler, this scum can be blown off from the water surface by opening this valve.

Sample valve

A sample valve is installed enabling connection to a sample cooler for taking test samples to perform boiler water analyses.

Inspection hole

Two small inspection holes are provided in the furnace wall to enable inspection of the burner flame. A proportion of the air supply is bled off from the burner fan to cool the window of the inspection hole, and prevent soot deposits.

Manhole

Two manholes placed at the boiler top and boiler bottom allow inside inspection of the steam/water drum.

Access doors

Access to the furnace and smoke outlet box are possible through the access doors placed at the bottom of the furnace and at the smoke outlet box respectively. Both access doors enable inspection of the generating tube bank.

Drain for furnace

The furnace bottom is provided with a socket for drain of the washing water.

Water level control

1 Description

The water level control is a modulating system at this type of boiler. The system is illustrated in Figure 1. The safety device system for too low water level alarm and burner cut out consists of a level float switch mounted as an external unit. For measuring and control of the water level, the boiler is equipped with a dp water level transmitter unit, which includes external reference and variable legs, and a dp-transmitter. The continuous 4-20 mA output signal from the dp-transmitter is processed in the control system, which provides level warnings/alarms and control of the regulating feed water valve.

Water level control system

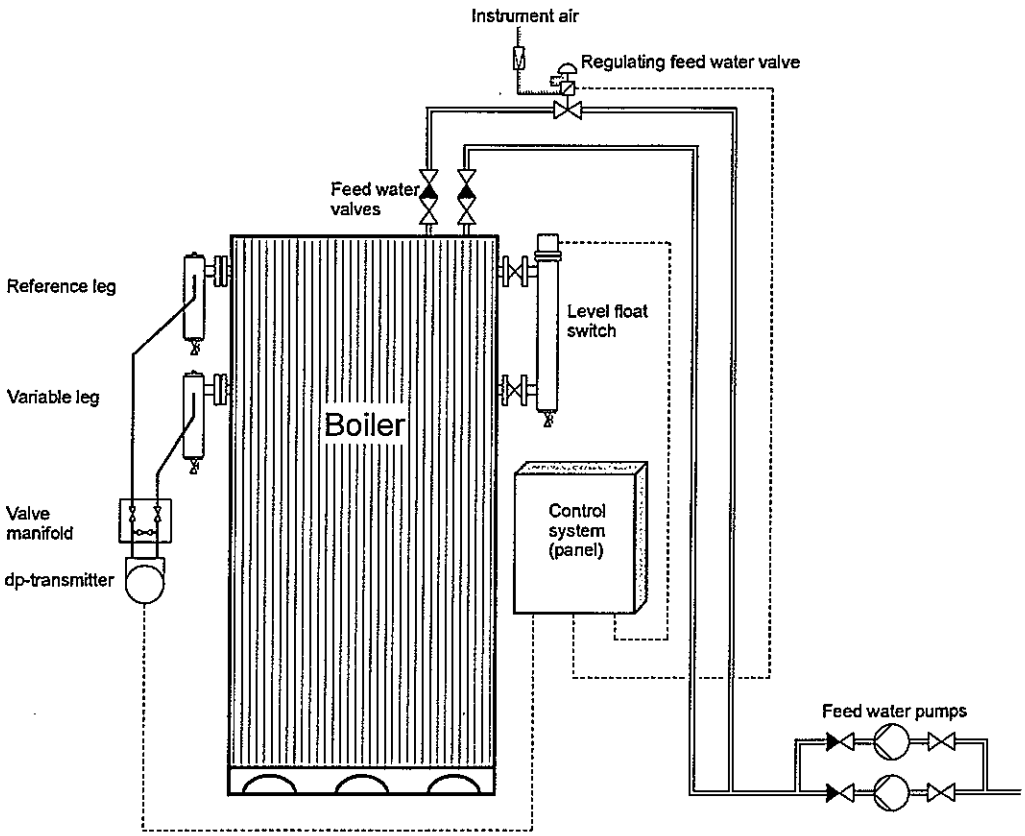


Figure 1 **dp_1_mod.cdr**

Gauge board

1 Description

The function of the gauge board is to control the burner and to give warning and alarm for low and high steam pressure.

- A pressure gauge is fitted for analogous reading of the actual steam pressure in the boiler. The pressure gauge is located on the local control panel.
- A pressure switch "high steam pressure" gives alarm and cut-off the burner when the steam pressure rises above the pre-adjusted set point. Furthermore, the pressure switch locks the burner in stop mode. Operation of the burner is only possible when the steam pressure falls below the differential set point of the pressure switch and the alarm is reset.
- A pressure transmitter connected directly on the boiler converts the actual steam pressure of the boiler into corresponding electric signals. The signals are used to give warnings for low/high steam pressure and alarm/burner cut-off for high steam pressure. Furthermore, the signals are used to control start/stop and modulation set point of the burner.

Start/stop of the boiler

1 General

The following chapters of the instruction manual describe the operation and maintenance of the pressure part. As this is only a part of the complete boiler plant, it is important to study the remaining chapters in this manual very thoroughly. It is especially important that the operator of the boiler plant becomes familiar with the operation instructions of the burner and the control panel.

Important: To ensure a safe and reliable operation of the boiler plant, all operation and/or maintenance of the boiler should be carried out only by skilled personnel.

2 Start-up

When the boiler is started, the lighten-up rate of the boiler must not be accelerated too much as this might cause an unnecessary overstrain of the boiler material by quick and uneven temperature rises. It might be necessary to perform a number of start/stop sequences to reduce the lighten-up rate.

Attention: At the commissioning start-up of the boiler and after any repair work of the refractory, it is very important to further reduce the lighting-up rate. This is because the new refractory still contains a small amount of water. When heated the water vaporises and expands which might cause fissures and cracks in the refractory. The burner must therefore only be operated at minimum load and in intervals of 1-2 minutes for the first hours. Between each operation interval the burner should remain stopped for approximately 8-10 minutes.

Before start-up of the boiler plant, some general work and check procedures must be considered.

Step A: Check that the main steam valve, by-pass valve and circulation valves if provided, scum valve, and blow-down valves are closed.

Step B: Open the feed water valves and the air valve. Fill the boiler with feed water to approximately 50 mm below normal water level. The water level rises due to expansion when the boiler is heated. If the temperature difference between the boiler and feed water exceeds approximately 50°C, the boiler must be filled very slowly.

Note: When filling a pressure less boiler, the shut-off valve after the feed water pump must be throttled. Otherwise the pump motor will be overloaded.

Step C: Check the water level in the water level gauges. Check frequently during the complete start-up. The water level gauges should be blown down several times to ensure a correct indication.

Step D: Check that the water level control system is connected and operational.

Step E: Check the oil system and start the fuel oil supply pump. Pre-heat the fuel oil if the burner should operate on heavy fuel oil.

Step F: Check the burner and the safety functions according to the separate instruction.

2.2 Start and pressure rise

The following work procedures must be followed during start-up of the boiler.

Step A: Check that the gauge board valve and pressure gauge valves are opened.

Step B: Check that the air valve is open if the boiler pressure is below 1.0 barg.

Step C: Start the burner on manual control and on low load. Check that the water level does not rise too high during the pressure rising period.

Step D: Drain via the blow down valves if the water level is too high.

Step E: If the air valve was opened close it when only steam blows out. A pressure reading should be indicated on the boiler pressure gauge before the air valve is closed.

Step F: Tighten all covers such as manholes, hand holes, inspection doors, etc. during the pressure rising period. If required, check all flange joints on the plant.

Step G: Change to automatic control of the burner when the boiler pressure is 0.5 barg lower than the working pressure of the boiler.

Step H: Open the by-pass valve slowly to heat-up and pressurise the steam system. If the boiler is not provided with a by-pass valve, the main steam valve should be used to heat-up and pressurise the steam system.

Step I: Open the main steam valve and close the by-pass valve.

Step J: Open the valves to the steam consumers carefully in order to avoid water chocks.

Step K: When the boiler is in normal operation, check that the water level control system and the gauge board functions are fully operational.

Note: After 3-4 weeks in operation, mud and deposits in the piping system may have accumulated in the boiler water. This may cause level variations which disturb the steam generation, and it is therefore recommended to blow down the boiler. It should then be inspected, cleaned, and refilled with boiler water.

3 Boiler stop

3.1 Normal boiler shut down

If necessary, the boiler can be shut down at any load without special preparations.

Note: When the boiler is stopped, sudden temperature and pressure drops should be avoided as they might expose mountings, pipe lines, and the boiler plant to inadmissible temperature gradients.

Step A: When minimum load is obtained, stop the burner.

Step B: Keep the water level at normal level until the boiler stops producing steam.

Step C: Stop the feed water pump and close the feed water valves.

Step D: Close the main steam valve.

3.2 Emergency shut down

The boiler must be taken out of service immediately if:

- parts of the heating surface have been glowing or the boiler shows recognisable deformations. The supervising authorities must be informed, and the boiler must not be used until approval from these authorities is available
- a substantial loss of water is noted
- the feed water system is unable to provide the necessary amount of feed water, e.g. due to failure of parts
- the safety valve cannot function
- sudden cracks or damage are noted in the refractory, and if steam or moisture is coming out of the refractory
- oil in the feed water is detected
- too high salinity level is detected

If an emergency shut down must be carried out, the fuel supply should be stopped. The main steam valve should be closed gradually, and the boiler must be cooled. The safety valves must not be operated. Parallel working boilers should be disconnected at once.

3.3 Stop for repair or inspection

The following describes the measures to be taken when the boiler is shut down for repair or inspection.

Step A: Clean the boiler from soot with water.

Step B: Operate the burner for at least 15 minutes after the soot removal to dry out the remaining water.

Step C: Stop the boiler as mentioned previously.

Step D: Check the furnace and the pin tubes with regard to cleanliness.

Step E: Empty the boiler from water and clean it. Check if lime stone appears.

Step F: Check and clean the outer fittings. Change gaskets where required.

Step G: Clean the feed water tank and feed water pipes.

Step H: Clean and grease the bearings of motor, pump, and fan.

Step I: Check and align the burner, if necessary.

Step J: If the boiler is shut down for a long period of time, the pin tubes must be thoroughly cleaned.

Step K: Check that the necessary spare parts are available. Order complementary parts in time.

Warning: It is of extreme importance that the boiler is NOT operated without water when the oil burner is in operation, e.g. due to disconnection of the water level safety devices. This will immediately cause complete break down of the boiler.

Boiler maintenance

1 Boiler maintenance

The boiler maintenance should always be executed with skill and in accordance with valid rules and regulations from the authorities, and below are given some recommendations for periodical inspections and maintenance.

1.1 Daily operation

During normal operation of the boiler some work and check procedures have to be considered every day.

Step A: Check the boiler steam pressure and the water level.

Step B: Check that the feed water control system is operational, see separate instructions.

Step C: Check the boiler water condition and make necessary countermeasures with regard to the feed and boiler water treatment. If necessary blow-down the boiler.

Step D: Check the function of the oil burner at different capacities through the inspection holes on the boiler.

Step E: Check the flue gas temperature after and/or the draft loss across the boiler. If either the temperature or the draft loss is too high, the pin-tube section must be cleaned.

1.2 Weekly routine checks

Step A: Drain each water level glass for about 10-15 seconds.

In case of contaminated boiler water or insufficient water treatment, the draining of the water level glasses must be done more often.

Step B: Check the safety water level device.

Step C: Depending on the boiler water tests blown-down the boiler. Open the blow-down valves quickly for a few seconds, and then close and open again for about 5-10 seconds.

Repeat this operation when required according to the boiler water tests.

Step D: Perform scum blow out by means of the scum valve when required. The scum blow out must be carried out until the drained water is clean.

1.3 Monthly routine checks

Step A: Test all stand-by pumps.

Step B: Check all boiler mountings for damage or leaks and repair/replace if necessary.

Step C: Check the function of the high steam pressure switch by lowering the set point or by raising the steam pressure, e.g. by closing the main steam valve slowly.

The burner must stop automatically.

2 Inspection of the boiler

2.1 Inspection of furnace

The furnace should be inspected at least twice a year. During this inspection the following issues should be taken into consideration:

- Check for cracks at the refractory lining and that the furnace walls are free from excessive soot deposits.
- Examine carefully the area opposite the burner. Too much soot deposits indicate that the burner should be adjusted.
- Check that the pin-tube elements are intact and that soot deposits are within normal limits.

2.2 Inspection of boiler water side

The boiler water side (interior) must be carefully inspected at least twice a year. This inspection of great importance and no doubt the most important of all the maintenance measures, since it has a direct influence on the boiler longevity and on the security.
At these inspections, hard deposits, corrosion and circulation disturbances can be found at an early stage, and preventive measures must be taken to avoid unexpected material damage and boiler breakdown.
Presence of hard deposits at the furnace wall and the pin-tubes reduces their heat transfer properties and decrease the capacity of the boiler.
Further, it is possible to make out if the feed water treatment has been satisfactory and if the blow-down has been carried out sufficiently.
Incorrect feed water treatment is commonly causing hard deposits or corrosion.
Insufficient blow-down will cause sludge deposits in the tubes and accumulation of sludge in the bottom of the boiler.
If hard deposits are not removed, it may lead to overheating in the boiler plate material which is exposed to the flame in the furnace wall area. This may cause material damages.
Incorrect feed water treatment does not always lead to hard deposits. For example, a too low or too high a pH-value may give an electrolytic reaction, causing corrosion in the boiler.

When the boiler interior is inspected, examine all parts carefully and be attentive to deposits, corrosion and cracks. It is advisable to pay special attention to this inspection. If any unusual signs are found, contact Aalborg Industries at once for advice.

2.3 Procedure and remarks for inspection

Step A: Shut off the boiler and allow it to cool (below 100°C).

Note: The boiler should NOT be depressurised by lifting the safety valves and then filled with cold feed water since the stress induced by too rapid cooling may cause damage.

Step B: Empty the boiler and close all valves.

If the boiler is connected to a second boiler, check that the valves between them are closed.

Step C: Unscrew and remove the manhole hatch(s) on the boiler and enter the boiler when it is sufficiently cold.

Check the welding in the boiler. A careful examination should be carried out with respect to any possible corrosion or crack formation.
Special care should be taken to the water line area in the pressure vessel where oxygen pitting may occur.
If deposits are found to be forming in the boiler tubes, the boiler should be chemically cleaned.
It is advisable to consult a company of cleaning specialists who will examine the boiler deposits and treat the boiler accordingly.

Note: After chemical treatment the boiler should be blown-down at least twice a day for approximately one week. This will ensure that excessive sludge deposits due to chemical treatment do not collect in the bottom of pressure vessel.

2.4 Contamination

If the boiler is contaminated with foreign substances like oil, chemicals, corrosion products etc., it is very important to act immediately to avoid damages to the boiler.
Layers of thin oil films, mud, etc. exposed to the heating surfaces causes a bad heat transfer in the boiler, leading to overheating followed by burned out pressure parts.
In order to remove such contamination, a boiling out or acid cleaning have to be performed immediately.

Note: Corrosion products from the pipe system or insufficient boiler water treatment may result in corrosion in the boiler itself. It is therefore important to observe that such circumstances do not occur in the system.

Boiling out

1 Boiling out

Before putting the boiler into operation for the first time, it should be boiled out to remove all protecting remedies and impurities on the boiler waterside.
The boiling out procedure is recommended to be carried out as described below:

Caution: Extreme care should be taken while handling the chemicals. The person handling the chemicals/solution should be properly dressed/protected.

Step A: Fill the boiler with a solution consisting of 4-5 kg trisodiumphosphate Na_3PO_4 per 1000 kg water. The chemicals can be added through the manhole.

Step B: Add feed water until the solution is visible in the water gauges above "lower water level".

Step C: Close the feed water valve (pump stopped).

Caution: Do never fill feed water into the boiler if the temperature difference between boiler and feed water exceeds 50°C.

Step D: Raise steam pressure slowly to working pressure, and keep the pressure for approx. 3-4 hours with closed main steam valve.

Step E: Scum until water level is between "Normal water level" and "High water level".

By this procedure grease and other impurities are removed from the internal surfaces of the boiler.

Step F: Start skimming by opening the scum valve, and lower the water level to lower edge of "Normal water level" mark.

Step G: Close the scum valve.

Step H: Refill the boiler with feed water and start skimming again in intervals of 30 minutes for a period of two hours.

Step I: Stop the boiling out procedure by switching off the burner.

Step J: Let the boiler water rest for about five minutes.

Step K: Carry out a final skimming.

Step L: Blow off the boiler water by opening the blow down valves.

Step M: Remember to open the air escape valve, to avoid a vacuum in the boiler when the boiler pressure decreases to approx. depressurised/atmospheric pressure.

Step N: Open the manhole and let the boiler cool down to approx. 100°C.

Step O: The boiler is to be flushed with clean water on the boiler waterside, when the temperature has decreased. The flushing removes remaining impurities.

Step P: Dismantle the bottom blow down valves, for cleaning and inspection because deposits/foreign substances will usually be accumulated in these valves and cause leaking if not cleaned.

Step Q: Inspect the boiler and remove any remaining deposits and foreign substances.

Step R: Finally, new gaskets to be fitted in all hand- and manholes before refilling the boiler with water to upper edge of "Low water level".

The boiler is now ready to be taken into service.

Note: During the first two weeks in operation we recommend to carry out frequently skimming and bottom blow down to remove impurities entering the boiler from the pipe system.

Water washing

1 Description

In order to keep the heat transfer area sufficiently clean the boiler is designed with a high flue gas velocity through the generating tube bank.
However, after long term operation, e.g. during combustion of poor quality oil or with reduced combustion quality, deposits can be formed on the heating surface. As most deposits mainly consist of non-soluble particles, which are held together by a water soluble bonding material, it is possible to clean the heating surface with water washing.

Water washing of the generating tube bank

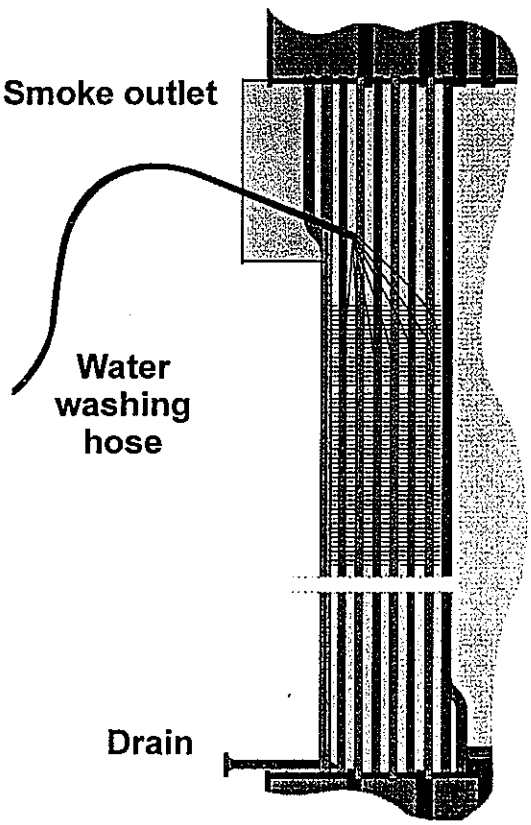


Figure 1 **ol_wash.cdr**

The MISSION™ OL boiler is easily cleaned from the smoke outlet box with a water hose. When water washing is carried out the boiler must be out of operation and the boiler temperature below 110°C.

After the water washing is completed the refractory at the furnace bottom must be cleaned with alkaline water due to the washing water is very corrosive. It must be observed that all the washing water and loosened deposits are removed from the boiler.

When the water washing has begun it must be completed so that all deposits are removed. This is because some types of coatings hardens and accordingly gets very difficult to loosen when they first have been saturated and then dry out.

The boiler must be boiled out immediately after the water washing has been completed in order to avoid damage on refractory and heating surfaces. The boiler must be lightened-up and pressurised as described in the chapter "Start/stop of the boiler".

Soot blowing

1 Description

Generally, there will be a self cleaning effect of the generating tube bank due to the high flue gas velocity. However, deposits are formed on the heating surfaces, e.g. due to combustion of poor quality oil or reduced combustion quality. These deposits will accumulate on the heating surface of the generating tube bank if not removed by cleaning.
The MISSION™ boiler is equipped with soot blowers for cleaning of the generating tube bank. The soot blowers are manually operated and are arranged for direct connection to the steam system of the ship. In order to obtain an efficient soot cleaning, the steam pressure must be at normal working pressure. Furthermore, the boiler load should not be lower than 50%. This ensures a sufficiently high velocity of the flue gas, which is necessary to carry loosened soot deposits out of the boiler. Figure 1 shows a soot blowing arrangement.
Because of the varying combustion parameters, it is impossible to specify exact time intervals between soot blowing. In general soot blowing is recommended every 24 hours.

Note: Excessive soot blowing by means of steam might cause erosion damage on the generating tube bank.

During operation of the boiler plant, the operating personnel should determine the necessity with regard to time intervals for soot blowing. This interval should then be increased or decreased to fit the specified plant.

2 Cleaning procedure

Step A: Check that the steam pressure is at normal working pressure.

Step B: Check that the main valve for soot blower and the two manually operated ball valves are closed.

Step C: Open the drain valve to drain water from the main tube for a few seconds and close it again.

Step D: Open the main valve.

Step E: Open the lower manually operated ball valve and soot blow for approximately five seconds.

Step F: Close the lower manually operated ball valve again.

Step G: Open the upper manually operated ball valve and soot blow for approximately five seconds.

Step H: Close the upper manually operated ball valve again.

Step I: Repeat step "D" to "G" 3-4 times.

Step J: Close the main valve.

Step K: Check that both ball valves are closed.

Illustration of a soot blowing arrangement

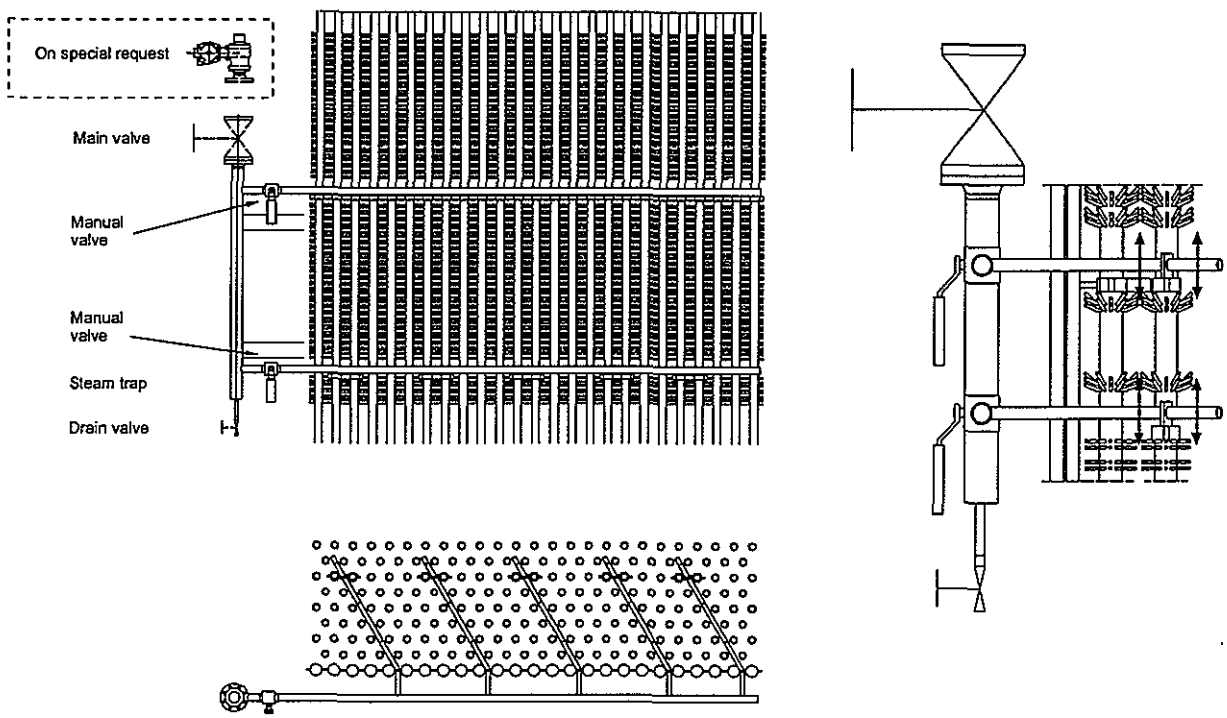


Figure 1 **sootblow1a.cdr**

Preservation

1 Preservation of the boiler

If the boiler is to be shut down for a period of 1-30 days, it should be top filled to prevent corrosion. Before top filling, it should be cleaned from soot deposits.
If the boiler is to be shut down for more than one month, different methods to prevent corrosion can be applied:

- Dry preservation.
- Wet preservation.
- Nitrogen preservation.
- VCI preservation.

The work procedures related to each of these preservation methods are described in the following:

1.1 Dry preservation

When this method is applied the boiler should be totally emptied off water and dried out.

Step A: Empty the water/steam contents inside the boiler by means of the bottom blow down at a boiler pressure of 3-5 barg. Open the boiler when it is depressurised and drain off any remaining water.

Step B: Manhole doors and hand hole covers should be opened when the boiler is still hot. If there is water left in the bottom of the boiler it must be removed, e.g., by using a vacuum cleaner.

Step C: If the boiler is cold, drying of the boiler can be done by either circulating dried air from a fan or by placing bags of silicagel inside the boiler.

Step D: Before the manhole doors and hand hole covers are closed, place a tray with burning charcoal to remove oxygen. As soon as the tray with charcoal is in position, close the manhole doors and hand hole covers using new gaskets.

Step E: Alternatively, a small steam phase inhibitor can be added to the boiler after cooling and careful draining. Afterwards the boiler should be closed completely.

1.2 Wet preservation

While dry preservation is a question of draining off water to avoid corrosion, the principle of wet preservation is to prevent oxygen from entering the boiler.
This method can be used for a short period of 'lay-up' (1-3 months).

Step A: The boiler is filled with treated boiler water and hydrazine is added until an excess of 100-200 ppm is obtained.

Step B: The water should be circulated continuously or at least once per week to avoid corrosion from any penetration of oxygen, and it is necessary to check the hydrazine concentration and add the necessary amount to have an excess of 100-200 ppm. Other oxygen binding agents can also be used.

The pH-value should be 9.5-10.5.

Note: If there is any risk of the temperature falling back below 0°C, this method should not be used to avoid frost damages.

As this preservation method involves applying hydrazine to the water inside the boiler, the boiler must be completely drained and refilled with fresh water before taken into service again.

1.3 Nitrogen preservation

The boiler should be drained, dried and sealed in the same way as mentioned in section "1.1, Dry preservation".

Step A: Make a connection point to the bottom of the boiler and open the air escape valve on top of the boiler.

Step B: Connect cylinders with nitrogen to the bottom connection point via a reduction valve and purge the boiler until there is no oxygen left.

Step C: Close the air escape valve.

Step D: Leave a cylinder with nitrogen connected to the boiler via a reduction valve and keep an overpressure of approximately 0.2 bar inside the boiler.

1.4 VCI preservation

An alternative to the above mentioned preservation methods may be the use of a so-called volatile corrosion inhibitor (VCI).
The VCI is a water soluble chemical which partly evaporates and protects both the water and steam spaces of the boiler. It should be able to eliminate the need for complete drainage and/or application of nitrogen, and may in particular be interesting when a forced circulation type exhaust gas boiler is installed in the steam system. The boiler must be effectively sealed from the atmosphere to maintain the corrosion protection.
The VCI is offered by various chemical companies and must be used in accordance with their recommendations.

Boiler repair - plugging of tubes

1 Plugging of tubes

In case of a leakage on a boiler tube, the burner must be stopped and the pressure lowered to atmospheric pressure.
If the leaking tube cannot be located immediately the boiler should be set on pressure by means of the feed water pumps so that the leakage will indicate which tube is damaged.

Step A: When the boiler is emptied of water remove the manhole covers in the steam drum and the water drum.

Step B: When the damaged tube is located it must be plugged with a conical tube plug. Before the tube plug is mounted clean the inside of the tube ends with a steel brush, so that no deposits are present in the tube.

Step C: When tubes have been plugged those should be renewed as soon as possible. Plugging of tubes results in reduced efficient heating surface and accordingly the boiler efficiency will decrease.

Note: Temporary repairs require more attention than a normal working boiler.

1.2 Plugging of furnace panel wall tubes

When a furnace tube has been plugged the furnace side of the damaged tube should be cut vertically along the connections with the fins between the tubes in the panel wall, see Figure 1.
Inside the rest of the tube and on the fins next to the damaged tube a number of anchors of heat resistant or stainless steel must be welded on.
Afterwards erection of refractory against the damaged tube and the neighbouring fins must be carried out in the full height inside the furnace.

Plugging of furnace tubes

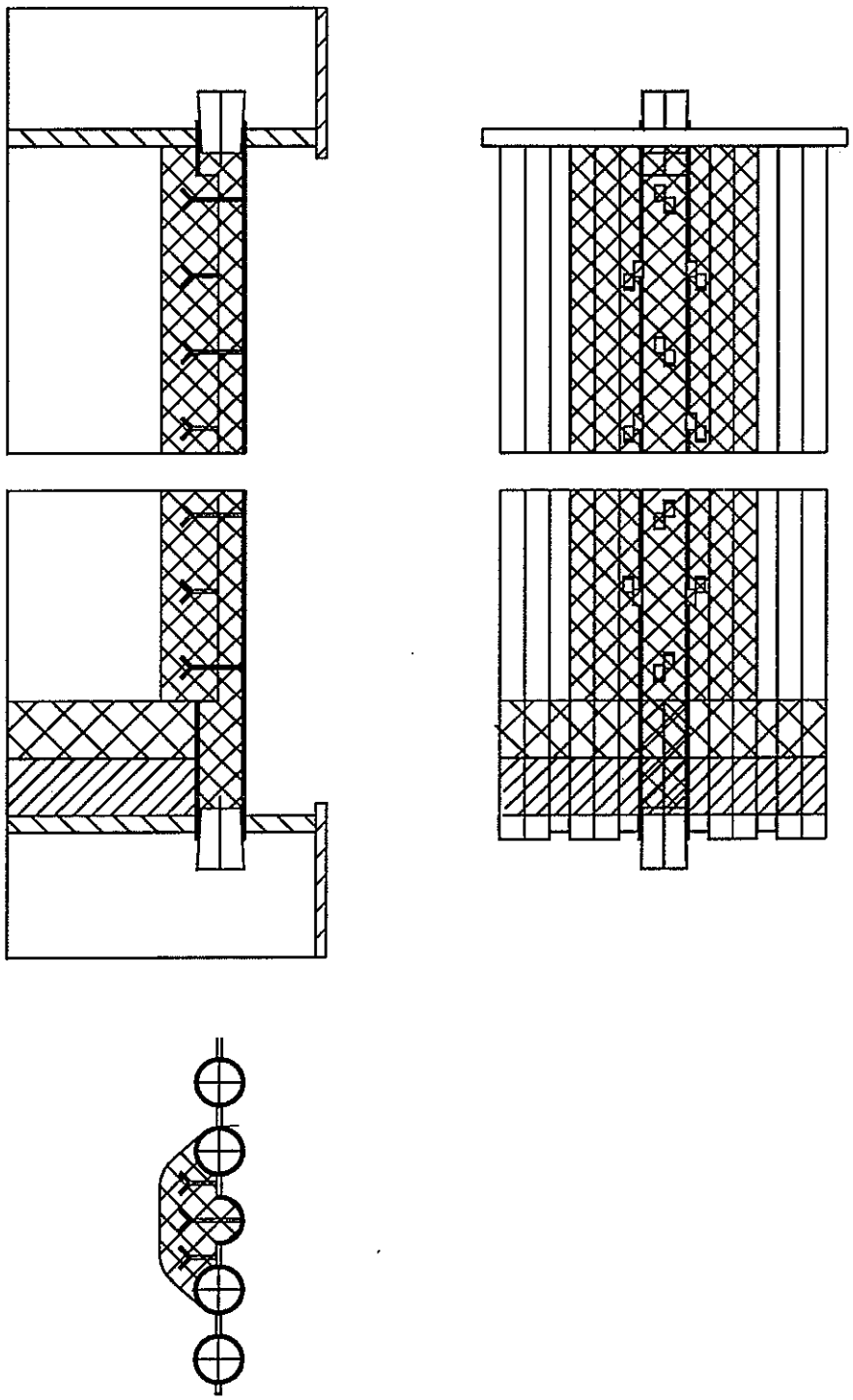


Figure 1 **plug01a.cdr**

1.3 Plugging of generating tubes

Plugging of the generating tubes are shown in Figure 2. Up to 10% of all generation tubes can be plugged with a conical plug but if more tubes are damaged, an exchange of tubes are necessary.

Plugging and replacement of generating tubes

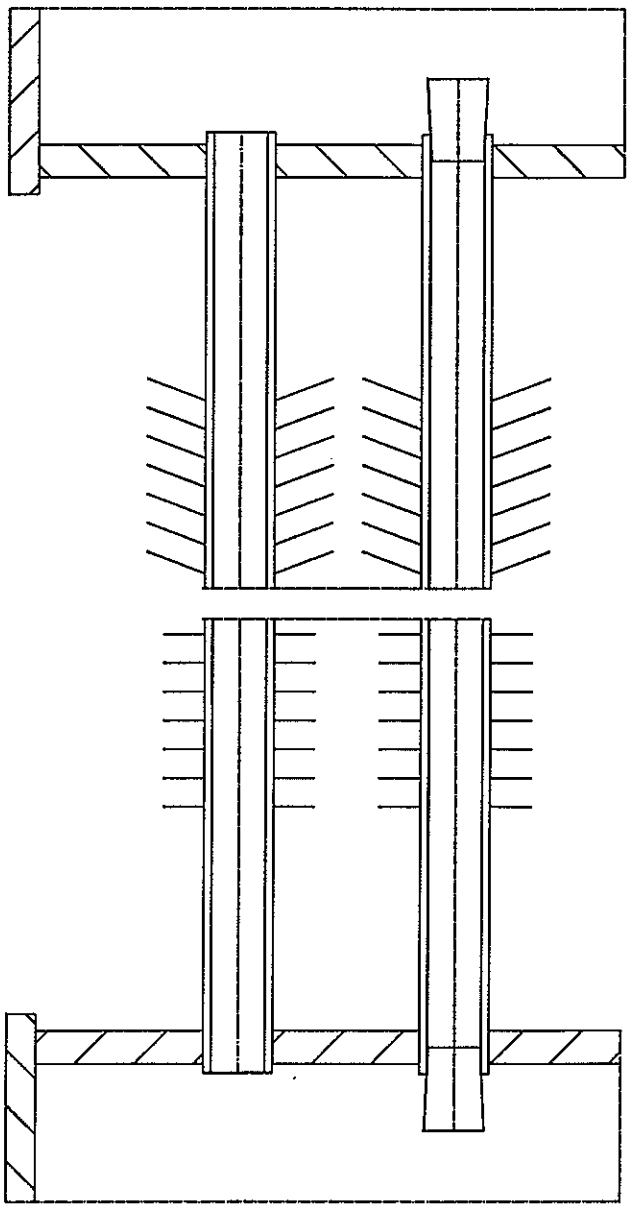


Figure 2 **plug04a.cdr**

Boiler repair - refractory

1 Refractory repair

The furnace floor is lined with an insulating material (Verilite R6), close to the casing covered with a layer of castable refractory (Plicast 31).
The refractory is made with expansion joints, which should under no circumstances be blocked or filled on purpose.
Even though the refractory is made with expansion joints, it will tend to make additional natural expansion joints, which will be seen as fissures. However, the fissures will generally close when the boiler is put into service. Please note the following guidelines when examining the fissures:

- white/light fissures, which are getting darker over the time and are closing when the boiler is in service and opening in cold condition, need no further attention.
- dark/black fissures suddenly occurred, seen in cold condition and are not closing when boiler is in service need to be repaired/filled up with refractory (Plicast 31).

All refractory subjected to wear will, eventually, need to be repaired. This can be done as a temporary repair or on a permanent basis.

1.1 Temporary repair

Smaller areas can be temporarily repaired making use of the repair mix Plistix 14, supplied separately with the boiler equipment.
The durability of such a repair depends on the location, but the more exposed to heat, the shorter lifetime. Generally, it is recommended to replace a temporary repair with a repair on a permanent basis within one year.
Temporary repairs in vertical places ought to be made "swallow tailed", see Figure 1, if possible. This secures a better attachment to the existing refractory.

Sketch indicating a "swallow tail" repair

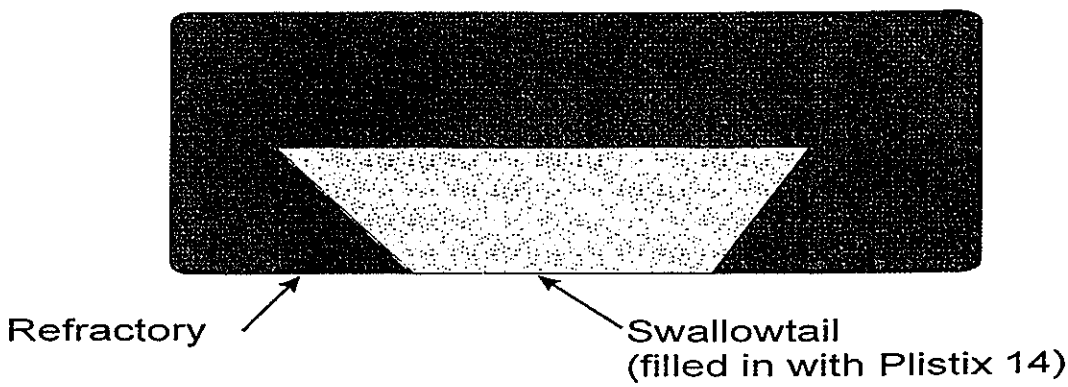


Figure 1 **swaltail.cdr**

The surface to which the temporary repair is performed, must always be clean, dry and rugged.
Mixing instructions for the castable refractory appears from the instruction on the plastic bucket.

Note: Plistix 14 must be applied to the site immediately when mixed.

The boiler can be lightened-up approx. 1 hour after the refractory has been applied. The refractory needs no further time for hardening.
If the boiler is pressurized, the lighting-up should be started with the burner in "on" position for one (1) minute and then in "off" for two (2) minutes, during the first half (½) hour. Then it can be started up according to the ordinary lighting-up procedure.

Note: Observe the safety rules regarding the refractory which can be seen on the plastic bucket.

1.2 Permanent repair

Major repairs and renewal of temporary repairs shall always be carried out and supervised by maker's specialists, among other things securing that correct drying-out time and lighting-up is observed.

1.3 Boilers with membrane furnace wall

The refractory applied to a damaged membrane furnace wall must be carried out as shown in Figure 2.

Refractory applied to a membrane furnace wall

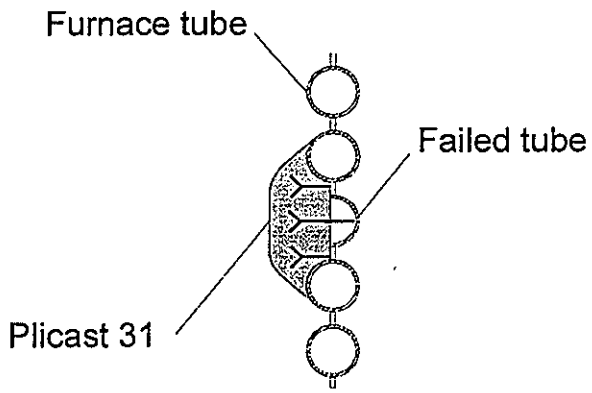


Figure 2 **plugrefrac.cdr**

Warning: Failed Y-anchors must only be replaced by Y-anchors made from heat resistant steel. Y-anchors made from incorrect materials will cause damage to the refractory.

2 Maintenance of refractory

Note: The refractory should be inspected once a year for shape and wear. It is recommended to carry out an inspection in due time prior to long repair periods such as dry docking, etc. Should a repair be required castable refractors and bricklayers can then be ordered on short notice.

If the refractory has been exposed to water, the refractory should be dried out as soon as possible. The drying out can be done by hot air (approx. 50°C) or by operating the oil burner.

Warning: However, if the burner is being used, the burner should be operated with great care.

Warning: Generated steam evaporated from water absorbed into the refractory might cause fissures and cracks when expanding, if the heat input from the oil burner is too heavy.

2.1 Typical refractory data

Below in Table 1 is a list of typical refractory data shown.

Refractory data			
	Verilite R6	Plicast 31	Plistix 14
Al_2O_3	32%	44%	48%
SiO_2	24%	46%	43%
Fe_2O_2	12%	1%	1%
TiO_2	1.6%	1%	1.9%
CaO	23.3%	6.5%	4.8%
MgO	6.1%	0.5%	0.2%
Alkanes	1%	1%	-
Na_2O	-	-	0.1%
K_2O	-	-	0.2%
Operating range	100-1000°C	20-1450°C	100-1420°C

Table 1

Feed and boiler water

1 General

Note: The recommended feed and boiler water characteristics are only valid for boilers with a working pressure below 20 barg.

There is a number of ways to produce good quality feed water for boiler plants. Methods such as e.g. reverse osmosis plants or ion exchange plants produce good quality distillate. Also evaporators generally produce good distillate. The important thing is that the distillate used should be clean and without foreign salt contamination.
In practice most distillates used contain minor parts of various salt combinations which can and must be chemically treated away. Furthermore, the distillate may contain dissolved gases like for example oxygen (O_2) and carbon dioxide (CO_2) which may lead to corrosion in the boiler, steam, and condensate system.

Important: Boiler and feed water must be chemically treated in order to avoid corrosion and scaling in the boiler.

2 Layout of the treatment system

The condition of the feed and boiler water is an essential part of the boiler operation and operation philosophy. The design and construction of the treatment system should therefore be considered carefully during layout of the plant. Aalborg Industries gives some general requirements and recommendations regarding the conditions of the feed and boiler water. However, there is several ways to obtain this results, or similar, by using different treatment systems. The following should therefore be considered already at the layout stage:

— Choose the treatment system that should be used.

— Present the condensate and feed water system to the supplier of the treatment system and inform about the operation philosophy of the plant.

— Let the supplier indicate where the injection points should be located and also inform if special equipment is required.

— Let the supplier inform about which test facilities is needed.

— Purchase the recommended equipment and install it in the correct way.

— Use the treatment system as soon as the boiler is taken into operation.

3 Feed and boiler water characteristics

The following text regarding feed and boiler water treatment is the normal recommendations given by Aalborg Industries. These recommendations should be followed strictly in order to have the best working conditions for the boiler plant and to extend the working life of the plant. The requirements/recommendations of the various values for feed and boiler water are listed in Table 1 below.

Requirements for feed and boiler water			
	Unit	**Feed water**	**Boiler water**
Appearance	-	Clear and free of mud	Clear and free of mud
Hardness	ppm $CaCO_3$	0 - 5	-
Chloride content	ppm Cl^-	<15	<100
"P" alkalinity	ppm $CaCO_3$	-	100 - 150
Total (T) alkalinity	ppm $CaCO_3$	-	<2 x "P" - Alkalinity
PH-value at 25°C	-	8.5 - 9.5	10.5 - 11.5
Hydrazine excess	ppm N_2H_4	-	0.1 - 0.2
Phosphate excess	ppm PO_4	-	20 - 50
Specific density at 20°C	Kg/m^3	-	<1.003
Conductivity at 25°C	µS/cm	-	<2000
Oil content	-	NIL	NIL

Table 1

If hydrazine (N_2H_4) is not used, sodium sulphate (Na_2SO_4) can be used instead, and the excess should be 30 - 60 ppm.
In cases where other kinds of oxygen binding agents are used, it is recommended that an excess of oxygen binding agents can be measured and indicates that no oxygen has been dissolved in the boiler water.
If it is requested to measure the content of dissolved oxygen directly, it is recommended to keep the value < 0.02 ppm.
In addition to the above values, the various water treatment companies will add further demands, depending on the method used for treatment of feed and boiler water.
However, the most important point is that the above values or their equivalents are observed and that a regular (daily) test of feed and boiler water is carried out.

3.1 Units of measurement

Concentrations are usually expressed in "ppm" i.e. parts solute per million. Concentrations for parts solution by weight are the same as "mg/litre".

3.1.1 Specific gravity

As guidance the following conversion can be used:

- 1 Be° = 10.000 mg/l total dissolved solids (TDS)
- 1 mg/l total dissolved solids = 2 µS/cm
- 1 µS/cm = 1 µmho

4 Feed and boiler water maintenance

The following are recommended water maintenance instructions. More exact details concerning analyses and blow downs should be set up together with the supplier of chemicals for water treatment.

4.1.1 Daily

Step A: Analyses of feed and boiler water.

4.1.2 Weekly

Step A: Skimming (surface blow down) according to analyses, but at least once per week (2 minutes with fully open valve).

Step B: Blow down (bottom blow down) according to analyses, but at least once per week (each blow down valve 1 minute in low load condition).

4.1.3 Monthly

Step A: Check the functions for salinity and oil detection systems.

4.1.4 Every six months

Step A: The boiler water side (interior) must be carefully inspected at least twice a year.

4.1.5 Yearly

Step A: Check of the water side of the boiler and hotwell/deaerator for corrosion and scaling.

Step B: Check the chemical pump unit.

5 Treatment systems / injection points

In the following tables and illustrations a number of different feed and boiler water treatment systems are shown together with the recommended location for the injection point of the individual chemicals as stated by the manufacturer. The general information regarding the injection point principle can be used as guidelines for the most common systems. But should there be any doubt for a specific system the manufacturer/supplier should be consulted in order to obtain the correct result.

Notes for tables/illustrations:

- Note No. 1: the preferred injection point of chemicals stated by the manufacturer/supplier.
- Note No. 2: the alternate injection point of chemicals stated by the manufacturer/supplier.
- Note No. 3: Valid for modulating feed water systems.
- Note No. 4: valid for on/off operating feed water systems. The chemical pump starts/stops together with the feed water pump.
- Note No. 5: valid for two boiler installation. Control of the chemicals in question work properly at an equal load condition (feed water flow) on the two boilers.

How to use the tables:

The tables can be used in different ways but the main idea is to do following:

Step A: Discover which manufacturer and type of chemicals that should be used for the actual boiler plant.

Step B: Use the name of the manufacturer and type of chemicals to select which tables that can be used.

Step C: Check the flow diagrams (Figure 1, Figure 2, or Figure 3) to find a diagram that matches the actual boiler plant.

Step D: Find in the selected tables the table which includes the matching diagram.

Step E: If more than one table is found to match the actual boiler plant in question it is recommended to use the method/table which includes note No. 1.

Step F: If no table is found to match the actual boiler plant in question it is recommended to seek assistance by the chemical manufacturer/supplier.

Chemical injection points

Manufacturer / supplier:	Ashland Chemical / Drew Marine Division				Table No. 1
Product name / method:	**Standard with Drewplex OX**				
Chemical name	**Injection point No.**	**Continuous**	**Batch**	**Note No.**	**Valid flow diagram No.**
Adjunct B	3, 3a, 3b		X	1	1, 2, 3
GC	3, 3a, 3b		X	1	
SLCC-A	3, 3a, 3b		X	1	
Drewplex OX	2, 2a, 2b	X		1, 3, 4	

Manufacturer / supplier:	Ashland Chemical / Drew Marine Division				Table No. 2
Product name / method:	**Standard with Amerzine**				
Chemical name	**Injection point No.**	**Continuous**	**Batch**	**Note No.**	**Valid flow diagram No.**
Adjunct B	3, 3a, 3b		X	1	1, 2, 3
GC	3, 3a, 3b		X	1	
SLCC-A	3, 3a, 3b		X	1	
Amerzine	2, 2a, 2b	X		1, 3, 4	

Manufacturer / supplier:	Ashland Chemical / Drew Marine Division				Table No. 3
Product name / method:	**Standard with Amerzine**				
Chemical name	**Injection point No.**	**Continuous**	**Batch**	**Note No.**	**Valid flow diagram No.**
Adjunct B	3		X		1
GC	3		X		
SLCC-A	3		X		
Amerzine	1	X		2, 3, 4	

Manufacturer / supplier:	Ashland Chemical / Drew Marine Division				Table No. 4
Product name / method:	**Standard with Amerzine**				
Chemical name	**Injection point No.**	**Continuous**	**Batch**	**Note No.**	**Valid flow diagram No.**
Adjunct B	3a, 3b		X		2, 3
GC	3a, 3b		X		
SLCC-A	3a, 3b		X		
Amerzine	1	X		2, 3, 4, 5	

Manufacturer / supplier:	Ashland Chemical / Drew Marine Division				Table No. 5
Product name / method:	**Drewplex AT / OX**				
Chemical name	**Injection point No.**	**Continuous**	**Batch**	**Note No.**	**Valid flow diagram No.**
Drewplex AT	3, 3a, 3b	X		1	1, 2, 3
Drewplex OX	2, 2a, 2b	X		1, 3, 4	

Chemical injection points (continued)

Manufacturer / supplier:	Ashland Chemical / Drew Marine Division	Table No. 6
Product name / method:	Drewplex AT / OX	

Chemical name	Injection point No.	Continuous	Batch	Note No.	Valid flow diagram No.
Drewplex AT	2, 2a, 2b	X		2, 3, 4	1, 2, 3
Drewplex OX	2, 2a, 2b	X		3, 4	

Manufacturer / supplier:	Ashland Chemical / Drew Marine Division	Table No. 7
Product name / method:	Drewplex AT with Amerzine	

Chemical name	Injection point No.	Continuous	Batch	Note No.	Valid flow diagram No.
Drewplex AT	3, 3a, 3b	X		1, 3, 4	1, 2, 3
Amerzine	2, 2a, 2b	X		1, 3, 4	

Manufacturer / supplier:	Ashland Chemical / Drew Marine Division	Table No. 8
Product name / method:	Drewplex AT with Amerzine	

Chemical name	Injection point No.	Continuous	Batch	Note No.	Valid flow diagram No.
Drewplex AT	2, 2a, 2b	X		2, 3, 4	1, 2, 3
Amerzine	2, 2a, 2b	X		3, 4	

Manufacturer / supplier:	Ashland Chemical / Drew Marine Division	Table No. 9
Product name / method:	Drewplex AT with Amerzine	

Chemical name	Injection point No.	Continuous	Batch	Note No.	Valid flow diagram No.
Drewplex AT	2, 2a, 2b	X		2, 3, 4	1, 2, 3
Amerzine	1	X		2, 3, 4, 5	

Manufacturer / supplier:	Ashland Chemical / Drew Marine Division	Table No. 10
Product name / method:	AGK-100 with Amerzine	

Chemical name	Injection point No.	Continuous	Batch	Note No.	Valid flow diagram No.
AGK-100	2, 2a, 2b	X		1, 3, 4	1, 2, 3
Amerzine	2, 2a, 2b	X		1, 3, 4	

Chemical injection points (continued)

Table No. 11

Manufacturer / supplier:	Ashland Chemical / Drew Marine Division				
Product name / method:	**AGK-100 with Amerzine**				
Chemical name	**Injection point No.**	**Continuous**	**Batch**	**Note No.**	**Valid flow diagram No.**
AGK-100	2, 2a, 2b	X		3, 4	1, 2, 3
Amerzine	1	X		2, 3, 4, 5	

Table No. 12

Manufacturer / supplier:	Ashland Chemical / Drew Marine Division				
Product name / method:	**AGK-100 with Amerzine**				
Chemical name	**Injection point No.**	**Continuous**	**Batch**	**Note No.**	**Valid flow diagram No.**
AGK-100	1	X		2, 3, 4, 5	1, 2, 3
Amerzine	1	X		2, 3, 4, 5	

Table No. 13

Manufacturer / supplier:	Marichem				
Product name / method:	**Standard**				
Chemical name	**Injection point No.**	**Continuous**	**Batch**	**Note No.**	**Valid flow diagram No.**
Alkalinity control	3, 3a, 3b		X	1, 3, 4	1, 2, 3
Phosphate	3, 3a, 3b		X	1, 3, 4	
Oxycontrol	2, 2a, 2b	X		1, 3, 4	
Marichem CCI	2, 2a, 2b	X		1, 3, 4	

Table No. 14

Manufacturer / supplier:	Marichem				
Product name / method:	**Standard**				
Chemical name	**Injection point No.**	**Continuous**	**Batch**	**Note No.**	**Valid flow diagram No.**
Alkalinity control	1		X	2, 3, 4	1
Phosphate	1		X	2, 3, 4	
Oxycontrol	2	X		3, 4	
Marichem CCI	2	X		3, 4	

Table No. 15

Manufacturer / supplier:	Marichem				
Product name / method:	**BWT new formula**				
Chemical name	**Injection point No.**	**Continuous**	**Batch**	**Note No.**	**Valid flow diagram No.**
B.W.T. new formula	2, 2a, 2b	X		1, 3, 4	1, 2, 3
Marichem CCI	2, 2a, 2b	X		1, 3, 4	

Chemical injection points (continued)

Table No. 16

Manufacturer / supplier:	Marichem				
Product name / method:	**BWT new formula**				
Chemical name	**Injection point No.**	**Continuous**	**Batch**	**Note No.**	**Valid flow diagram No.**
B.W.T. new formula	1		X	2, 3, 4, 5	1, 2, 3
Marichem CCI	2, 2a, 2b	X		3, 4	

Table No. 17

Manufacturer / supplier:	Marichem				
Product name / method:	**BWT**				
Chemical name	**Injection point No.**	**Continuous**	**Batch**	**Note No.**	**Valid flow diagram No.**
B.W.T. powder	2, 2a, 2b	X		1, 3, 4	1, 2, 3
Marichem CCI	2, 2a, 2b	X		1, 3, 4	

Table No. 18

Manufacturer / supplier:	Marichem				
Product name / method:	**BWT**				
Chemical name	**Injection point No.**	**Continuous**	**Batch**	**Note No.**	**Valid flow diagram No.**
B.W.T. powder	1		X	2, 3, 4, 5	1, 2, 3
Marichem CCI	2, 2a, 2b	X		3, 4	

Table No. 19

Manufacturer / supplier:	Unitor Chemicals				
Product name / method:	**I**				
Chemical name	**Injection point No.**	**Continuous**	**Batch**	**Note No.**	**Valid flow diagram No.**
Hardness control	3, 3a, 3b		X	1	1, 2, 3
Alkalinity control	3, 3a, 3b		X	1	
Oxygen control	2, 2a, 2b	X		1, 3, 4	
Condensate control	2, 2a, 2b	X		1, 3, 4	

Table No. 20

Manufacturer / supplier:	Unitor Chemicals				
Product name / method:	**I**				
Chemical name	**Injection point No.**	**Continuous**	**Batch**	**Note No.**	**Valid flow diagram No.**
Hardness control	1		X	2	1
Alkalinity control	1		X	2	
Oxygen control	2	X		3, 4	
Condensate control	2	X		3, 4	

Chemical injection points (continued)

Manufacturer / supplier:	Unitor Chemicals	Table No. 21
Product name / method:	II	

Chemical name	Injection point No.	Continuous	Batch	Note No.	Valid flow diagram No.
Hardness control	3, 3a, 3b		X	1	1, 2, 3
Alkalinity control	3, 3a, 3b		X	1	
Cat sulphite L (CSL)	2, 2a, 2b	X		1, 3, 4	
Condensate control	2, 2a, 2b	X		1, 3, 4	

Manufacturer / supplier:	Unitor Chemicals	Table No. 22
Product name / method:	II	

Chemical name	Injection point No.	Continuous	Batch	Note No.	Valid flow diagram No.
Hardness control	1		X	2	1
Alkalinity control	1		X	2	
Cat sulphite L (CSL)	2	X		3, 4	
Condensate control	2	X		3, 4	

Manufacturer / supplier:	Unitor Chemicals	Table No. 23
Product name / method:	Liquitreat	

Chemical name	Injection point No.	Continuous	Batch	Note No.	Valid flow diagram No.
Liquitreat	3, 3a, 3b		X	1	1, 2, 3
Condensate control	2, 2a, 2b	X		1, 3, 4	
(Oxygen control)	2, 2a, 2b	X		1, 3, 4	

Manufacturer / supplier:	Unitor Chemicals	Table No. 24
Product name / method:	Liquitreat	

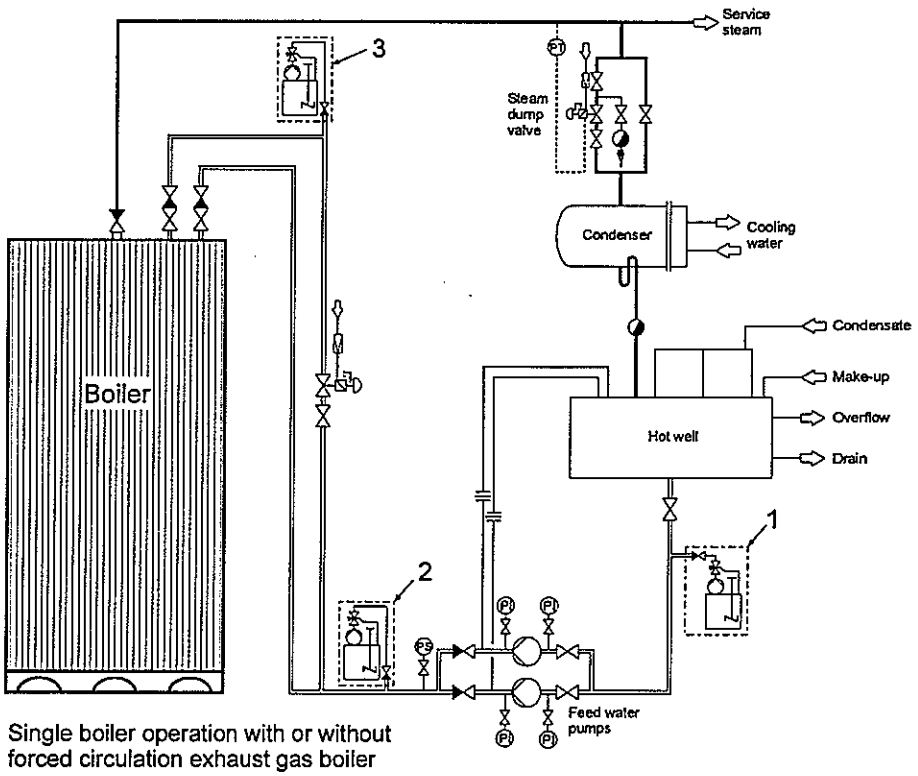
Chemical name	Injection point No.	Continuous	Batch	Note No.	Valid flow diagram No.
Liquitreat	1		X	2	1
Condensate control	2, 2a, 2b	X		3, 4	
(Oxygen control)	2, 2a, 2b	X		3, 4	

Manufacturer / supplier:	Unitor Chemicals	Table No. 25
Product name / method:	Combitreat	

Chemical name	Injection point No.	Continuous	Batch	Note No.	Valid flow diagram No.
Combitreat	3, 3a, 3b		X	1	1, 2, 3
Condensate control	2, 2a, 2b	X		1, 3, 4	
Oxygen control	2, 2a, 2b	X		1, 3, 4	

Chemical injection points (continued)					
Manufacturer / supplier:		**Unitor Chemicals**			**Table No. 26**
Product name / method:		**Combitreat**			
Chemical name	**Injection point No.**	**Continuous**	**Batch**	**Note No.**	**Valid flow diagram No.**
Combitreat	1		X	2	1
Condensate control	2	X		3, 4	
Oxygen control	2	X		3, 4	

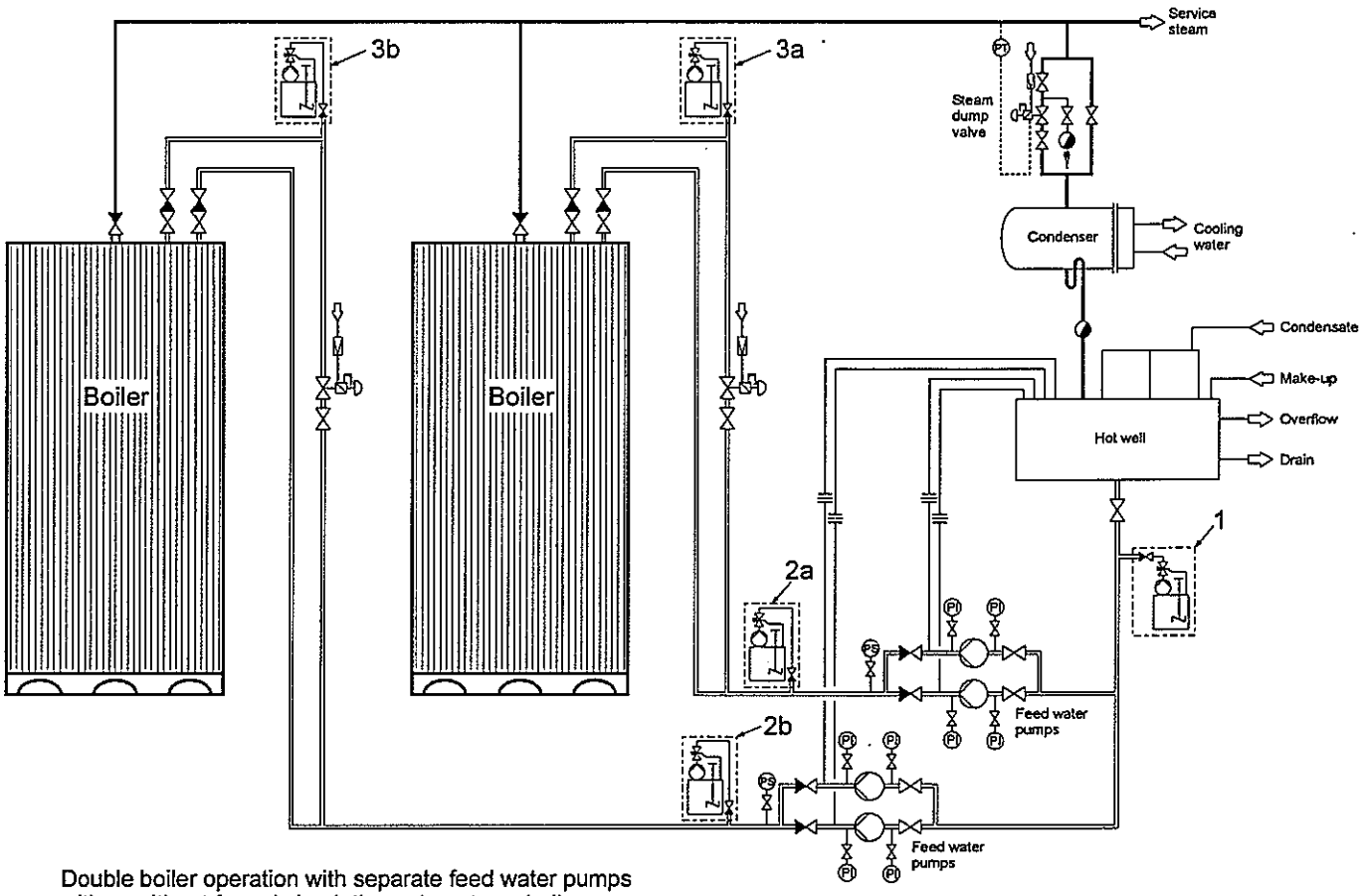
Flow diagram No.: 1



Single boiler operation with or without forced circulation exhaust gas boiler

Figure 1 **flowdiag_1.cdr**

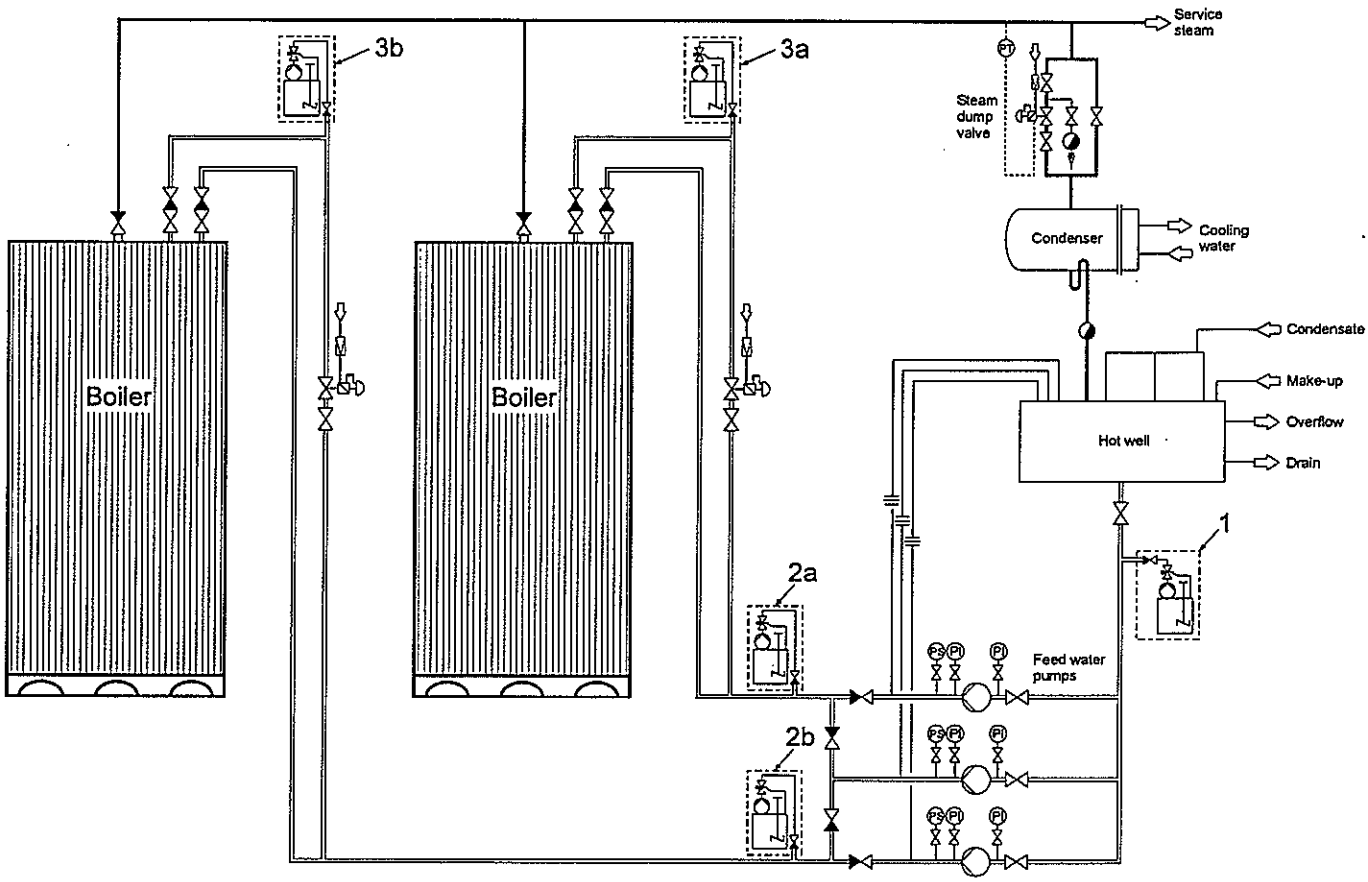
Flow diagram No.: 2



Double boiler operation with separate feed water pumps
with or without forced circulation exhaust gas boiler

Figure 2 **flowdiag_2.cdr**

Flow diagram No.: 3



Double boiler operation with common feed water pumps
with or without forced circulation exhaust gas boiler

Figure 3 **flowdiag_3.cdr**

Commissioning

1 General

The following commissioning instructions are valid for steam atomising burners type KBSD with Y-atomisers and with a standard delivery of individual parts for the burner unit and supply systems from AALBORG INDUSTRIES.
Prior to the commissioning, the instructions for the individual parts of the burner unit and supply systems should be studied. The special instructions for the boiler and the control system should also be consulted. The instructions should only be considered as a guideline. This is due to the fact that each plant should be commissioned individually to obtain the best burner performance for the specific plant.

Attention: If the burner unit and supply systems include parts, which are not standard delivery from AALBORG INDUSTRIES, the specific instructions for these parts should be ignored in the following sections. The actual instructions for the specific parts should be thoroughly studied and followed during commissioning.

During commissioning of the burner unit and supply systems, it might be necessary to adjust some regulation parameters, timer settings, etc. in the control system to optimise the function of the plant. These adjustments are not described in the following sections, but should be carried out as the optimisation requirements emerge. Please see the instructions for the control system.

1.1 Pre-service checks

Before commissioning, the following work steps must be carried out:

Step A: Check that the boiler is ready for operation according to the special instructions for the boiler

Step B: Increase or decrease the water level in the boiler to approximately 50 mm below normal water level.

Step C: Check the electric wiring.

Step D: Switch on the power for the boiler plant and reset the system on the local panel or the computer.

Step E: Check that the control system is operational according to the special instructions for the control system.

Step F: Pre-adjust the pressure switch and pressure transmitter set points for boiler operation.

The position numbers mentioned in the following sections refer to the illustrations in Figure 1 and Figure 2. The position numbers consist of an identification letter and a position number code. Position numbers with the identification letters "G and R" refer to Figure 1, and position numbers with the identification letter "F" refer to Figure 2. The oil system is shown as a plant with two boilers, but is also valid for a plant with only one boiler.

Illustration of the oil system

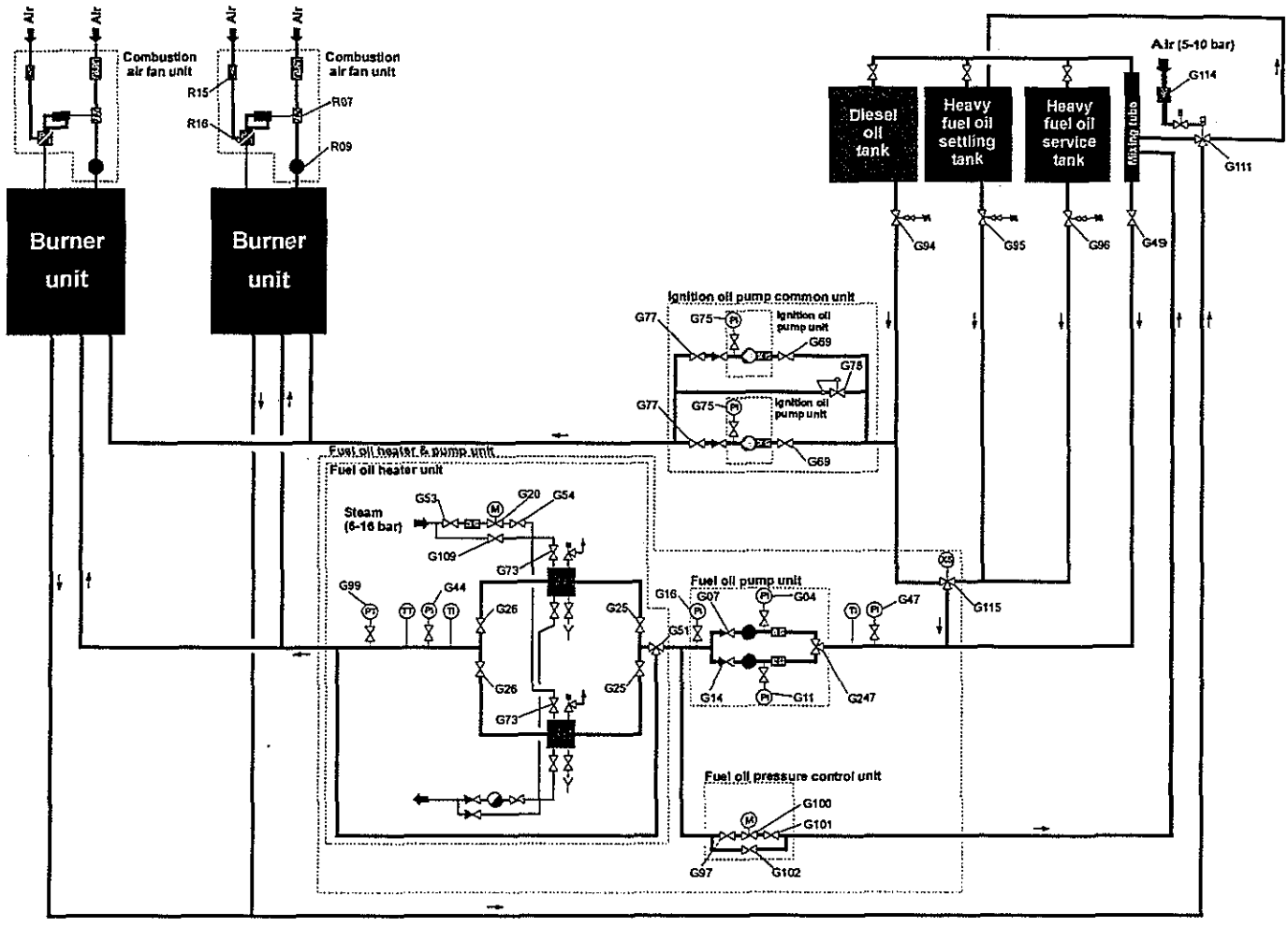


Figure 1 **F_oilsys1b.cdr**

Illustration of the burner unit and supply systems

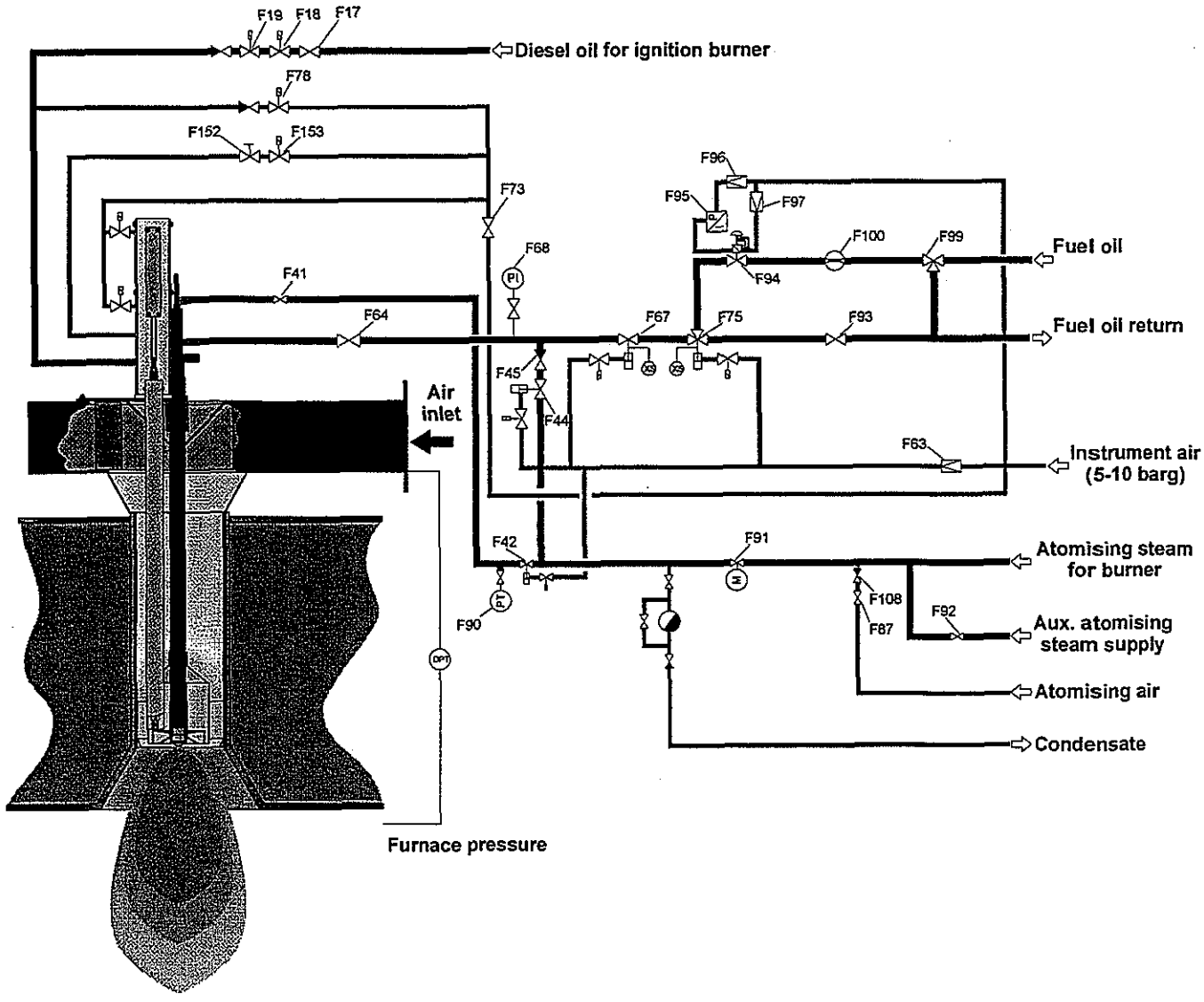


Figure 2 **Burnoilsy1c.cdr**

2 Commissioning

2.1 Commissioning adjustments of the burner unit

On delivery from Aalborg Industries, the burner unit has been pre-adjusted to fit the task. Even though the burner unit has been pre-adjusted, it is advisable to carry out additional checks during commissioning. These checks should be carried out with regard to adjustment of the atomiser and swirlers, and ignition electrodes, etc. This means that it is necessary to pull out the burner lance, swirlers, and ignition burner.

2.1.1 Dismantling

Step A: Remove the flame scanners.

Step B: Close the stop valves (F41 and F64).

Step C: Dismount the flexible hoses for fuel oil and atomising steam to the burner lance.

Step D: Dismount the flexible hose for combustion air to the ignition burner.

Step E: Dismount the flexible hoses for ignition oil and purge air to the ignition burner.

Step F: Dismount the flexible hoses for the air servo cylinder on the ignition burner.

Step G: Dismount the cable for the magnetic switch on the ignition burner.

Step H: Remove the two spark plug caps from the ignition burner.

Step I: Note the position of the front plate and unscrew the bolts from the front plate.

Step J: Lift up the front plate in the lifting eyes including the burner lance, swirlers, and ignition burner by means of a tackle. Be careful not to damage the packing between the wind-box and front plate.

2.1.2 Adjustment of the atomiser and swirlers distance

Step A: Check the distance between the atomiser tip and the inner ring of the primary swirler. The factory setting is 25 mm. Adjust if necessary.

Note: An exact distance cannot be given, but has to be determined when the burner is in operation. If the flame has a tendency to pulsate at low loads, it might be necessary to readjust the distance.

Step B: Loosen the bolt, which fixes the primary swirler to the burner lance protection tube. Adjust the primary swirler to the desired position, and tighten the bolt again.

Step C: Loosen the bolt, which fixes the secondary swirler to the burner lance protection tube. Adjust the secondary swirler into a position in which the inner ring of the secondary swirler and the outer ring of the primary swirler are at the same level. Tighten the bolt again. This corresponds to an equal movement of the secondary swirler to the same numerical distance as the primary swirler movement. Tighten the bolt again.

Step D: Loosen the bolt, which fixes the burner lance protection tube to the front plate. Adjust the protection tube into a position in which the outer ring of

the secondary swirler and the beginning of the quarl (burner cone) are at the same level. This corresponds to an opposite movement of the protection tube to the same numerical distance as the swirlers movement. Tighten the bolt again.

Step E: If an adjustment is carried out, loosen the fixing screws that hold the air servo cylinder of the ignition burner. Move it in the same direction and to the same numerical distance as the primary swirler movement. The factory setting between the ignition burner and the primary swirler is 5 mm. Tighten the fixing screws again.

2.1.3 Adjustment of the ignition burner

Step A: Check the position of the oil nozzle for the ignition burner. The oil nozzle tip should be at the same level as the end of the ignition burner mixing tube. Adjust if necessary.

Step B: Check the position of the ignition electrodes. The ignition electrodes should be 10-12 mm in front of the atomiser tip and 8-12 mm above the atomiser tip. The distance between the electrodes should be adjusted to 4 mm. Adjust if necessary.

Note: An exact setting of the ignition electrodes cannot be given, but has to be established when the ignition burner is in operation.

Step C: Unscrew the two screws that fix the mixing tube to the electrode holder and pull out the mixing tube.

Step D: Loosen the centre screw that fixes the oil supply pipe and adjust to the desired position. Tighten the centre screw again.

Step E: Dismount the oil nozzle from the oil supply pipe and check that the nozzle is clean. Assemble after check/cleaning.

Step F: Loosen the two Allen screws that fix the ignition electrodes and adjust to the desired position. Tighten the Allen screws again.

Step G: Assemble the electrode holder and the mixing tube. Screw in the two screws on the mixing tube.

2.1.4 Measurements

Step A: Before the burner unit is assembled, check and note the commissioning measurements. The obtained measurements should be inserted in the chapter "Measurement and settings".

2.1.5 Assembling

Step A: Check the condition of the packing between the wind-box and the front plate. Replace if necessary.

Step B: Mount the front plate including the burner lance, swirlers, and ignition burner onto the wind-box. The front plate should be mounted in the same position as before.

Step C: Screw in the bolts on the front plate. The nuts must be tightened crosswise.

Step D: Mount the flexible hose for combustion air to the ignition burner.

Step E: Mount the flexible hoses for ignition oil and purge air to the ignition burner.

Step F: Mount the flexible hoses for the air servo cylinder on the ignition burner.

Step G: Mount the cable for the magnetic switch on the ignition burner.

Step H: Mount the two spark plug caps on the ignition burner.

Step I: Insert the flame scanners.

2.1.6 Clean the burner lance and atomiser

Step A: Unscrew the two Allen screws on the burner lance flange and pull out the burner lance.

Step B: Dismount the atomiser and screw cap from the burner lance and check that the lance is clean.

Step C: Clean the atomiser and screw cap. The factory has greased the atomiser to protect it from corrosion.

Step D: Replace the two O-rings on the atomiser and assemble the atomiser, screw cap, and burner lance.

Step E: Insert the burner lance into the protection tube and screw in the two Allen screws into the flange connection.

Step F: Mount the flexible hoses for fuel oil and atomising steam to the burner lance.

2.2 Commissioning of the oil system

When the oil system is commissioned, it should initially be flushed by means of an external pumping system. This must be done to ensure that the oil system is not clogged-up and to prevent foreign objects from entering the pump unit which might cause damage.
On delivery the oil system of the burner unit is by-passed by means of the three-way valve (F99). This prevents foreign objects from entering the flow meter, oil flow regulation valve, etc. The position of the valve should not be changed before flushing of the oil system is completed. The valve is locked in this position by means of a screw.

Warning: When the oil system is commissioned on diesel oil, the tracing of the piping system must be off.

2.2.1 Commissioning

Step A: Check that oil is present in the diesel oil tank. Open the quick closing valve (G94), which connects the diesel oil tank to the oil system.

Step B: Select diesel oil on the manually operated three-way valve (G115). Check that the local panel and computer indicate diesel oil operation. Open the stop valve (G49) for the mixing tube.

Step C: Turn the manually operated three-way valve (G247) for oil flow through both pumps.

Step D: Open the stop valves for the pressure gauges (G04, G11, G16, and G47).

Note: The stop valves for the pressure gauges on the pump unit should only be opened for pressure control purposes. The stop valves should be closed during normal operation.

Step E: Close the stop valves (G97 and G101), and open the by-pass valve (G102).

Step F: By-pass the pre-heaters by means of the manually operated three-way valve (G51), and close the stop valves (G25 and G26) for both pre-heaters.

Step G: Open the stop valves for the pressure gauge (G44) and the pressure transmitter (G99).

Step H: Check that the three-way valve (F99) is locked in a position which by-passes the oil system of the burner unit.

Step I: Apply air to the pneumatic three-way valve (G111). Adjust the air pressure to 5-10 barg on the air filter/reduction unit (G114).

Step J: Check the position of the pneumatic three-way valve (G111). In normal position, the return oil is led to the mixing tube. The micro switch box mounted on the valve and the control system should also indicate this position.

Note: When the fuel is changed by means of the three-way valve (G115), the three-way valve (G111) automatically changes position and returns the fuel oil to the heavy fuel oil settling tank for a period of time. This time period is set in the control system.

Step K: Rotate the oil pumps by hand to ensure a free and an uninterrupted rotation.

Step L: Adjust the circuit breakers for both pumps to suit full load current of the motors. The current appears from the motor identification plate and/or the electric diagrams.

Step M: The oil pumps must be filled with diesel oil prior to operation. The vent valve installed on the outlet side of the pump unit must be opened until the air has escaped from the suction side of the pump. As soon as diesel oil emerges, the vent valve may be closed.

2.2.2 Flushing the oil system

Step A: Set the burner into manual operation mode on the local panel or the computer.

Step B: Start one of the oil pumps and check that it is running with the correct direction of rotation. Open the vent valve again until only diesel oil emerges.

Step C: Stop the pump and start the other oil pump. Perform the same check and venting procedures.

Note: The pressure relief valve installed in each pump is factory set and checked and should not be adjusted during commissioning.

Step D: Flush the oil system for a few hours with one oil pump in operation. The total flushing time should be determined with regard to the size of the oil system and the amount of impurities (particles, grease, etc.). Check the complete oil system for leaks.

Step E: If the oil pressure is too low or too high, the pressure can be adjusted on the by-pass valve (G102) to a suitable level.

Step F: Close the stop valves (G53, G54, and G109). These valves must be kept closed during the complete flushing period.

Step G: After 1/4 of the pre-determined flushing period, open the stop valves (G25 and G26) for one of the pre-heaters. Turn the three-way valve (G51) for oil flow through the pre-heaters.

Note: The set points for the pre-heater safety valves are factory set and checked and should not be adjusted during commissioning.

Step H: After 1/2 of the pre-determined flushing period, open the stop valves (G25 and G26) for the other pre-heater. Close the stop valves (G25 and G26) for the first pre-heater.

Step I: After 3/4 of the pre-determined flushing period, stop the operational oil pump.

Step J: By-pass the pre-heaters by means of the manually operated three-way valve (G51), and close the stop valves (G25 and G26) for both pre-heaters.

Step K: Commission the oil pressure regulating valve (G100). Set the valve into manual mode on the local panel or computer.

Step L: Move the actuator mounted on the valve into mid-stroke position by means of the hand wheel. By use of the local panel, apply short impulses in each direction of the movement and check that the directions of movement are correct.

Step M: Set the oil pressure regulating valve (G100) into automatic mode on the local panel or computer again. Move the actuator to the end positions (open/closed) by means of the digital output test menu in the local panel. Check that it is switched off automatically. Check that external moving parts are able to move without obstruction.

Note: In a double boiler plant one of the local panels must be switched off when the digital output test menu is used. Otherwise the valve moves continuously up and down because one panel sends up signals, and the other sends down signals.

Step N: Open the stop valves (G97 and G101), and close the by-pass valve (G102).

Step O: Adjust the set point to be 20-25 bar measured at the burner inlet flange.

Note: An exact value cannot be given. If the pressure loss in the actual oil system is high, the oil pressure must be set at a higher level to ensure that the burner receives a sufficient amount of oil. If, on the other hand, the pressure loss is low, the oil pressure must be set at a lower level to ensure that the oil flow regulation valve is operating within a suitable range.

Step P: Start one of the oil pumps for final flushing.

Step Q: When flushing is completed, stop the operational oil pump and clean the oil filters in the fuel oil supply pump unit. Vent the oil pumps after the filters have been cleaned.

Step R: Commission the steam regulating valve (G20) as described for the oil pressure regulating valve (G100).

Step S: Open the stop valves (G53, G54).

2.2.3 Check and adjust the pressure transmitter

Step A: Check that the oil pressure indicated on the local panel and computer is identical to the pressure indicated on the pressure gauge (G44).

Step B: Adjust the range of the pressure transmitter (G99) in the calibration menu of the local panel if necessary.

Note: If the pressure transmitter (G99) and pressure gauge (G44) are mounted at different height levels and far apart, the pressure loss resulting from height difference and friction should be taken into consideration.

2.2.4 Check the low warning and start of stand-by oil pump function

Step A: Adjust the set point for low warning and start of the stand-by oil pump on the local panel or the computer.

Step B: Start one of the oil pumps and set the other pump into stand-by mode.

Step C: Set the oil pressure regulating valve (G100) into manual mode on the local panel or computer and decrease the pressure gradually until the set point is reached. The operating oil pump should stop, and the pump in stand-by mode should start. The local panel and the computer should indicate a low warning. Readjust if necessary.

Step D: Switch operation mode of the pumps and carry out the same procedure.

2.2.5 Check the low oil pressure alarm and trip function

Step A: Adjust the set point for low alarm and trip on the local panel or the computer.

Step B: Decrease the pressure somewhat until the set point is reached. The operating stand-by pump should stop, and an alarm should be indicated on the local panel and the computer. Readjust if necessary.

Step C: Set the oil pressure regulating valve (G100) into automatic mode and reset the alarms.

2.2.6 Check the trip function for overload

Step A: Check the trip function for overload by pressing the test button for the pump in operation on the circuit breaker.

Step B: The pump stops, and a warning for pump failure should be indicated on the local panel and the computer.

Step C: When the stand-by pump is started, perform the same test with this pump.

Step D: Reset the circuit breakers and all alarms after testing.

2.2.7 Commissioning of the oil system on the burner unit

Step A: Check that the oil pumps are stopped.

Step B: Open the stop valves for the pressure gauge (F68).

Step C: Unscrew the screw that locks the position of the three-way valve (F99). Turn the three-way valve for oil flow through the burner unit. Lock the valve in this position. Open the stop valve (F93).

Step D: Apply air to the pneumatic shut-off valves (F42, F44, and F67) and the pneumatic three-way shut-off valve (F75). Adjust the air pressure to 5-10 barg on the air filter/reduction unit (F63).

Step E: Check the position of the pneumatic three-way shut-off valve (F75) and the pneumatic shut-off valve (F67). The valves must be in position closed which means that the oil is led back to the oil system. When the micro switches on the valves (F67 and F75) are activated, the position is indicated on the local panel and computer.

Step F: Commission the oil flow meter (F100). Check that the oil flow meter and pick-up sensor are installed correctly. The flow meter equipment sends a continuous pulse signal to the control system. This signal must be converted into an analogous flow by settings in the control system.

Step G: Set the values for max. oil and beats/litre in the local panel or computer. The max. oil value is the maximum oil flow in l/h at 100% burner load on heavy fuel oil. The value for beats/litre can be taken from the identification of the oil flow meter.

Step H: Unscrew the pick-up sensor from the oil flow meter.

Step I: Tap the pick-up sensor quickly against an object and check that it records the signals. The red LED flashes.

Step J: Mount the pick-up sensor again.

Step K: Check and adjust the oil flow settings for minimum load, ignition load, etc. in the local panel or computer.

Step L: Commission the oil flow regulation valve (F94). Check that the output signal range from the I/P converter (F95) corresponds to the instrument input signal range on the oil flow regulation valve (F94). The pressures appear from the identification plates.

Step M: Disassemble the cover of the oil flow regulation valve by unscrewing two cover screws and lift up the cover. See also the specified instruction for the oil flow regulation valve.

Step N: Check and adjust C_V (valve characteristic) to fit the plug and seat ring by moving the adjustment knob along the C_V scale. Table 1 shows the C_V setting for each burner size.

Adjustment of C_V		
Burner size	**Maximum flow coefficient C_V**	**Setting C_V**
KBSD 950	1.2	0.85
KBSD 1200	1.2	1.02
KBSD 1500	1.2	1.2
KBSD 1900	2.3	1.5
KBSD 2250	2.3	1.6
KBSD 2650	2.3	1.85
KBSD 3000	2.3	2.3
KBSD 3350	2.3	2.3
KBSD 4150	3.8	3.4

Table 1

Step O: Apply air to the I/P converter (F95). Adjust the air pressure on the filter/reduction unit (F96). The pressure setting appears from the identification plate on the converter.

Step P: Apply supply air to the oil flow regulation valve (F94). Adjust the air pressure on the filter/reduction unit (F97). The pressure setting appears from the identification plate on the valve.

Step Q: Set the oil flow into manual mode on the local panel or computer.

Step R: Set the regulation output to 0% (4 mA) by means of the soft keys on the local panel or by settings on the computer.

Step S: Adjust the pressure indicated on the instrument gauge to the low input signal range, by means of the zero adjustment screw on the I/P converter. The instrument gauge is the left pressure gauge on the oil flow regulation valve, and the low input signal range appears from the identification plate.

Step T: Set the regulation output to 100% (20 mA) by means of the soft keys on the local panel or by settings on the computer.

Step U: Adjust the pressure indicated on the output gauge to the high input signal range, by means of the span adjustment screw on the I/P converter. The output gauge is the right pressure gauge on the oil flow regulation valve, and the high input signal range appears from the identification plate.

Step V: Repeat the work steps "S", "T", and "U" several times until the adjustments are acceptable.

Step W: Set the oil flow regulation valve into automatic mode on the local panel or computer.

Step X: Start one of the oil pumps. Set the stand-by oil flow to 0% in the local panel or computer.

Step Y: Adjust the turn take-up screw of the oil flow regulation valve until the piston rod just begins to move. The local panel and computer must indicate 0% oil flow. Tighten with the lock nut.

Step Z: Set the stand-by oil flow back to the original set point.

2.3 Commissioning of the ignition oil system

When the ignition oil pumps are commissioned, the burner should be operated in emergency mode. This is because the ignition oil pumps only operate in the ignition sequence during burner start, and a number of start/stop operations are necessary to check and adjust the system.

2.3.1 Commissioning

Step A: Turn the key placed inside the local control panel into emergency operation.

Step B: Check that the quick closing valve (G94) is open and open the stop valves (G69 and G77).

Step C: Open the stop valve for the pressure gauge (G75).

Note: The stop valve for the pressure gauge should only be opened for pressure control purposes. The stop valve should be closed during normal operation.

Step D: Close the stop valve (F17) on the burner unit.

Step E: Rotate the ignition oil pump by hand to ensure a free and an uninterrupted rotation.

Step F: Adjust the circuit breaker for the ignition oil pump to suit full load current of the motor. The current appears from the motor identification plate and/or the electric diagrams.

Step G: When the ignition oil pump is commissioned, the pump and the pipe system must be filled with diesel oil and ventilated. The vent valve installed in the pump must be opened until the air has escaped. As soon as diesel oil emerges, the vent valve may be closed.

Step H: Press the ignition button on the emergency panel for the pump, and keep it pressed.

Caution: The ignition oil pump should only be operated for a limited period of time during the following commissioning procedure. Due to a continuous re-circulation, the diesel oil is eventually heated. This could damage the pump due to the low viscosity of the heated diesel oil.

Step I: Check that it is running with the correct direction of rotation. Open the vent valve again until only diesel oil emerges.

Step J: Adjust the opening pressure on the pump to 8-10 bar.

Note: The pressure at the ignition oil burner should be approximately 8 bar. This means that the pressure loss resulting from height difference and friction should be taken into consideration.

Step K: Stop the pump and turn the key into automatic operation.

Step L: Open the stop valve (F17).

Note: The pressure relief valve (G78) is factory set and checked and should not be adjusted during commissioning.

Step M: In plants with two ignition oil pumps, the previously described procedures should be performed.

2.3.2 Check the trip function for overload

Step A: Check the trip function for overload by pressing the test button on the circuit breaker.

Note: An alarm for ignition oil pump failure will not be indicated. If this failure arises during normal start-up sequence, the burner will trip due to ignition flame failure.

Step B: Reset the circuit breaker after testing.

2.4 Commissioning of the combustion air system

When the combustion air system is commissioned, it should be checked that the combustion air fan and the air duct system have been installed and supported correctly. If possible, an inside inspection of the air duct system should also be carried out to ensure that it is free of obstacles, e.g. loose parts, insulating material, etc.

2.4.1 Commissioning of the I/P positioner

Step A: Check that the I/P positioner (R16) is connected as a 2-wire system and apply electric power to the I/P positioner.

Step B: Check that the I/P positioner is in P manual mode. The display must show "NOINIT". If this is not the case press the hand symbol key once. This key is located behind the cover of the I/P positioner.

Step C: Apply air to the I/P positioner and adjust the air pressure to 4-6 bar on the filter/reduction unit (R15).

Step D: Unscrew the cover of the I/P positioner. Use the push buttons ▲▼ to carefully move the actuator and check that the mechanics is functioning.

Step E: Carry out an automatic initialisation of the I/P positioner. Call configure mode by pressing the hand symbol key (>5sec.). See the specified instruction for the I/P positioner.

Step F: Set the actuator type to linear (WAY) in the menu item "1.YFCT".

Step G: Set the rated angle of the feedback in menu item "2.YAGL". The value should be set to 90°.

Step H: Check that the ratio selector arm is set to 90° on the I/P positioner devise.

Step I: Set the leverage (stroke range) in menu item "3.YWAY". The stroke range is the height difference of the guide rail.

Step J: Start the automatic initialisation with the parameter value "Strt" in menu item "4.INIT". The I/P positioner then runs through the initialisation steps "RUN 1" to "RUN 5".

Step K: Set the I/P positioner into manual mode. Open and close the inlet vanes (R07) several times by manually operating the I/P positioner to demonstrate an uninterrupted operation.

Step L: Set the I/P positioner into automatic mode and mount the cover again.

Step M: Check that the micro switch, which controls the closed position of the inlet vanes, is activated. The inlet vanes must be in closed position when the burner is in normal stop mode. If the burner is started during normal operation condition, and the micro switch is deactivated, a sequence failure alarm will be indicated.

2.4.2 Commissioning of the differential pressure transmitter

It is possible to set the start of scale and full scale of the dp-transmitter even if there is no pressure source available ("blind" calibration). Please also see the specified instruction for the dp-transmitter.

Step A: Set the air flow into manual mode on the local panel or computer.

Step B: Set the regulation output to 0% (4 mA) by means of the soft keys on the local panel or by settings on the computer.

Step C: Unscrew the screws that hold the protective cover of the dp-transmitter for access to the push buttons.

Step D: Use the "M" key to select modes on the dp-transmitter. When a mode is selected, the keys ↑ and ↓ are used to change the mode value.

Step E: Set the values in mode 4 (electrical damping), 9 (output in error situation), 10 (pushbuttons functions), 11 (characteristic), 12 (transition point characteristic), 13 (value displayed), and 14 (engineering units). mm H_2O can e.g. be selected as engineering units in mode 14.

Step F: Select mode 5 using the "M" key.

Step G: Use the ↑ or ↓ key to set the start of scale in the selected engineering unit. If mm H_2O is selected as engineering units, then the set start of scale to 0 mm H_2O.

Step H: Press both the ↑ and ↓ keys simultaneously for about 2 seconds, and the start of scale is set to zero (in the selected engineering unit).

Step I: Set the regulation output to 100% (20 mA) by means of the soft keys on the local panel or by settings on the computer.

Step J: Select mode 6 using the "M" key.

Step K: Use the ↑ or ↓ key to set the full scale in the selected engineering unit. The full scale value should normally be set to 300 mm H_2O.

Step L: Set the regulation output to 0% (4 mA) again by means of the soft keys on the local panel or by settings on the computer.

Step M: Set the air flow into automatic mode on the local panel or computer.

Step N: Mount the protective cover of the dp-transmitter again.

Important: The set range of the dp-transmitter should be checked when the burner is in operation at 100% load on heavy fuel oil. The actual differential pressure must not exceed or be too far below the set range of the dp-transmitter. If this is the case, the full scale value must be corrected. This will affect all settings made of the air/oil ratio and they must adjusted once more.

2.4.3 Commissioning checks and operation

Step A: Rotate the combustion air fan by hand to ensure a free and an uninterrupted rotation.

Step B: Check the electrical wiring at the terminals of the combustion air fan. The wiring must be performed according to the wiring shown in the electrical diagrams.

Step C: Adjust the circuit breaker for the combustion air fan to suit full load current of the motor. The current appears from the motor identification plate and/or the electric diagrams.

Step D: Turn the keys placed inside the local control panel and the power panel into emergency operation.

Step E: Close the inlet vanes by means of the potentiometer inside the local control panel.

Step F: Start the combustion air fan (R09) on the operating switch inside the power panel and check that it is running with the correct direction of rotation.

Step G: Check that the combustion air fan and the air duct system do not produce any abnormal mechanical noises.

Step H: Check the combustion air fan and the air duct system for any abnormal vibrations.

Step I: Check the air duct system for leaks.

Step J: Open the inlet vanes for the combustion air fan fully by means of the potentiometer.

Step K: Check the current consumption of the combustion air fan. The current must not exceed the full load current stated on the motor identification plate and/or the electric diagrams.

Step L: Set the combustion air fan to minimum load by means of the potentiometer.

Step M: Check the temperature of the fan bearings. The bearing temperature must be at a constant level after approximately 30 minutes of operation. If the temperature continues to increase, stop the combustion air fan and check the bearings.

Step N: Close the inlet vanes for the combustion air fan by means of the potentiometer inside the local control panel and stop the combustion air fan on the operating switch inside the power panel.

Step O: Turn the keys placed inside the local control panel and the power panel into automatic operation.

2.4.4 Check the trip function for overload

Step A: Start the combustion air fan by means of the digital output test menu in the local panel.

Note: In a double boiler plant, one of the local panels must be switched off when the digital output test menu is used. Otherwise the fan continuously starts and stops because one panel sends start signals, and the other sends stop signals.

Step B: Press the test button on the circuit breaker for the combustion air fan.

Step C: The fan stops, and an alarm for combustion air fan failure should be indicated on the local panel and computer.

Step D: Reset the circuit breaker.

2.5 Commissioning of the steam atomising system

In normal operation, atomising steam is supplied from the boiler drum or from an auxiliary supply system. When the burner is commissioned, atomising steam may not be available. If this is the case, compressed air can be used as the atomising medium.
The function of the steam regulating valve can, however, be checked at this point.

2.5.1 Commissioning of the steam regulating valve

Step A: Commission the steam regulating valve (F91). Set the valve into manual mode on the local panel or computer.

Step B: Move the actuator mounted on the valve into mid-stroke position by means of the hand wheel. By use of the local panel, apply short impulses in each direction of the movement and check that the directions of movement are correct.

Step C: Set the steam regulating valve (F91) into automatic mode on the local panel or computer again. Move the actuator to the end positions (open/closed) by means of the digital output test menu in the local panel. Check that it is switched off automatically. Check that external moving parts are able to move without obstruction.

Step D: Check and adjust the pressure settings in the control system. At low loads, the steam atomising pressure should be set to approximately 2-3 bar. The pressure settings should be gradually increased to 6-7 bar at full load. The final settings must be determined during burner operation.

Step E: Check and adjust the setting for low steam atomising pressure alarm on the local panel or computer. The alarm should be checked when the burner is in automatic operation.

2.5.2 Commissioning without atomising steam

Step A: Close the stop valve (F92), and open the stop valves (F87 and F41).

Step B: Open the stop valve for the pressure transmitter (F90).

Step C: Check that the pneumatic shut-off valve (F42) opens and closes when signals are applied to the valve by means of the digital output test menu in the local panel.

Step D: Open the non-return valve (F45), and check that the stop valve (F64) is open.

Step E: Check that the pneumatic shut-off valve (F44) opens and closes when signals are applied to the valve by means of the digital output test menu in the local panel.

3 Start-up

To continue the commissioning procedures, the oil system must be in normal operation, and the atomising system must be set to compressed air operation if atomising steam is not available. Furthermore, the ignition oil system and combustion air system must be operational.
Prior to the actual start-up of the burner, some additional checks should be carried out with regard to the ignition oil burner and the burner start-up sequence. When these checks are completed, the burner should be commissioned on diesel oil and finally on heavy fuel oil.

Attention: Before and during start-up, the furnace must be checked with regular intervals for oil spillage. If an oil spillage is present in the furnace, the cause must be determined and the failure must be rectified. The furnace should be purged until it is free of oil.

3.1 Additional commissioning checks

3.1.1 Check the ignition burner

Step A: Turn the keys placed inside the local control panel and the power panel into emergency operation.

Step B: Close the inlet vanes of the combustion air fan (R09) by means of the potentiometer inside the local control panel. Start the combustion air fan on the operating switch inside the power panel.

Step C: Open the inlet vanes for the combustion air fan to approximately 15-20% by means of the potentiometer.

Step D: Open the throttle valve (F152) for combustion air to the ignition burner.

Step E: Close the stop valve (F17) to the ignition burner.

Step F: Press the ignition button on the emergency panel and keep it pressed.

Step G: Check that the ignition burner is inserted.

Step H: Check the ignition spark between the electrodes. Use the inspection holes to visually check the ignition spark. The ignition electrodes should be adjusted if necessary.

Step I: Release the ignition button and check that the ignition burner is drawn back after the time period for purge has expired.

Step J: Open the stop valves (F17 and F73).

Step K: Press the ignition button again and keep it pressed. Check that the solenoid valves (F18, F19, and F153) are opened and that the ignition burner is inserted at the same time.

Step L: Check the ignition flame. Use the inspection holes to visually check the ignition flame. Adjust the ignition electrodes, the throttle valve for combustion air, or the opening pressure on the ignition oil pump if necessary.

Step M: Release the ignition button and check that the solenoid valves (F18, F19, and F153) close.

Step N: Check that the solenoid valve (F78) opens and that the ignition burner is purged with air.

Step O: Check that the ignition burner is drawn back after the end of the purge period.

Step P: Adjust the time period for purge to a suitable level on the timer placed inside the local control panel.

Step Q: Check the ignition burner several times to ensure a reliable ignition.

Step R: Close the inlet vanes for the combustion air fan by means of the potentiometer inside the local control panel and stop the combustion air fan on the operating switch inside the power panel.

Step S: Turn the keys placed inside the local control panel and the power panel into automatic operation.

3.1.2 Check the burner start-up sequence

In automatic mode, the start/stop sequences of the burner are carried out by the control system. A condition for the initiation of the start-up sequence is that no safety interlock alarms are present. If a safety interlock alarm is present, the cause must be corrected.
The following check of the start-up sequence should be carefully monitored on site to demonstrate the correct function of the start-up sequence locally. The start sequence is also indicated on the local panel and computer.

Step A: Close the stop valve (F64).

Step B: Check that the air damper (R07) is in closed position.

Step C: Set the burner into manual operation mode on the local panel or computer.

Step D: Start one of the oil pumps.

Step E: Check that the oil flow regulation valve (F94) is in stand-by position (stand-by oil flow).

Step F: Start the burner on the local panel or computer.

Step G: Check that the combustion air fan (R09) starts.

Note: The combustion air fan is set for a minimum operation time of 20 minutes in automatic mode to avoid more than three starts per hour.

Step H: Check that the pneumatic shut-off valve (F42) opens and that the burner is supplied with the atomising medium.

Step I: Check that the air damper is moved into purge position.

Step J: Check that the combustion air fan damper is moved into ignition position after the furnace purge period.

Step K: Check that the oil flow regulation valve is in ignition position (ignition oil flow).

Step L: Check that the ignition burner is inserted and ignited.

Step M: Check that the pneumatic three-way valve (F75) and the pneumatic shut-off valve (F67) change position.

Step N: Check that diesel oil to the ignition burner is shut-off and that it is purged with air.

Step O: Because the stop valve (F64) is closed, the burner start-up fails due to flame failure. Check that the pneumatic three-way valve (F75) and the pneumatic shut-off valve (F67) change position immediately after the flame failure alarm appears.

Step P: Open the stop valve (F64) and reset all alarms.

3.2 Commissioning on diesel oil

When the burner is commissioned, the boiler pressure and temperature must not be intensified too rapidly as this might cause stresses in the boiler. The burner should be kept in minimum firing position during the first commissioning period. In manual operation mode, the burner load can be controlled by means of the soft keys on the local panel and/or by settings on the computer.
When the burner is stopped during normal operation, the burner lance is purged with atomising steam, and the remaining oil in the lance is atomised into furnace and burned. To ensure a complete combustion of the oil during steam purging, it is important to carry out this procedure with the correct air/fuel ratio. If the combustion air flow is too low, the combustion produces black smoke, and if the air flow is too high, the flame blows out before the combustion is completed.
The correct air flow for the combustion can be determined by comparing the oil pressure at the atomiser and the steam atomising pressure. When these pressures are identical, the oil flow atomised into the furnace does not change when steam purging

is initiated. This means that the present air flow suits the combustion. This load is the steam purge position load and must be set in the control system.
When the burner is commissioned on diesel oil and/or when the atomising medium is compressed air, the steam purge position should be pre-adjusted to approximately 25%. The final setting should be determined when the burner is commissioned on heavy fuel oil, and the atomising medium is steam.

3.2.1 Operation of the burner

Due to the risk of stresses in the boiler, the burner should only be operated at relatively short intervals during the initial start-up. When the burner is stopped during this firing-up procedure, the remaining safety interlock alarms can be checked and adjusted.

Step A: Check and adjust the steam purge position on the local panel or computer.

Step B: Start the burner in manual operation mode on the local panel or computer.

Step C: Check that the burner ignites when the oil valves open and that it remains ignited when the ignition burner is shut-off and retracted.

Note: A number of starts may be necessary before the burner ignites. If ignition of the burner fails despite of several attempts, adjust the ignition oil flow, the correction factor for air/fuel ratio, or the atomising pressure on the local panel or computer.

Step D: Check that the burner is in minimum firing position after start-up.

Step E: Check that the flame does not pulsate. Adjust the correction factor, air/fuel ratio, and/or minimum load if necessary

Step F: Check the shape and colour of the flame. Measure the CO_2 and/or the O_2 content and adjust the correction factor or air/fuel ratio if necessary.

Step G: Check the colour of the flue gas. Measure the soot spot No. It should not exceed a soot spot No. of 1-3 (Bachrach). Adjust the correction factor or air/fuel ratio if necessary.

Note: The final adjustment of the combustion parameters, e.g. air/fuel ratio, minimum load, steam atomising pressure, etc. should be carried out when the burner operates on heavy fuel oil and with steam as atomising medium. It is therefore advisable to adjust the correction factor instead of the air/fuel ratio when the burner is commissioned on diesel oil.

3.2.2 Check the stop sequence

Step A: The stop sequence should also be carefully monitored on site. Operate the burner for a few minutes.

Step B: Set the burner load to steam purge position and stop the burner.

Step C: Check that the pneumatic three-way valve (F75) and the pneumatic shut-off valve (F67) change position.

Step D: Check that the pneumatic shut-off valve (F44) for steam purge opens at the same time as the oil valves close. The flame failure equipment is inactive when the burner is purged.

Step E: Check that the pneumatic shut-off valve (F42) for atomising steam closes after the end of the steam purge 1 period.

Step F: Check that the pneumatic shut-off valve (F44) for steam purge closes after the end of the steam purge 2 period.

Step G: Check that the air damper moves to post purge (purge) position if this sequence step is active.

Step H: Check that the oil flow is in stand-by position and that the air damper is closed after the end of the steam purge 2/post purge period.

Step I: Check that the combustion air fan stops. The fan only stops if it has been operating more than 20 minutes.

Step J: Check that the furnace is free of oil spillage.

3.2.3 Check the safety interlock alarm for flame failure equipment

Step A: When the burner is in operation, check the flame failure equipment by removing one of the flame scanners from the holder and cover the sensor. The burner shuts down, and an alarm for flame failure is indicated on the local panel and computer. Reset all alarms.

Step B: Check and simulate a glowing furnace by using a flash light pointed directly at the flame scanner.

Step C: Set the burner into start mode. The local panel and computer should indicate an alarm for flame failure.

Step D: Mount the flame scanner into the holder and reset all alarms.

Step E: Perform the same checks with the other flame scanner.

3.2.4 Check the safety interlock alarm for lance inserted

Step A: When the burner is in operation, unscrew the two Allen screws on the burner lance flange. Carefully lift the lance a few [mm]. The burner shuts down, and an alarm is indicated on the local panel and computer.

Step B: Screw in the two Allen screws into the flange connection and reset the alarm. Start the burner again.

3.2.5 Check the safety interlock alarm for oil valves

Step A: Set the burner into stop mode, turn the pneumatic shut-off valve (F67) a few degrees from closed position by means of a tool. An alarm for oil valve not in position should be indicated on the local panel and computer. Reset the alarm after testing and start the burner again.

Step B: Set the burner into stop mode, turn the pneumatic three-way valve (F75) a few degrees from the present position by means of a tool. An alarm for oil valve not in position should be indicated on the local panel and computer. Reset the alarm after testing.

3.2.6 Check the safety interlock alarm for low oil pressure

Step A: When the burner is in operation, check the low oil pressure alarm and trip function as described in the paragraph "Commissioning of the oil system". The burner shuts down, and an alarm for low oil pressure is indicated on the local panel and computer. Reset the alarms after testing.

3.2.7 Check the safety interlock alarm for too low water level

Step A: When the burner is in operation, perform a live test of the water level safety devise. The other too low water level alarm actuated by the water level controller must be deactivated. This can be done by temporarily lowering the alarm set point in the local panel or computer. Decrease the water level until the burner shuts down, and an alarm for too low water level is indicated on the local panel and computer.

Step B: Increase the water level in the boiler and reset the alarm. Adjust the set point for too low water level actuated by the water level controller to the original set point.

Step C: When the burner is in operation, perform a live test of the water level controller. The too low water level alarm actuated by the safety device must be deactivated like described above. Decrease the water level until the burner shuts down, and an alarm for too low water level is indicated on the local panel and computer.

Step D: Increase the water level in the boiler and reset the alarm. Adjust the set point for too low water level actuated by the safety device to the original level.

3.2.8 Change to atomising steam supply

When the boiler pressure is approximately 3 bar, the atomising medium should be changed to steam supply.

Step A: Stop the burner and close the stop valve (F87).

Step B: Check that the steam regulating valve (F91) is in automatic mode on the local panel or computer.

Step C: Open the valve for atomising steam on the boiler.

Step D: Open the valves for the steam trap.

Step E: Start the burner and carry out the remaining commissioning procedures.

Note: If the burner load is increased during start-up, the air/fuel ratio should be checked and adjusted at the different loads.

3.2.9 Check the safety interlock alarm for low steam atomising pressure

Step A: Set the steam regulating valve (F91) into manual mode on the local panel or computer.

Step B: Lower the steam atomising pressure gradually until the set point for low warning is reached. The local panel and computer should indicate a low warning.

Step C: Lower the steam atomising pressure somewhat until the set point for low alarm is reached. The burner shuts down, and an alarm is indicated on the local control panel and computer.

Step D: Set the steam regulating valve (F91) into automatic mode on the local panel or computer and reset the alarm.

3.2.10 Check the safety interlock alarm for high steam pressure

Step A: When the burner is in operation, raise the boiler pressure until the set point for high warning is reached. The local panel and computer should indicate a high warning.

Step B: With the burner in operation, check the alarm and trip function for high steam pressure. Deactivate one of the alarms. Raise the steam pressure until the burner shuts down, and an alarm is indicated on the local panel and computer.

Step C: Perform the same check with the other high steam pressure alarm.

Step D: With both alarms activated, reset all alarms.

3.2.11 Check the active safety interlock alarms in emergency operation

Step A: When the burner is stopped, turn the keys placed inside the local control panel and power panel into emergency operation.

Step B: Operate the burner as described in the chapter "Manual operation".

Step C: When the burner is in operation, check the safety interlock alarms for flame failure and too low water level as described previously.

Step D: When the safety interlock alarms have been tested, turn the keys into automatic operation and reset all alarms.

3.3 Commissioning on heavy fuel oil

When the burner has been commissioned on diesel oil and when steam is available for heating, the commissioning on heavy fuel oil can be carried out.

3.3.1 Change of fuel

The change of fuel from diesel oil to heavy fuel oil is achieved by manually operating the three-way valve (G115). When heavy fuel oil is selected, the three-way valve (G111) automatically changes position and returns the oil to the heavy fuel oil settling tank for a period of time. This arrangement is necessary to avoid a continuous heating of the re-circulated diesel oil when the burner is in stop mode. The viscosity of the re-circulated diesel oil decreases and with it also the lubrication characteristic. This will cause damage to the oil pumps.
After the pre-set time period has expired, the three-way valve (G111) returns to normal position. The time period must be set with regard to minimum oil flow and the quantity of oil in the system.

Step A: Stop the burner.

Step B: Check that oil is present in the heavy fuel oil tank. Open the quick closing valve (G95) which connects the heavy fuel oil tank to the oil system. To avoid cavitation of the oil pumps, the viscosity of the oil in the heavy fuel oil tank should not exceed 380 cSt. If necessary, the oil tank should be heated.

Step C: Check and adjust the switchover time for the three-way valve (G111) on the local panel or computer.

Step D: Select heavy fuel oil on the manually operated three-way valve (G115). Check that the local panel and computer indicate heavy fuel operation.

Step E: Check that the three-way valve (G111) changes position. It should also be checked that the valve is changed back to normal position when the time period has expired.

Step F: Select one of the pre-heaters for operation. The other pre-heater should be in stand-by mode.

Step G: Open the stop valves (G25 and G26) for the operational pre-heater and check that the stop valves (G25 and G26) are closed for the stand-by pre-heater.

Step H: Turn the three-way valve (G51) for oil flow through the pre-heaters.

Step I: Check that the steam regulating valve (G20) for the pre-heaters is in automatic mode on the local panel or computer.

Step J: Close the stop valve (G73) for the stand-by pre-heater and open the stop valve (G73) slowly for the operational pre-heater.

Step K: Adjust the temperature set point for the steam regulating valve (G20) on the local panel or computer. The viscosity of the oil at the atomiser should be between 15-20 cSt. The pre-heating temperature can be determined by means of the chart in the chapter "Viscosity-temperature chart".

Step L: Check that the tracing systems for the oil system and the burner unit are operational.

Step M: Check that the temperature is raised to the desired set point. Adjust if necessary.

Step N: Check the set points for low alarm, low warning, and high alarm on the local panel or computer. Adjust if necessary.

3.3.2 Operation on heavy fuel oil

When the burner is commissioned on heavy fuel oil, final adjustments of the combustion process should be carried out to achieve high quality performance data. The aim is to operate the burner with lowest possible O_2 content and highest possible CO_2 content without the risk of an uncompleted combustion (black smoke). At the same time the reliability of the burner must be ensured.
A number of initiative actions can be performed to improve and optimise the combustion process such as adjusting the air/fuel ratio, the steam atomising pressure, and the position of the swirlers. Adjustments of the air/fuel ratio and the steam atomising pressure are made by settings in the control system.
The air/fuel ratio should be checked and adjusted through the complete burner range to ensure a correct combustion. The air/fuel ratio can be checked by measurements of the soot spot No. and the O_2 content and/or the CO_2 content in the flue gas. The visual appearance of the flame should also be checked. If the amount of combustion air to the burner for a given oil flow is too low, the combustion will be uncompleted, and it produces black smoke. Although the O_2 content is low, and the CO_2 content is high, the air flow should be increased. If, on the other hand, the O_2 content is high and the CO_2 content is low, it indicates that the air flow for the combustion process must be decreased.
It is not only the air/fuel ratio which is an important factor for the combustion process, but also the pressure of the atomising steam.
The steam atomising pressure should be adjusted and optimised to suit the combustion process through the complete burner range. The pressure can be checked by measurements of the soot spot No. and visible control of the flame. If the steam atomising pressure is too low at a given burner load, the flame has a tendency to sparkle, and the soot spot No. increases. Furthermore, the flame becomes unstable at low loads due to poor atomisation of the oil. If the steam atomising pressure is too high, the combustion zone is cooled, and the flame becomes unstable at low loads.
The shape of the flame can be adjusted by changing the position of the swirlers. The flame should be adjusted to a shape in which minimum contact to the furnace walls and bottom is achieved. The adjustment should be checked when the burner is in full load condition. An adjustment of the swirlers towards the furnace results in a slim and long flame, and the opposite movement results in a wide and short flame. An adjustment of the swirlers also results in a change of the distance between the atomiser and the root of the flame.

The following commissioning steps imply that the lighting-up procedure of the boiler is completed and that a sufficient load demand is present to carry out adjustments at 100% load.

Step A: Set the correction factor of the air/fuel ratio in neutral position (correction factor = 100) on the local panel or computer. The correction factor is used to adjust the air/fuel ratio if the calorific value of the oil is changed, e.g. when the bunker type is changed.

Step B: Start the burner in manual operation mode and check that it ignites when the oil valves open and remains ignited when the ignition burner is shut-off and retracted. Adjust the ignition oil flow, the air/fuel ratio, or the steam atomising pressure if necessary.

Step C: Start the burner several times to ensure a reliable ignition of the burner.

Step D: Adjust the oil flow to minimum load.

Step E: Check that the flame is stable and carry out measurements of the soot spot No. and O_2 content and/or CO_2 content. Adjust the minimum oil flow, the air/fuel ratio, or the steam atomising pressure if necessary.

Step F: Carry out the same measurements through the complete burner range in steps of 10%. Adjust the air/fuel ratio and/or the steam atomising pressure if necessary. At full load the shape of the flame should be checked, and the swirlers should be adjusted if necessary.

Step G: The measurements obtained for the combustion process through the complete range together with a number of comparable combustion data should be noted and inserted in the chapter "Measurements and settings".

3.3.3 Adjust the steam purge position

Step A: When the burner is in operation, increase or decrease the load until the oil pressure at the atomiser and the steam atomising pressure are identical.

Step B: Set this load as the steam purge position load on the local panel or computer.

Step C: Stop the burner and check it during steam purging. The burner must not produce black smoke or blow out the flame before the combustion is completed. Adjust the steam purge position load if necessary.

3.3.4 Check the safety interlock alarm for high and low oil temperature

Step A: When the burner is in operation, set the steam regulating valve (G20) into manual mode on the local panel or computer.

Step B: Increase the temperature gradually until the set point for high alarm is reached. The burner shuts down, and an alarm is indicated on the local panel and computer.

Step C: Decrease the temperature and reset all alarms. Start the burner again.

Step D: Decrease the temperature gradually until the set point for low alarm is reached. The burner shuts down, and an alarm is indicated on the local panel and computer. The set point for low warning should also be checked during this test.

Step E: Set the steam regulating valve (G20) into automatic mode on the local panel or computer and reset all alarms.

3.3.5 Additional function checks

Step A: Check/adjust additional safety interlock alarms if provided. A number of alarms might be included in the safety interlock circuit depending on the specified function and/or the classification society.

Step B: If the boiler is intended to operate in a master-slave operating system, the function of this system should be checked with regard to operation mode and burner load.

Step C: If the boiler is intended to operate in inert gas mode, the function of this operation mode should be checked with regard to operation and burner load.

Operating instructions

1 General

The following operation instructions are valid for steam atomising burners of type KBSD with Y-atomisers and with a standard delivery of individual parts for the burner unit and supply systems from AALBORG INDUSTRIES.

Attention: If the burner unit and supply systems include parts, which are not standard delivery from AALBORG INDUSTRIES, the specific instructions for these parts should be ignored in the following sections. The actual instructions for the specific parts should be thoroughly studied and followed during operation of the burner.

The operation instructions in the following sections describe the normal burner operations with regard to preparation for start-up on the selected fuel type, normal start/stop, change of fuel, etc. It is implied that the boiler, burner, control system, and additional equipment for the boiler plant have been commissioned and are fully operational.

1.1.1 Descriptions

In the following sections various operating procedures are described such as:

- Diesel oil mode
- Heavy fuel oil mode
- Normal start/stop
- Change from diesel oil operation to heavy fuel oil operation
- Change from heavy fuel oil operation to diesel oil operation
- Change of operational pre-heater
- Change of heavy fuel oil bunker type
- Prolonged stop

1.1.2 Position numbers

The position numbers mentioned in the following sections refer to the illustrations in Figure 1 and Figure 2. The position numbers consist of an identification letter and a position number code. Position numbers with the identification letters "G and R" refer to Figure 1, and position numbers with the identification letter "F" refer to Figure 2. The oil system is shown as a plant with two boilers, but is also valid for a plant with only one boiler.

Illustration of the oil system

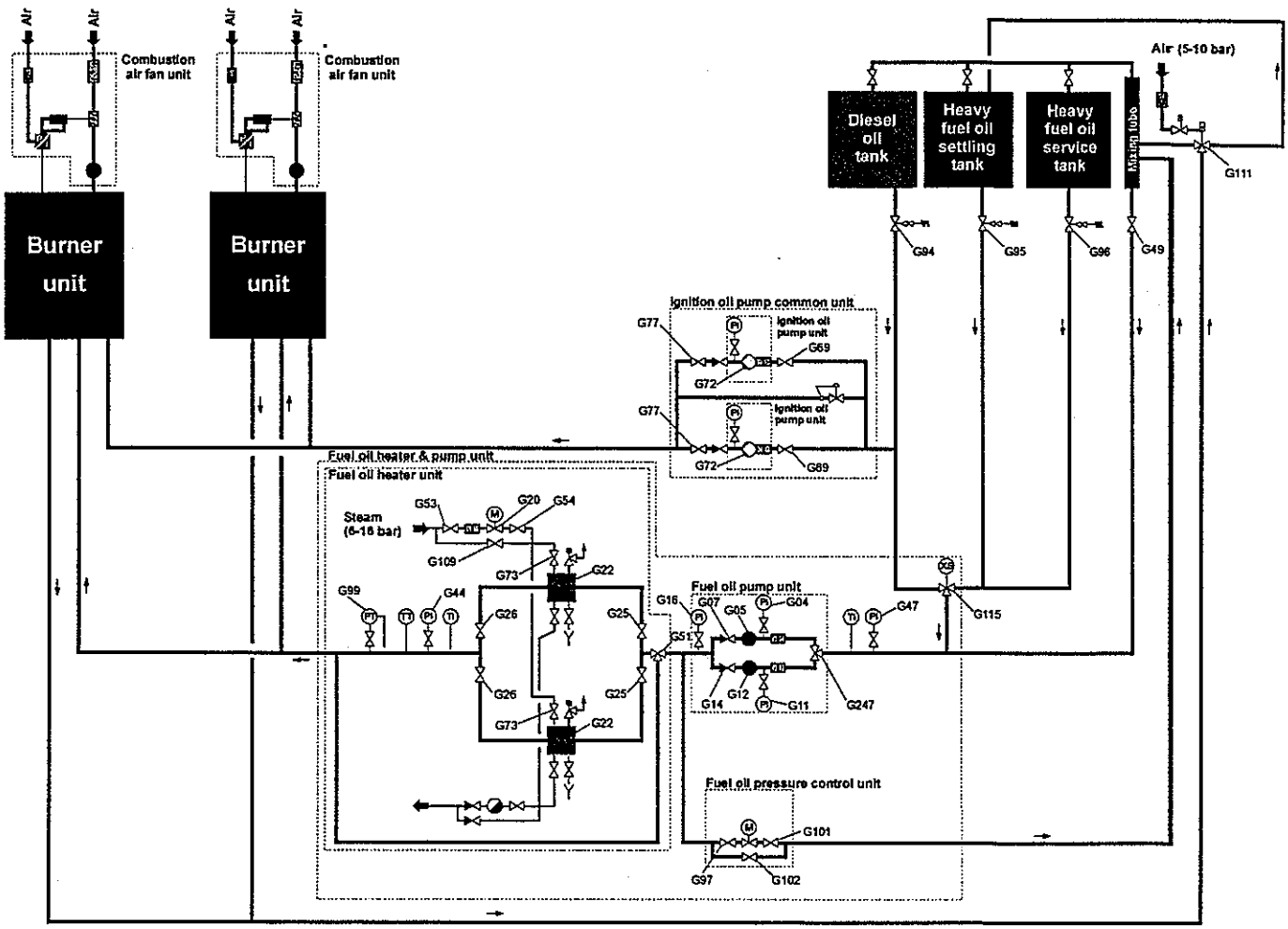


Figure 1 **F_oilsys2b.cdr**

Illustration of the burner unit and supply systems

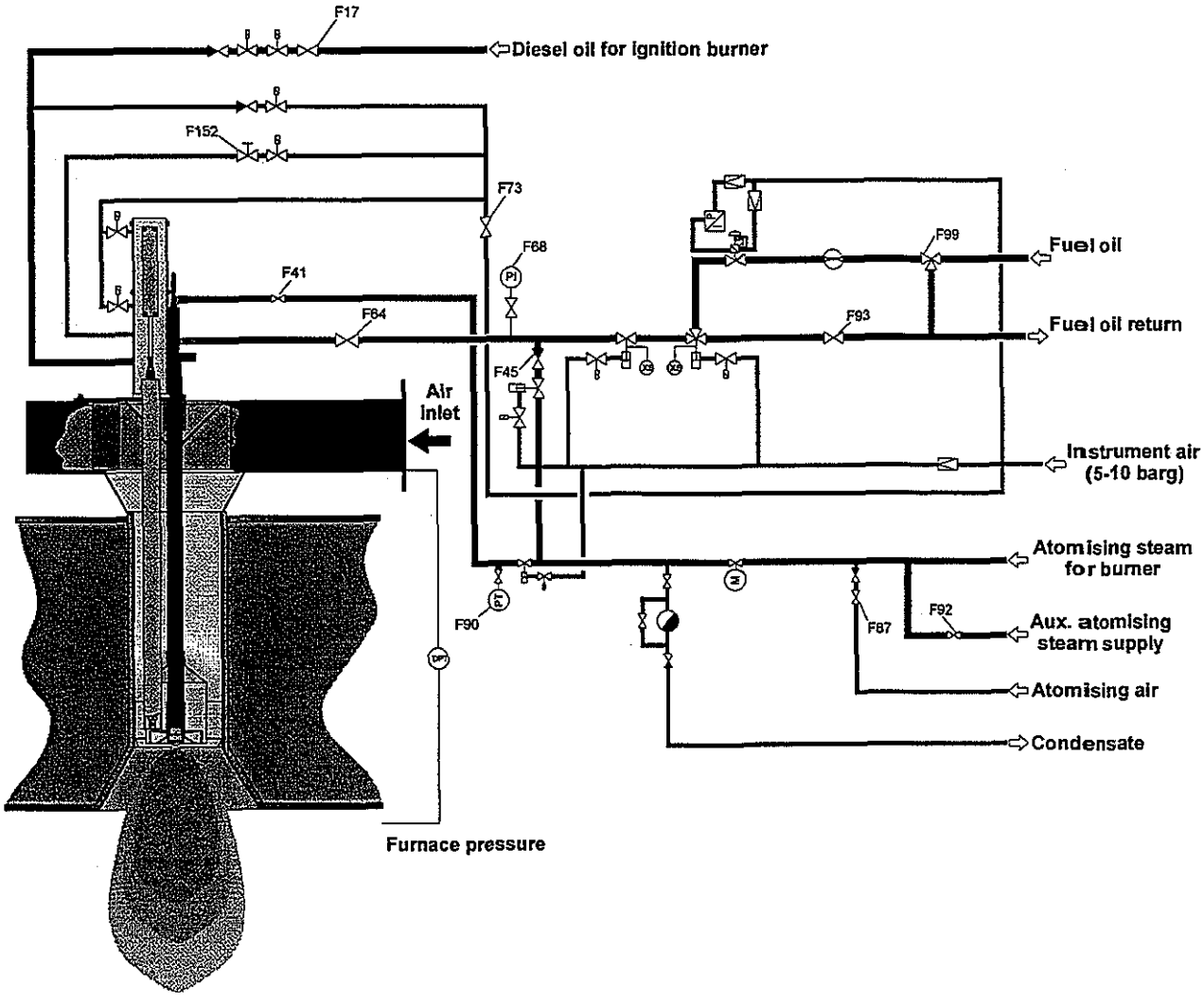


Figure 2 **Burnoilsy2c.cdr**

2 Operating Instructions

2.1 Diesel oil mode

This section describes the actions that must be carried out before the burner unit and oil system are operational on diesel oil.

Step A: Check that oil is present in the diesel oil tank. Open the quick closing valve (G94), which connects the diesel oil tank to the oil system.

Step B: Select diesel oil on the manually operated three-way valve (G115).

Step C: Open the stop valve (G49) for the mixing tube.

Step D: Turn the manually operated three-way valve (G247) for oil flow through both pumps.

Step E: Open the stop valves for the pressure gauges (G04, G11, G16, and G47).

Note: The stop valves for the pressure gauges on the pump unit should only be opened for pressure control purposes. During normal operation, the stop valves should be closed.

Step F: Open the stop valves (G97 and G101), and close the by-pass valve (G102).

Step G: By-pass the pre-heaters by means of the manually operated three-way valve (G51), and close the stop valves (G25 and G26) for both pre-heaters (G22).

Step H: Check that the stop valve (G109) is closed.

Step I: Close the stop valves (G73) for both pre-heaters.

Step J: Open the stop valves for the pressure gauges (G44 and F68) and the pressure transmitter (G99).

Step K: Open the stop valves (G69 and G77) for the ignition oil pumps (G72).

Step L: Open the stop valves (F93 and F64).

Step M: Check the position of the three-way valve (F99). The position must be set for oil flow through the burner unit.

Step N: Open the stop valves (F17 and F73).

Step O: Check that the throttle valve (F152) is not in closed position.

Step P: Open the stop valve for the pressure transmitter (F90).

Step Q: Open the stop valve (F41) and the non-return valve (F45).

Step R: Open the valve for atomising steam on the boiler.

Step S: Open the valves for the steam trap.

Step T: Set one of the oil pumps into operation mode and the other oil pump into stand-by mode. If the burner is in automatic operation mode, the oil pumps will not be operational before start-up of the burner is initiated.

Note: If atomising steam is not available from the boiler, open the stop valve (F92) for supply from the auxiliary steam system or open the stop valve (F87) for supply from the compressed air system. Compressed air for atomising should only be used if steam is not available.

2.2 Heavy fuel oil mode

This section describes the actions, which must be carried out before the burner unit and oil system are operational on heavy fuel oil. It is implied that steam is available for heating and atomising.

Step A: Check that oil is present in the heavy fuel oil settling tank. Open the quick closing valve (G95) that connects the heavy fuel oil settling tank to the oil system.

Step B: Select heavy fuel oil on the manually operated three-way valve (G115).

Step C: Open the stop valve (G49) for the mixing tube.

Step D: Turn the manually operated three-way valve (G247) for oil flow through both pumps.

Step E: Open the stop valves for the pressure gauges (G04, G11, G16, and G47).

Note: The stop valves for the pressure gauges on the pump unit should only be opened for pressure control purposes. During normal operation, the stop valves should be closed.

Step F: Open the stop valves (G97 and G101), and close the by-pass valve (G102).

Step G: Open the stop valves for the pressure gauges (G44 and F68) and the pressure transmitter (G99).

Step H: Open the stop valves (F93 and F64).

Step I: Check the position of the three-way valve (F99). The position must be set for oil flow through the burner unit.

Step J: Open the stop valves (G25 and G26) for the pre-heater (G22), which should be in operation and check that the stop valve (G25) is closed for the stand-by pre-heater.

Step K: Turn the manually operated three-way valve (G51) for oil flow through the pre-heaters.

Step L: Check that the valves in the drain pipes from the pre-heaters are closed and that the valves from the pre-heaters to the steam trap are open.

Step M: Open the stop valves (G53 and G54) and close the stop valve (G109).

Step N: Open the stop valve (G73) for the operational pre-heater and close the stop valve (G73) for the stand-by pre-heater.

Step O: Start one of the oil pumps and set the other into stand-by mode.

Step P: Check that the tracing systems for the oil system and the burner unit are operational.

Step Q: Open the stop valves (G69 and G77) for the ignition oil pumps (G72).

Step R: Open the stop valves (F17 and F73).

Step S: Check that the throttle valve (F152) is not in closed position.

Step T: Open the stop valve for the pressure transmitter (F90).

Step U: Open the stop valve (F41) and the non-return valve (F45).

Step V: Open the valve for atomising steam on the boiler or the stop valve (F92) for supply from the auxiliary steam system.

Step W: Open the valves for the steam trap.

2.3 Normal start/stop

The control system automatically starts, stops, and regulates the burner in normal operation depending on the steam demand. When the steam pressure is below the set point for operation, the burner commences the start-up sequence. If the main steam valve and by-pass valve are closed, the burner operates in minimum firing position after start-up until the differential pressure between the boiler and the main steam line is within the set point for which modulation free mode is allowed. If, on the other hand, the main steam valve and by-pass valve are open prior to burner start-up, the pressure in the boiler and the pressure of the main steam line are equalised, and the burner operates in modulation free mode.
In modulation free mode, the control system attempts to maintain the steam pressure at the desired set point by regulation of the burner load. The burner can be regulated through the complete load range from minimum firing load to full load.
However, should the steam demand decrease below the minimum firing load of the burner, the steam pressure will increase to the set point for burner stop. The burner stops and remains stopped until the set point for burner operation is reached again.

2.4 Change from diesel oil operation to heavy fuel oil operation

When the fuel supply is changed from diesel oil operation to heavy fuel oil operation, the following work steps should be carried out:

Step A: Check that oil is present in the heavy fuel oil settling tank. Open the quick closing valve (G95) which connects the heavy fuel oil settling tank to the oil system. To avoid cavitation of the oil pumps, the viscosity of the oil in the heavy fuel oil tank should not exceed 380 cSt. If necessary, the oil tank should be heated.

Step B: Select heavy fuel oil on the manually operated three-way valve (G115). When heavy fuel oil is selected, the three-way valve (G111) automatically changes position and returns the oil to the heavy fuel oil settling tank for a period of time. This arrangement is necessary to avoid a continuous heating of the re-circulated diesel oil when the burner is in stop mode. The viscosity

of the re-circulated diesel oil decreases and with it also the lubrication characteristic. This will cause damage to the oil pumps. After the pre-set time period has expired, the three-way valve (G111) returns to normal position.

Note: When the fuel type is changed from diesel oil to heavy fuel oil, an alarm for low oil temperature may arise. If the burner is in operation, it will shut down due to this alarm. To prevent burner shut-down, the set point for low oil temperature can be temporarily decreased in the control system.

Step C: Select one of the pre-heaters for operation. The other pre-heater should be in stand-by mode.

Step D: Open the stop valves (G25 and G26) for the operational pre-heater and check that the stop valve (G25) is closed for the stand-by pre-heater.

Step E: Turn the manually operated three-way valve (G51) for oil flow through the pre-heaters.

Step F: Check that the valves in the drain pipes from the pre-heaters are closed and that the valves from the pre-heaters to the steam trap are open.

Step G: Check that the stop valves (G53 and G54) are open and that the stop valve (G109) is closed.

Step H: Check that the steam regulating valve (G20) for the pre-heaters is in automatic mode.

Step I: Open the stop valve (G73) for the operational pre-heater and close the stop valve (G73) for the stand-by pre-heater.

Step J: Check that the tracing systems for the oil system and the burner unit are operational.

Step K: Check the heavy fuel oil temperature. The viscosity of the oil at the atomiser should be between 15-20 cSt. The pre-heating temperature can be determined by means of the chart in the chapter "Viscosity-temperature chart".

2.5 Change from heavy fuel oil operation to diesel oil operation

When the fuel supply is changed from heavy fuel oil operation to diesel oil operation, the following work steps should be carried out:

Step A: Check that oil is present in the diesel oil tank. Open the quick closing valve (G95), which connects the diesel oil tank to the oil system.

Step B: Select diesel oil on the manually operated three-way valve (G115). The three-way valve (G111) automatically changes position and returns the oil

to the heavy fuel oil settling tank for a period of time. After the pre-set time period has expired, the three-way valve (G111) returns to normal position. If the burner is in stop mode, the oil pumps will not be operational, and the pump will stop.

Step C: By-pass the pre-heaters by means of the manually operated three-way valve (G51), and close the stop valves (G25 and G26) for both pre-heaters (G22).

Step D: Close the stop valve (G73) for the operational pre-heater and check that the stop valve (G73) for the stand-by pre-heater is closed.

Step E: Check that the tracing of the piping system is off when the burner is in diesel oil operation.

Caution: Heating of diesel oil in the piping system must be avoided.

2.6 Change of pre-heater

When the pre-heater is changed, the following work steps should be carried out:

Step A: Open the stop valves (G25 and G26) for the pre-heater which should be operational.

Step B: Open the stop valve (G73) for the pre-heater which should be operational.

Step C: Close the stop valve (G73) for the pre-heater which should be in stand-by mode.

Step D: Close the stop valve (G25) for the pre-heater which should be in stand-by mode.

2.7 Change of heavy fuel oil bunker type

If the heavy fuel oil bunker type is changed and the calorific value of the oil changes, the air/fuel ratio should be adjusted to obtain the correct combustion data. This is done by changing the correction factor of the air/fuel ratio on the local panel or computer. If the correction factor is set to a value above 100, the air flow for the combustion process decreases. If the correction factor is set to a value below 100, the air flow for the combustion process increases. This means that if the calorific value of the oil increases, the value of the correction factor should be decreased to obtain the same combustion data and visa versa.

2.8 Prolonged stop

When the boiler plant is stopped for a long period of time, the oil system including the pre-heaters should be flushed with diesel oil before the plant is shut down. Furthermore, the tracing must be switched off.

Emergency operation

1 General

In the rare event of a total break down of the control system, the burner unit with belonging systems can be operated in emergency operation. Due to the fact that the majority of the safety interlock trips and alarms are overruled in emergency mode, the safety precautions for the plant must be observed very carefully.

Please note that in emergency operation mode the safety interlocks are reduced to:

- Too low water level
- Flame failure

Warning: When the burner operates in emergency mode, it is very important that the boiler plant is carefully and continuously supervised by the ship engineering personnel. Pay special attention to the steam pressure and water level.

In emergency mode, the burner unit and supply systems are operated from inside the local control panel and the power panel. Various operating switches and potentiometers are provided inside the panels for operating purposes.
Before emergency operation of the burner is initiated, attempts to restart the control system must be performed. If restart of the control system is impossible, the work steps of the following sections must be followed.

1.2 Manual operation of the burner supply systems

Step A: Turn the key placed inside the power panel into emergency operation.

Step B: Start one of the oil pumps on the operating switch inside the power panel.

Step C: Adjust the oil pressure on the pressure regulating valve to a level of 20-25 bar at the burner unit inlet flange. The adjustment is carried out by means of the manually operated hand wheel on the actuator.

Step D: If the burner is operating on heavy fuel oil, the oil temperature must be adjusted on the steam regulating valve for the pre-heaters. The viscosity of the oil at the atomiser should be between 15-20 cSt. The pre-heating temperature can be determined by means of the chart in the chapter "Viscosity-temperature chart". The adjustment is carried out by means of the manually operated hand wheel on the actuator.

Note: The automatic water level regulation is not operational in emergency mode. This means that the water level in the boiler must be adjusted in a similar way as the regulation of the oil pressure and oil temperature. If supplied by Aalborg Industries the feed water pumps can be set into operation by means of the operating switches inside the power panel.

1.3 Manual operation of the burner unit

Step A: Turn the key placed inside the local control panel into emergency operation.

Step B: Close the inlet vanes for the combustion air fan by means of the potentiometer inside the local control panel. The inlet vanes should be in closed position before start-up to reduce the current consumption.

Step C: Start the combustion air fan on the operating switch inside the power panel.

Step D: Purge the furnace with combustion air by opening the inlet vanes to maximum position on the potentiometer for the combustion air fan. The combustion air flow should be kept at maximum flow for at least 60 seconds.

Warning: Insufficient purging may cause danger of furnace explosions.

Step E: Close the steam regulating valve for atomising steam. The valve can be closed by means of the manually operated hand wheel on the actuator.

Step F: Push the button for steam atomising inside the local control panel.

Step G: Adjust the steam atomising pressure on the steam regulating valve to a level of 2-3 bar. The adjustment is carried out by means of the manually operated hand wheel on the actuator.

Step H: Set the air flow to ignition load position, approximately 15-20% load, by reducing the position of the inlet vanes on the potentiometer for the combustion air fan. When the percentage value of the air flow is unreadable due to break down of the control system, the scale of the potentiometer can be used as a first-hand percentage indicator for the combustion air flow. The final setting of the potentiometer for ignition load and all other loads must be determined by visual checks of the flame and the flue gas when the burner is in operation. The percentage values from the control system and the percentage values of the settings on the potentiometer are incomparable. This is because the values from the control system are the feed back signals from the combustion process (dp-transmitter), and the values from the potentiometer are output signals to the positioner which operates the inlet vanes for the combustion air fan.

Step I: Set the oil flow to ignition load position, approximately 15-20% load, by means of the potentiometer for the oil flow regulation valve. When the oil flow is unreadable due to break down of the control system, the pressure indicated on the pressure gauge just before the burner must be used as an indicator for the oil flow.

Step J: Press the button for ignition inside the local control panel and keep it pressed.

Step K: When the ignition flame is established, push the button for oil valves inside the local control panel.

Step L: Release the ignition button when the lamp that indicates flame on is illuminated.

Step M: The burner is now in operation, and adjustments of the burner load must be carried out as described in the following section.

1.4 Operating instructions in emergency mode

The request for regulations of the burner load should be deducible from the actual demand for process steam. The optimal operation form for the burner is to minimise the number of load alterations as this will facilitate the burner operation in emergency mode. Regulations of the burner load must be performed by manual adjustments of the combustion parameters, e.g. oil flow, air flow, atomising steam pressure, etc.
When the burner load is changed, it is important to differentiate between increases or decreases of the load. This is due to the fact that an incorrect air/fuel ratio towards a rich oil mixture causes an incomplete combustion that will produce black smoke. If the burner load is increased, the air flow should be regulated before the oil flow, and opposite the oil flow should be regulated before the air flow if the burner load is decreased.

Step A: Adjust the air flow and oil flow to the desired load by means of the potentiometers inside the local control panel. The scale of the potentiometer for the combustion air fan and the oil pressure indicated on the pressure gauge just before the burner can be used for first-hand settings. The final settings must be determined by visual checks of the flame and the flue gas.

Step B: Adjust the steam atomising pressure on the steam regulating valve to suit the combustion. The adjustment is carried out by means of the manually operated hand wheel on the actuator. If the steam atomising pressure is too low at a given burner load, the flame has a tendency to sparkle. Furthermore, the flame becomes unstable at low loads due to poor atomisation of the oil. If the steam atomising pressure is too high, the combustion zone is cooled, and the flame becomes unstable at low loads.

Step C: Readjust the oil pressure if necessary. When the burner operates at increased loads, the oil pressure to the burner will fall due to the increased amount of oil for the combustion. To ensure that the burner receives a sufficient amount of oil, it might be necessary to adjust the oil pressure on the pressure regulating valve. If the load decreases, a reduction of the oil

pressure might also be necessary. The adjustments are carried out by means of the manually operated hand wheel on the actuator.

Step D: If the burner is operating on heavy fuel oil, adjustments of the oil temperature might be necessary at large burner load variations. The oil temperature should be adjusted on the steam regulating valve for the pre-heaters by means of the manually operated hand wheel on the actuator.

Step E: Adjust the water level in the boiler if necessary. The water level must be carefully and continuously supervised during operation of the boiler plant. When one of the feed water pumps is in operation, the water level can be regulated on the feed water control valve by means of the manually operated hand wheel on the actuator.

1.5 Stop the burner in emergency mode

Step A: Adjust the air flow and oil flow to steam purge position load by means of the potentiometers inside the local control panel.

Step B: Adjust the steam atomising pressure on the steam regulating valve to the same level as the oil pressure just before the burner.

Step C: Press the button for steam purge inside the local control panel and keep it pressed. The oil valves close immediately, and the valve for steam purge opens.

Step D: When steam purging is completed, the release the button. The purging is completed when the remaining oil in the burner lance is atomised into the furnace which is indicated by the extinction of the flame.

Step E: Push the button for atomising steam inside the local control panel.

Step F: Close the inlet vanes for the combustion air fan by means of the potentiometer.

Step G: Stop the combustion air fan. The fan should be kept in operation if it is contemplated to operate the burner with frequent intervals. This is because it should be avoided to start the fan more than three times per hour.

Step H: Adjust the oil pressure and temperature if necessary.

Step I: When the burner is in stand-by mode, and oil is circulated in the oil system, the oil flow must be adjusted to minimum oil flow position by means of the potentiometer for the oil flow regulation valve.

Note: If the burner operates on diesel oil, the oil system should stopped if burner operations are of infrequent occurrences. A continuous re-circulation of the diesel oil might damage the oil pumps due to heating of the oil.

Step J: If the fuel supply is changed from diesel oil to heavy fuel oil, the position of the pneumatic three-way valve, which leads the return oil to the mixing tube or the heavy fuel oil settling tank, should be changed for a period of time. The position of the three-way valve can be changed by means of a manual switch on the solenoid valve. The time period must be determined with regard to minimum oil flow and the quantity of oil in the system.

Maintenance

1 Recommended maintenance intervals

To ensure a safe and reliable function of the burner, inspection must take place with frequent intervals as described below. The inspection should be carried out by competent and properly trained personnel familiar with the operating and maintenance procedures relevant for this type of plant.

1.1 Safety regulations for maintenance work

Always ensure that the electrical power is off and that nobody can start the boiler unit before commencing maintenance work.
All pipes, drums, etc. must be depressurised before any maintenance work is carried out on these.

1.2 Continuous maintenance

- Control panels and other electrical equipment should be kept clean and dry. Check that no foreign matter accumulates in or around them.
- Replace lamps, contactors, and other components when they cease to function or show signs of deterioration. A part, replaced before it actually fails, could save a costly delay.

1.3 Periodical maintenance

The following check list should be followed every two weeks. Dependent on the operation conditions, however, some items may need more frequent attention.
For maintenance work procedures, we refer to the separate instructions concerning each item.

1.3.1 Periodical maintenance - burner and fuel oil supply system

- Check that all connections are tightened and that the wiring is in a good condition.
- Check that the fan inlet is kept clean of unintended obstructions.
- Check pipe work for leaks, particularly on flanges, joints, and connections. Repair any leaks which may cause safety risks.
- Check the general condition of pipe work, lagging, and tracing.
- Check that the glands of manual valves are tight enough to prevent easy operation of the valve.
- Oil filters should be inspected and cleaned.

- Manually operated valves should be periodically operated, if possible, to ensure free movement.
- Check the pneumatic shut-off valves, placed just before the burner lance, for leaks.
- Check and clean the flame scanner.

1.3.2 Burner air register and swirlers

If the burner plant is to perform according to the specification, it is important that the burner register and the swirlers are kept clean and in good condition. Inspection should be carried out at regular intervals.
Large quantities of dust-laden air will pass through the register, and inevitably this tends to build up deposits. These deposits should be brushed off.
The swirlers and all other surfaces exposed to radiation heat should be checked for being free of carbon or heat erosion.

1.3.3 Atomiser

Before any examination can be made, the atomiser must be cleaned. This is normally done by soaking in a paraffin or carbon remover to wash off any oil films. This also has the purpose of loosening carbon deposits. It may also be necessary to use a soft metal scraper to lift away any heavy carbon deposits. A hardened scraper should not be used as it could possibly damage the atomiser.
The cleaned atomiser should then be examined for damage, and the holes checked for wear.
The O-ring must be replaced every time the atomiser is disassembled.
Before fitting the cap nut, the thread should be covered with an unhardening high temperature compound.

1.3.4 Ignition burner

The ignition burner is one of the most exposed items and needs a frequent maintenance.

- The electrodes should be cleaned and the insulation material checked for any damage. Be careful not to damage the ceramic insulation pieces.
- The nozzle should be checked and cleaned.
- If the spray pattern hits the other parts of the igniter despite it is cleaned, the nozzle should be changed.

Note: Be careful not to change position of nozzle and electrodes as this may cause problems with, e.g. ignition, instability, or build-up of carbon deposit.

Faults and rectifying faults

1 Trouble shooting

The trouble shooting list is based on a proper set-up of the burner plant during commissioning and/or service and that no further adjustments of the air/fuel ratio, etc. have taken place.
Please note that the trouble shooting list is general for steam atomising burners and has not been made for any particular plant, but is based on several years of experience. Therefore, the cause for your specific problem may not be mentioned and vice versa. You are always welcome, however, to contact our Service department for advice or service assistance.
Check availability of power and fuel supplies before commencing detailed checks.
Ensure that burner plant wiring diagrams relevant to the particular installation are available.
When the cause of a lockout should be located, it can be of assistance to know the start/stop cycle or at which point of operation the lockout occurred, e.g. modulating.
The trouble shooting list can be seen in Table 1.

Fault finding chart		
Fault	**Possible causes**	**Remedy**
No ignition/ignition flame failure	Ignition burner oil pump faulty Oil pressure too low Oil nozzle blocked/worn out Ignition electrodes dirty/out of adjustment Ignition transformer faulty Solenoid valve faulty Burner control faulty	Repair or replace oil pump/ motor Restore oil pressure Clean/replace nozzle Clean/readjust Replace ignition transformer Exchange solenoid valve unit Replace/repair control unit
Flame failure of main flame during ignition	Ignition flame not established Oil valves not open Atomising air/steam pressure too low Purge steam valve open Oil temperature too high/low Oil flow too low	See above Check air pressure/replace oil valve Check air/steam pressure Check purge valve Adjust temperature Adjust oil flow/clean atomiser
Unstable main flame	Oil amount too low Oil temperature too low/high Blocking of some of the steam/oil holes in the atomiser Water in the atomising steam	Raise the oil amount Readjust oil temperature Clean atomiser Check the water trap, if provided
Flame smoky or red	Too much fuel oil or too little air	Readjust air/oil ratio or correction factor
Flame white or colourless	Too much air or too little oil	Readjust air/oil ratio or correction factor
Flame with starlets or sparks	Poor atomisation, low oil temperature or atomising air/steam incorrect pressure Damaged atomiser nozzle	Reset fuel oil temp. to correct value/ensure condensate-free steam Replace nozzle
Flame flutters and goes out	Too little oil in min. load	Reset fuel quantities
Burner shut down	Shut down due to safety circuits or faulty components	Please refer to the electrical layout/diagram for specific information

Table 1

Measurements and settings

1 General description

Each plant has its individual service conditions depending on the actual design and layout of the burner and the boiler plant. Exact values for the burner cannot be given, but have to be determined at the commissioning or by later adjustments.
The following pages show the standard measurements and settings for a plant which includes one KBSD burner. This enables the user to obtain some of the most important measurements and settings related to the burner for later reference.
It is recommended that the user completes the scheme shortly after commissioning when normal service conditions have been established.

2 Burner measurements and settings

Table 1 and Table 2 show a standard measuring/setting scheme. Figure 1 shows a diagram in which it is possible to mark the air/fuel ratio curve. The values should be taken from No. 1 and No. 10 in the tables.
During commissioning, an adjustment of some measures related to the burner lance/swirler distance blades may be necessary. These measures are shown in Figure 2.
In Table 3 the original measures are given, and columns are reserved for writing the measures established during commissioning or by later adjustments.

Boiler Water Treatment Programme

Shipboard Log Sheet - for Adjunct B and G C

Ship: **M.T BULL KALIMANTAN** Owner: **PT.GEMILANG BINA LINTAS TIRTA**

Boiler Maker: **AALBORG** Type: **CPH-20** Pressure, kgf / cm^2: **7 - 16** Water volume: **10** Ton

IMO/Lloyd No.: **92223318**

Year: **2002** Month: **Agust-19** Make up: ☐ Shore ☑ Distilled ☐ Mixed

Boiler identification: **Auxiliary Boiler NO.2 P** Eg: Aux Boiler / Exhaust Gas Boiler / Boiler 1

	Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
P Alkalinity	160																															
Less than 20=0,15 Ltr	150																															
20-90=0,10Ltr	140																															
90-130=Satisfactory	130																															
More than 150=Blow-	120																															
down	110																															
	100																															
	90																															
	80																															
	70																															
	60																															
	50																															
	40																															
	30																															
	20																															
	<20																															
Drewplex AT	LTR						2														2											
Liquitreat	LTR																															
Blow Down T/B		X							X						X				X						X					X		
Chloride (ppm)	60																															
0-40	50																															
Over 40=Blowdown	40																															
	30																															
	20																															
	10																															
	0																															
Boiler PH	>11.0																															
	7.0-11.0																															
	<7.0																															
Appearance	Cloudy																															
	Clear																															
	Coloured																															
Condensate PH	≥9.2																															
Less than 8,3=+25%	8.8-9.0																															
8,3-8.6	8.3-8.6																															
More than 8,6=-25%	8,2																															
	≤8.0																															
Condensate	≥20																															
Chloride	≤20																															
Condensate contr. Ltr.	1																															
Hotwell	≥90																															
Temp °C	81-90																															
	70-80																															
	61-69																															
	≤60																															

ADD DREWPLEX AT 4 LTR

DWI ARJUNA AJI PUTRA
4TH ENGINEER

AGUS WAHYUDIN
CHIEF ENGINEER

Boiler Water Treatment Programme

Shipboard Log Sheet - for Adjunct B and G C

Ship: **M.T BULL KALIMANTAN** Owner: **PT.GEMILANG BINA LINTAS TIRTA**

Boiler Maker: **AALBORG** Type: **CPH-20** Pressure, kgf / cm^2: **7 - 16** Water volume: **10** Ton

IMO/Lloyd No.: **92223318**

Year: **2002** Month: **Agust-19** Make up: [ ] Shore [V] Distilled [ ] Mixed

Boiler identification: **Auxiliary Boiler NO. 1 S** Eg: Aux Boiler / Exhaust Gas Boiler / Boiler 2

	Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
P. Alkalinity (ppm)	160																															
Less than 20=0,15 Ltr	150																															
20-90=0,10Ltr	140																															
90-130=Satisfactory	130																															
More than 150=Blow-	120																															
down	110																															
	100																															
	90																															
	80																															
	70																															
	60																															
	50																															
	40																															
	30																															
	20																															
	<20																															
Drewplex AT	LTR					2															2											
Liquiteat	LTR																															
Blow Down T/B					X						X						X						X						X			
Chloride (ppm)	60																															
0-40	50																															
Over 40=Blowdown	40																															
	30																															
	20																															
	10																															
	0																															
Boiler PH	>11.0																															
	7.0-11.0																															
	<7.0																															
Appearance	Cloudy																															
	Clear																															
	Coloured																															
Condensate PH	≥9.2																															
Less than 8,3=+25%	8.8-9.0																															
8,3-8.6	8.3-8.6																															
More than 8,6=-25%	8,2																															
	≤8.0																															
Condensate	≥20																															
Chloride	≤20																															
Condensate contr. Ltr.	1																															
Hotwell	≥90																															
Temp °C	81-90																															
	70-80																															
	61-69																															
	≤60																															

COMMENTS: ADD CHEM. DREWPLEX AT 4

DWI ARJUNA AJI PUTRA
4TH ENGINEER

AGUS WAHYUDIN
CHIEF ENGINEER

PT GEMILANG BINA LINTAS TIRTA
SHIP MANAGEMENT

MAINTENANCE / REPAIR REPORT (14.05 2009) **E - 09**

Vessel's Name : MT BULL KALIMANTAN

Date : 21 AUGUST 2019

Place (port) : BALIKPAPAN ANCHORAGE

PMS no :

Equip. / Unit : BURNER AND AIR ROTARY CUP BOILER NO. 1	Type :	Mfr. :AALBORG
Last Maintenance : Last Survey :	Running hrs since last maint. / overhaul : 30 Day	
Type of Work : CLEANED		

Detail of Work :

- Carry out safety meeting all engine crew
- Switch off breaker power motor
- Put apply warning board notice in panel control
- Disconnect fuel oil pipe and air
- Open manhole burner boiler
- Remove rotary and burner
- Cleaning all part and DO filter in burner
- Assembly all part and fitted fuel pipe
- Switch on breaker power and take out apply warning board notice in panel control
- Test running and found satisfactory

Parts Replaced / Renewed :

DWI ARJUNA AJI PUTRA
4TH ENGINEER

AGUS WAHYUDIN
CHIEF ENGINEER

PT GEMILANG BINA LINTAS TIRTA
SHIP MANAGEMENT

MAINTENANCE / REPAIR REPORT (14.05 2009) **E - 09**

Vessel's Name : MT BULL KALIMANTAN

Date : 13 AUGUST 2019

Place (port) : BALIKPAPAN ANCHORAGE

PMS no :

Equip. / Unit : BURNER AND AIR ROTARY CUP BOILER NO. 2	Type :	Mfr. :AALBORG
Last Maintenance : Last Survey :	Running hrs since last maint. / overhaul : 30 Day	
Type of Work : CLEANED		

Detail of Work :

- Carry out safety meeting all engine crew
- Switch off breaker power motor
- Put apply warning board notice in panel control
- Disconnect fuel oil pipe and air
- Open manhole burner boiler
- Remove rotary and burner
- Cleaning all part and DO filter in burner
- Assembly all part and fitted fuel pipe
- Switch on breaker power and take out apply warning board notice in panel control
- Test running and found satisfactory

Parts Replaced / Renewed :

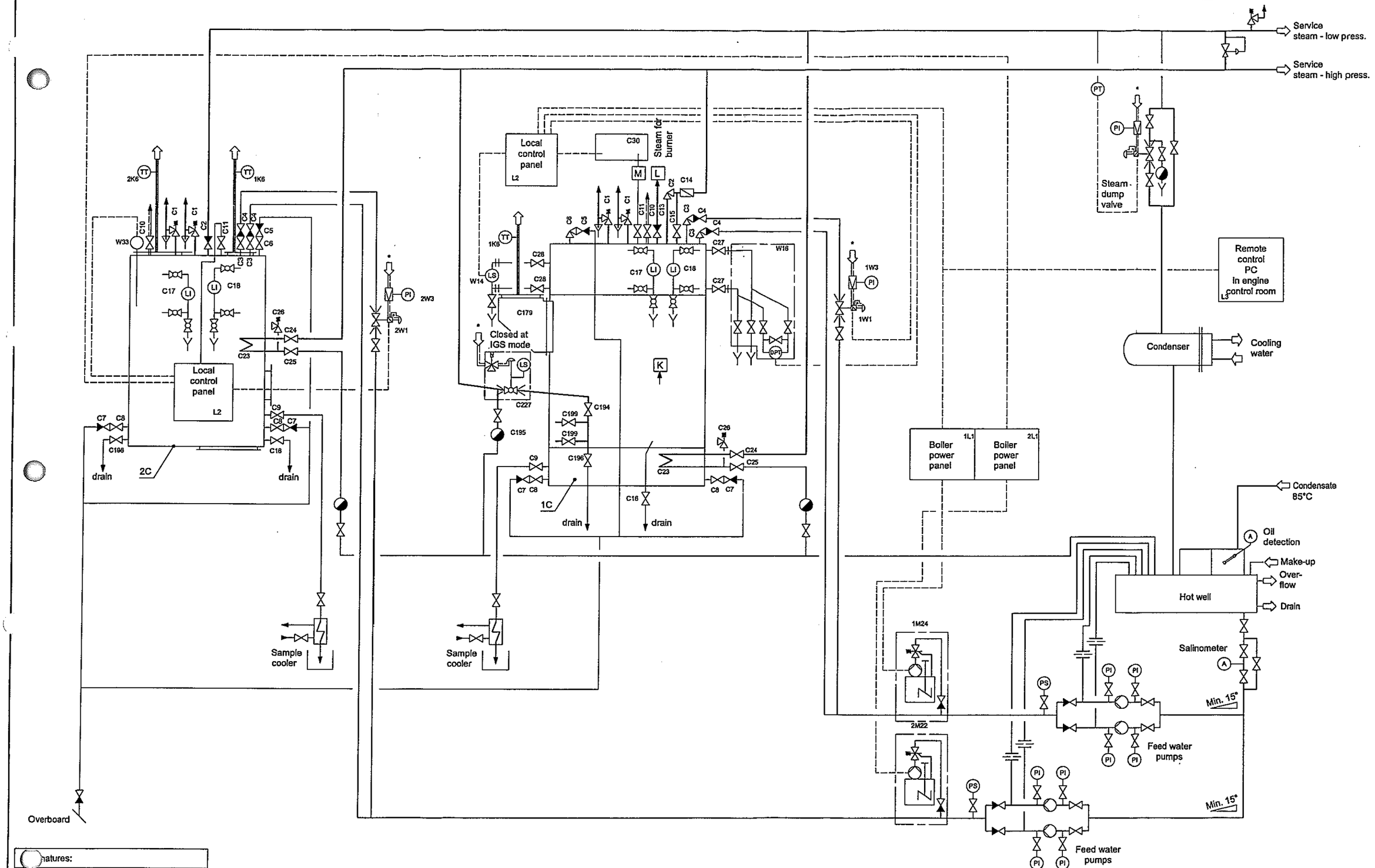
DWI ARJUNA AJI PUTRA
4TH ENGINEER

AGUS WAHYUDIN
CHIEF ENGINEER

LAMPIRAN 2

PROCESS FLOW DIAGRAM (PFD) DAN P&ID (PIPING & INSTRUMENTATION DIAGRAM)

Description	Index	Date	Drawn	Appr.
Item 2 C16 added	a	14.05.2002	ISk	BeP



natures:

- Steam
- Water
- Chemicals
- Air
- Blow down/drain lines
- External wiring
- Oil
- Exhaust gas

NOTE:
- Components specified by item no. are supplied by AI
- Items: see separate list of parts.
- For electrical connections, see actual electrical wiring diagrams.
- * Instrument air
- For connections: [X] see burner arrangement drawing

Customer	Samsung Heavy Industries Koje Shipyard			
Society	DNV	DNV		
Newb. No.	1408	1409		
Project No.	735365-66	735367-68		
Boiler No.	11269	11271		
Boiler No.	11270	11272		

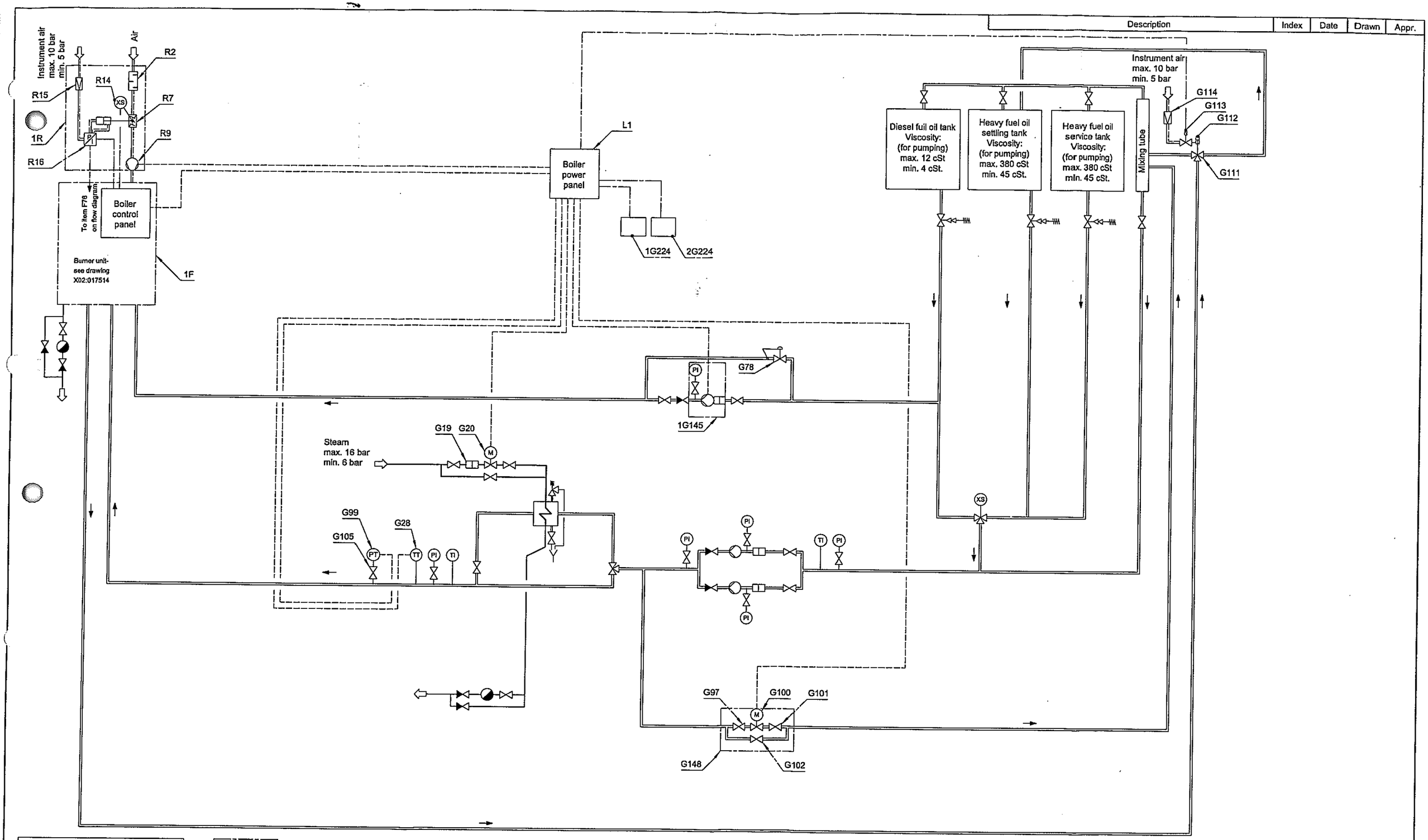
AALBORG INDUSTRIES

Plot Date:

Title:
1 x MISSION OL 35000 + 1 x MISSION OC 1600/1600
Steam/water system
Feed water regulation modulating
Flow diagram

Drawn	ISk	Date	05.10.2001
Appr.	HJK	Date	05.10.2001
Weight		Scale: 1:1	Size A2
Article/Drawing No:	X01 : 017508		Index a

Description	Index	Date	Drawn	Appr.



Signatures:

- Steam
- Water
- Chemicals
- Air
- Blow down/drain lines
- External wiring
- Oil
- Exhaust gas

Unit

NOTE:

- All heavy fuel oil piping to be steam traced piping and insulated
- Components specified by Tag No. are supplied by AI
- Components: see separate list of parts

Customer	Samsung Heavy Industries Koje Shipyard			
Society	DNV	DNV		
Newb. No.	1408	1409		
Project No.	735365-66	735367-68		
Boiler No.	11269	11271		
Boiler No.	11270	11272		

AALBORG INDUSTRIES

Plot Date:

Title:

1 x KBSD 2650

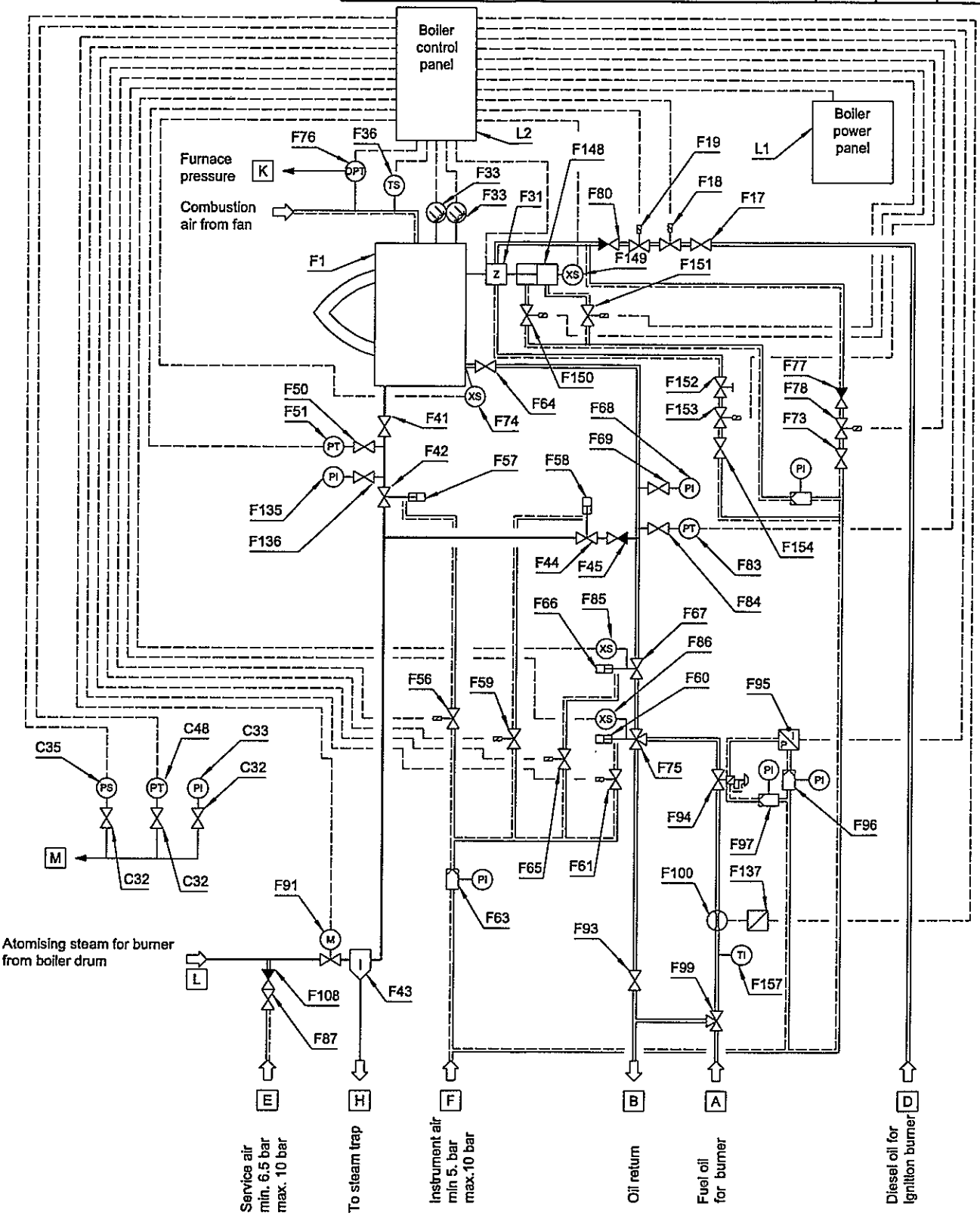
Oil system

Burner operation modulating

Flow diagram

Drawn	Date
ISk	05.09.2001
Appr.	Date
HJK	05.09.2001
Weight	Scale: 1:1 / Size A2
Article/Drawing No:	Index
X02 : 017515	

Description	Index	Date	Drawn	Appr.
Minor change	a	02.07.2002	ISk	HJK



NOTE:

- Components specified by item no. are supplied by AI
- Items: see separate list of parts
- For electrical connections, see actual electrical wiring diagrams.
- For connections [X] - see burner arrangement drawing.

Customer	Samsung Heavy Industries Koje Shipyard			
Society	DNV	DNV		
Newb. No.	1408	1409		
Project No.	735365-66	735367-68		
Boiler No.	11269	11271		
Boiler No.	11270	11272		

Signatures:

- Steam
- Water
- Chemicals
- Air
- Blow down/drain lines
- External wiring
- Oil
- Exhaust gas

AALBORG INDUSTRIES

Plot Date:

Title:

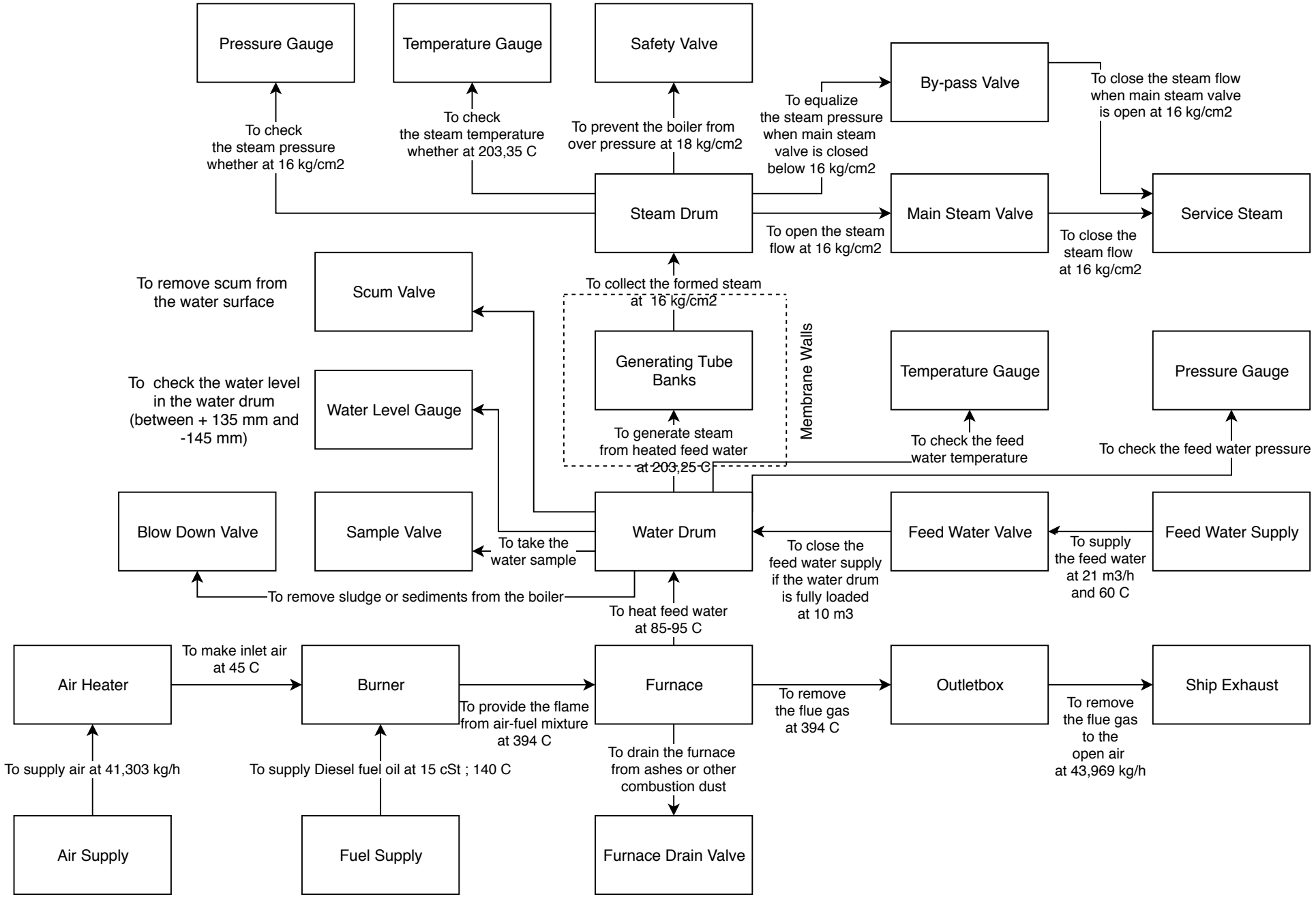
1 x KBSD 2650

Burner unit

Burner operation modulating

Flow diagram

Drawn	Date	Size
STh	30.08.2001	
Appr. JMN	Date 30.08.2001	
Weight	Scale: 1:1	A3R
Article/Drawing No: X02 : 017514		Index a


Pressure Gauge
Temperature Gauge
Safety Valve
By-pass Valve
To close the steam flow when main steam valve is open at 16 kg/cm2
To check the steam pressure whether at 16 kg/cm2
To check the steam temperature whether at 203,35 C
To prevent the boiler from over pressure at 18 kg/cm2
To equalize the steam pressure when main steam valve is closed below 16 kg/cm2
Steam Drum
Main Steam Valve
Service Steam
To open the steam flow at 16 kg/cm2
To close the steam flow at 16 kg/cm2
To remove scum from the water surface
Scum Valve
To collect the formed steam at 16 kg/cm2
Membrane Walls
Generating Tube Banks
Temperature Gauge
Pressure Gauge
To check the water level in the water drum (between + 135 mm and -145 mm)
Water Level Gauge
To generate steam from heated feed water at 203,25 C
To check the feed water temperature
To check the feed water pressure
Blow Down Valve
Sample Valve
Water Drum
Feed Water Valve
Feed Water Supply
To take the water sample
To close the feed water supply if the water drum is fully loaded at 10 m3
To supply the feed water at 21 m3/h and 60 C
To remove sludge or sediments from the boiler
To heat feed water at 85-95 C
Air Heater
To make inlet air at 45 C
Burner
Furnace
Outletbox
Ship Exhaust
To provide the flame from air-fuel mixture at 394 C
To remove the flue gas at 394 C
To remove the flue gas to the open air at 43,969 kg/h
To supply air at 41,303 kg/h
To supply Diesel fuel oil at 15 cSt ; 140 C
To drain the furnace from ashes or other combustion dust
Air Supply
Fuel Supply
Furnace Drain Valve

LAMPIRAN 3

FUNCTION AND FUNCTIONAL FAILURE STATEMENTS

Equipment Item: Burner				
Function			*Functional Failure*	
Item No.	*Function Statement*	*Function Type*	*Item No.*	*Functional Failure Statement*
1	To provide the flame from air-fuel mixture at 394°C	Primary	1.1	No flame appeared
			1.2	Unstable flame
			1.3	Flame temperature above 394°C
			1.4	Flame temperature below 394°C

Equipment Item: Furnace				
Function			*Functional Failure*	
Item No.	*Function Statement*	*Function Type*	*Item No.*	*Functional Failure Statement*
2	To heat feed water at 85-95°C	Primary	2.1	No heat to feed water in water drum
			2.2	Feed water temperature above 95°C
			2.3	Feed water temperature below 85°C

Equipment Item: Water Drum				
Function			*Functional Failure*	
Item No.	*Function Statement*	*Function Type*	*Item No.*	*Functional Failure Statement*
3	To collect boiler feed water at 10 m^3 fully loaded in one hour	Primary	3.1	No feed water collected from feed water supply
			3.2	Fully loaded faster than one hour
			3.3	Fully loaded slower than one hour

Equipment Item: Generating Tube Banks				
Function			*Functional Failure*	
Item No.	*Function Statement*	*Function Type*	*Item No.*	*Functional Failure Statement*
4	To generate steam of feed water at 203.35°C	Primary	4.1	No steam generated flow from water drum
			4.2	Steam temperature below 203.35°C
			4.3	Steam temperature above 203.35°C

Equipment Item: Steam Drum				
Function			*Functional Failure*	
Item No.	*Function Statement*	*Function Type*	*Item No.*	*Functional Failure Statement*
5	To collect the steam from tube banks at 16 kg/cm^2	Primary	5.1	No steam collected from tube banks
			5.2	Steam pressure below 16 kg/cm^2
			5.3	Steam pressure above 16 kg/cm^2

Equipment Item: Main Steam Valve				
Function			*Functional Failure*	
Item No.	*Function Statement*	*Function Type*	*Item No.*	*Functional Failure Statement*
6	To open steam flow at 16 kg/cm^2	Primary	5.1	No steam flow from steam drum
			5.2	Valve is unable to be fully opened
			5.3	Valve is open while steam pressure is below 16 kg/cm^2
7	To close steam flow below 16 kg/cm^2	Primary	6.1	Valve is unable to be fully closed
			6.2	Valve is close while steam pressure is above 16 kg/cm^2

Equipment Item: By-Pass Valve				
Function		*Functional Failure*		
Item No.	*Function Statement*	*Function Type*	*Item No.*	*Functional Failure Statement*
8	To equalize the steam pressure between the boiler and the steam system when main steam valve is closed below 16 kg/cm²	Primary	8.1	No steam flow from steam drum
			8.2	Bypass valve is unable to be fully opened or closed
			8.3	By-pass valve is open while main steam valve is opened at 16 kg/cm²

Equipment Item: Safety Valve				
Function		*Functional Failure*		
Item No.	*Function Statement*	*Function Type*	*Item No.*	*Functional Failure Statement*
9	To prevent the boiler from over pressure at 18 kg/cm²	Primary	9.1	Unable to automatically open when the steam pressure is at 18 kg/cm² or above
			9.2	Unable to automatically close when the steam pressure is below 18 kg/cm²

Equipment Item: Temperature Gauge				
Function		*Functional Failure*		
Item No.	*Function Statement*	*Function Type*	*Item No.*	*Functional Failure Statement*
10	To measure the temperature of the feed water and steam.	Primary	10.1	No indicator work
			10.2	Unable to display proper measurement

Equipment Item: Pressure Gauge				
Function		*Functional Failure*		
Item No.	*Function Statement*	*Function Type*	*Item No.*	*Functional Failure Statement*
11	To measure the pressure of the feed water and steam.	Primary	11.1	No indicator work
			11.2	Unable to display proper measurement

Equipment Item: Scum Valve				
Function		*Functional Failure*		
Item No.	*Function Statement*	*Function Type*	*Item No.*	*Functional Failure Statement*
12	To remove floating impurities (scum) from the water surface	Primary	12.1	Unable to remove the scum
			12.2	Unable to open or close

Equipment Item: Water Level Gauge				
Function		*Functional Failure*		
Item No.	*Function Statement*	*Function Type*	*Item No.*	*Functional Failure Statement*
13	To check the feed water level in the water drum	Primary	13.1	Wrong water level display
			13.2	Chocked water/steam side
			13.3	Stuck ball
			13.4	Breakage of glass

Equipment Item: Blow Down Valve				
Function		*Functional Failure*		
Item No.	*Function Statement*	*Function Type*	*Item No.*	*Functional Failure Statement*
14	To remove sludge or sediments from the boiler.	Primary	14.1	Unable to open or close
			14.2	Unable to remove the sludge
15	To prevents steam/water from flowing into an empty boiler by mistake	Secondary	15.1	Steam/water flow into an empty boiler by mistake

Equipment Item: Sample Valve				
Function		*Functional Failure*		
Item No.	*Function Statement*	*Function Type*	*Item No.*	*Functional Failure Statement*
16	To take the feed water sample	Primary	16.1	Unable to open or close
			16.2	Leaking valve seat

Equipment Item: Feed Water Valve				
Function		*Functional Failure*		
Item No.	*Function Statement*	*Function Type*	*Item No.*	*Functional Failure Statement*
17	To close automatically the feed water supply if the water drum is fully loaded at 10 m^3	Primary	17.1	Unable to open or close automatically when water drum is fully loaded at 10 m^3
			17.2	Leaking valve seat

Equipment Item: Outletbox				
Function		*Functional Failure*		
Item No.	*Function Statement*	*Function Type*	*Item No.*	*Functional Failure Statement*
18	To remove the flue gas from the furnace to the open air via ship exhaust system (funnel) at 394°C and 43,969 kg/h.	Primary	18.1	Flue gas is unable to flow out
			18.2	Flowing flue gas is below 43,969 kg/h
			18.3	Flowing flue gas is above 43,969 kg/h
			18.4	No flue gas flow from outletbox

Equipment Item: Furnace Drain Valve				
Function		*Functional Failure*		
Item No.	*Function Statement*	*Function Type*	*Item No.*	*Functional Failure Statement*
19	To remove the combustion dust from the furnace.	Primary	19.1	Unable to open or close
			19.2	Leaking valve seat

Equipment Item: Air Heater				
Function		*Functional Failure*		
Item No.	*Function Statement*	*Function Type*	*Item No.*	*Functional Failure Statement*
20	To make the inlet air temperature to the burner at 45°C	Primary	20.1	No heat out at all
			20.2	Air leakage
			20.3	The inlet air temperature to the burner is above 45°C
			20.4	The inlet air temperature to the burner is below 45°C

Equipment Item: Membrane Walls				
Function		*Functional Failure*		
Item No.	*Function Statement*	*Function Type*	*Item No.*	*Functional Failure Statement*
21	To create a gastight construction for tube banks.	Primary	21.1	Crack damage
			21.2	Corrosion
22	To make the cooling effect as high as possible in the furnace.	Secondary	22.1	No cooling effect in the furnace

LAMPIRAN 4

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS (FMECA)

LAMPIRAN 4 – FMECA WORKSHEET

Equipment	Function	No. Item	Functional Failure	Failure Mode	Causes	Failure Characteristic	Local Effect	End Effect	Consequence Category	Severity	Current Likelihood	Current Risk	Failure Detection/Corrective Measures
Burner	To provide the flame from air-fuel mixture at 394°C	1.1	No flame appeared	1. No fuel and air supply	1. Not working fuel pump	Random failure, Wear-out failure	Difficulties on boiler start	System shut down	Explosion	Catastrophic	Remote	Medium	Flow meter and pressure gauges indicate no flow of fuel oil. Fuel indicator on panel switch on. Fuel inlet valve is automatically closed. Burner fails to start
					2. Not working air fan	Random failure	Difficulties on boiler start	System shut down	Explosion	Catastrophic	Remote	Medium	Flow meter and pressure gauges indicate no flow of intake air. Air supply indicator on the panel switch on. Air heater is switched off. Burner fails to start.
				2. No fire generated from stoker	1. Broken lighter	Random failure, Wear-out failure	Boiler fails to start	System shut down	Explosion	Critical	Frequent	High	No flame detected on flame eye sensor. Air and fuel supply are closed. Burner fails to start.
					2. Electrical problems	Random failure, Wear-out failure	Boiler fails to start	System shut down	Explosion	Critical	Occasional	Medium	No flame detected on flame eye sensor. Air and fuel supply are closed. Burner fails to start.
		1.2	Unstable flame	1. Fuel and air supply interference	1. Blockage at nozzle	Random failure, Wear-out failure	Difficulties on boiler start	Underfired	Explosion	Critical	Frequent	High	No flame detected on flame eye sensor. Air and fuel supply are closed. Burner fails to start.
					2. Air supply leakage	Random failure	Difficulties on boiler start	Underfired	Loss of Containment	Critical	Occasional	Medium	No flame detected on flame eye sensor. Air and fuel supply are closed. Burner fails to start.
					3. Fuel supply leakage	Random failure	Difficulties on boiler start	Underfired	Loss of Containment	Critical	Remote	Medium	No flame detected on flame eye sensor. Air and fuel supply are closed. Burner fails to start.

LAMPIRAN 4 – FMECA WORKSHEET

Equipment	Function	No. Item	Functional Failure	Failure Mode	Causes	Failure Characteristic	Local Effect	End Effect	Consequence Category	Severity	Current Likelihood	Current Risk	Failure Detection/Corrective Measures
		1.3	Flame temperature is above 394°C	1. Overflow fuel supply	1. Excess fuel in air-fuel mixture	Random failure	Overheating	Overfired	Explosion	Critical	Probable	High	Temperature indicates higher required fire temps tend to decrease burner firing performance
		1.4	Flame temperature is below 394°C	1. Overflow air supply	1. Lower fuel mixture	Random failure	Lower boiler performance	Underfired	Explosion	Critical	Occasional	Medium	Temperature indicates lower required fire temps tend to increase burner firing performance
Furnace	To heat feed water at 85-95°C	2.1	No heat to feed water in water drum	1. Not working burner	1. No fuel and air supply	Random failure	No generated steam	System shut down	Explosion	Critical	Probable	High	No fire from burner. Flame detector sends signal to control system to shut down.
					2. No fire generated from stoker	Random failure	No generated steam	System shut down	Explosion	Critical	Probable	High	No fire from burner. Flame detector sends signal to control system to shut down.
		2.2	Feed water temperature is above 95°C	1. Over performance burner	1. Over supply fuel	Random failure	Overpressure	Overfired	Explosion	Critical	Probable	High	Higher temperature detected by thermal sensor. Control display show the alarm.
				2. Under normal feed water level	1. Lower feed water supply performance	Random failure	Lower steam capacity	Overheating	Explosion	Critical	Occasional	Medium	Higher temperature detected by thermal sensor. Control display show the alarm.
					2. Feed water level control interference	Random failure	Feed water supply is not automatically stopped	Overheating	Safety	Major	Probable	Medium	Higher temperature detected by thermal sensor. Control display show the alarm.
					3. Leakage	Random failure	Lower steam pressure	Under performance	Loss of Containment	Catastrophic	Occasional	High	Higher temperature detected by thermal sensor. Control display show the alarm.
		2.3	Feed water temperature is below 85°C	1. Under performance burner	1. Under supply fuel	Random failure	Lower pressure	Underfired	Explosion	Major	Remote	Medium	Lower temperature detected by thermal sensors. Burner firing performance needs to increase.

LAMPIRAN 4 – FMECA WORKSHEET

Equipment	Function	No. Item	Functional Failure	Failure Mode	Causes	Failure Characteristic	Local Effect	End Effect	Consequence Category	Severity	Current Likelihood	Current Risk	Failure Detection/Corrective Measures
					2. Under supply air	Random failure	Poor air-fuel mixture	Underfired	Explosion	Major	Remote	Medium	Lower temperature detected by thermal sensors. Burner firing performance needs to increase.
				2. Over normal feed water level	1. Higher feed water supply performance	Random failure	Higher steam capacity	Overfired	Explosion	Critical	Probable	High	Feed water valve close the supply according to water level alarm indicates higher level.
Water Drum	To collect boiler feed water at 10 m^3 fully loaded in one hour	3.1	No feed water collected from feed water supply	1. Feed water supply interference	1. Feed water pump failure	Random failure, Wear-out failure	No feed water supply	System shut down	Explosion	Catastrophic	Probable	High	Lower capacity of the feed water detected by flow meter. Control display show the alarm.
					2. Feed water tank storage problem	Random failure	No feed water supply	System shut down	Loss of Containment	Critical	Occasional	Medium	Lower capacity of the feed water detected by flow meter. Control display show the alarm.
					3. Leakage along feed water supply line	Random failure	Lower feed water capacity	System shut down	Loss of Containment	Critical	Probable	High	Lower capacity of the feed water detected by flow meter. Control display show the alarm.
		3.2	Fully loaded faster than one hour	1. Over performance feed water supply	1. Over performance of feed water pump	Random failure	-	No effect of interest	-	Minor	Remote	Low	No additional actions required
		3.3	Fully loaded slower than one hour	1. Under performance feed water supply	1. Under performance of feed water pump	Random failure	Longer time to provide steam	Under performance	Explosion	Major	Remote	Medium	Lower flow feed water interferes the required feed water supply to the boiler. Control display show the alarm. Check the feed water pump.
					2. Interference along feed water supply line	Random failure	Longer time to provide steam	Under performance	Loss of Containment	Major	Occasional	Medium	Lower flow feed water interferes the required feed water supply to the boiler. Control display show the alarm. Check the feed water line.

LAMPIRAN 4 – FMECA WORKSHEET

Equipment	Function	No. Item	Functional Failure	Failure Mode	Causes	Failure Characteristic	Local Effect	End Effect	Consequence Category	Severity	Current Likelihood	Current Risk	Failure Detection/Corrective Measures
Generating Tube Banks	To generate steam of feed water at 203.35°C	4.1	No steam generated flow from water drum	1. Blockage on tubes	1. Corrosion	Random failure, Wear-out failure	Interference on generated steam	System shut down	Explosion	Major	Probable	High	No steam flow detected. Flow meter sends signal to control system to shut down the system automatically. General analysis required.
					2. Water contaminant	Random failure	Interference on generated steam	System shut down	Explosion	Major	Remote	Medium	No steam flow detected. Flow meter sends signal to control system to shut down the system automatically. General analysis required.
					3. Broken tubes	Random failure, Wear-out failure	Lower steam flow to steam drum	System shut down	Explosion	Critical	Probable	High	No steam flow detected. Flow meter sends signal to control system to shut down the system automatically. General analysis required.
				2. Lower or no feed water in water drum	1. Lower or no feed water supply	Random failure	No steam generated	System shut down	Explosion	Critical	Occasional	High	No steam flow detected. Flow meter sends signal to control system to shut down the system automatically. General analysis required.
					2. Feed water supply leakage	Random failure	Lower steam generated	System shut down	Loss of Containment	Major	Occasional	Medium	No steam flow detected. Flow meter sends signal to control system to shut down the system automatically. General analysis required.
					3. Feed water supply broken fittings	Random failure, Wear-out failure	Lower feed water supply	System shut down	Explosion	Major	Remote	Medium	No steam flow detected. Flow meter sends signal to control system to shut down the system automatically.

LAMPIRAN 4 – FMECA WORKSHEET

Equipment	Function	No. Item	Functional Failure	Failure Mode	Causes	Failure Characteristic	Local Effect	End Effect	Consequence Category	Severity	Current Likelihood	Current Risk	Failure Detection/Corrective Measures
													General analysis required.
		4.2	Steam temperature below 203.35°C	1. Under performance burner	1. Under supply fuel	Random failure	Lower pressure	Underfired	Explosion	Major	Remote	Medium	Lower temperature detected by thermal sensors. Burner firing performance needs to increase.
					2. Under supply air	Random failure	Poor air-fuel mixture	Underfired	Explosion	Major	Remote	Medium	Lower temperature detected by thermal sensors. Burner firing performance needs to increase.
				2. Higher feed water level	1. Over performance of feed water pump	Random failure	-	No effect of interest	-	Minor	Remote	Low	No additional actions required
				3. Overheat loss	1. Bad insulation	Random failure, Wear-out failure	Need more fuel to burn	Lower efficiency	Safety	Major	Remote	Medium	Higher temperature detected by thermal sensor. Control display show the alarm.
					2. Generated steam leakage	Random failure	Steam exposure	Under performance	Explosion	Critical	Occasional	High	Boiler steam leakage detected by pressure gauge sends signal to control system to shut down.
		4.3	Steam temperature above 203.35°C	1. Over performance burner	1. Over supply fuel	Random failure	Overpressure	Overfired	Explosion	Critical	Probable	High	Higher temperature detected by thermal sensor. Control display show the alarm.
				2. Lower feed water level	1. Under supply feed water	Random failure	Lower steam flow to steam drum	Under performance	Explosion	Major	Occasional	High	Higher temperature detected by thermal sensor. Control display show the alarm.
Steam Drum	To collect the steam from tube banks at 16 kg/cm²	5.1	No steam collected from tube banks	Overheat loss	Generated steam leakage	Random failure, Wear-out failure	No steam generated	System shut down	Explosion	Critical	Probable	High	Boiler steam leakage detected by pressure gauge sends signal to control system to shut down.

LAMPIRAN 4 – FMECA WORKSHEET

Equipment	Function	No. Item	Functional Failure	Failure Mode	Causes	Failure Characteristic	Local Effect	End Effect	Consequence Category	Severity	Current Likelihood	Current Risk	Failure Detection/Corrective Measures
		5.2	Steam pressure below 16 kg/cm²	Under pressure	Lower firing performance of burner	Random failure	Lower steam supply to service	Lower efficiency	Safety	Minor	Remote	Low	No additional actions required
		5.3	Steam pressure above 16 kg/cm²	Over pressure	Higher firing performance of burner	Random failure	Overpressure	Overfired	Safety	Major	Occasional	Medium	Higher pressure detected by pressure gauge sends signal to control system to show the alarm.
Main Steam Vavle	To open steam flow at 16 kg/cm²	6.1	No steam flow from steam drum	No steam collected from steam drum	No steam generated from tube banks	Random failure	No steam generated	System shut down	Loss of Containment	Critical	Probable	High	No steam flow detected. Flow meter sends signal to control system to shut down the system automatically. General analysis required.
		6.2	Valve is unable to be fully opened	Valve damage occurence	Clogging, corrosion or any other strange objects	Random failure, Wear-out failure	Steam flow interference	Under performance	Loss of Containment	Major	Remote	Medium	Lower steam flow detected by flow meter that sends signal to control system to show the alarm.
		6.3	Valve is open while steam pressure is below 16 kg/cm²	Mechanical damage or input signal error	Valve components damage and error in signal transmission	Random failure	Underpressure	No effect of interest	Explosion	Minor	Improbable	Low	No additional actions required
	To close steam flow below 16 kg/cm²	7.1	Valve is unable to be fully closed	Mechanical damage or input signal error	Valve spring is clogged and error in signal transmission	Random failure, Wear-out failure	Oversupply service steam	Lower efficiency	Safety	Major	Occasional	Medium	Lower steam flow detected by flow meter that sends signal to control system to show the alarm.
		7.2	Valve is close while steam pressure is above 16 kg/cm²	Mechanical damage or input signal error	Valve spring is clogged and error in signal transmission	Random failure	Overpressure	No effect of interest	Safety	Minor	Remote	Low	No additional actions required

LAMPIRAN 4 – FMECA WORKSHEET

Equipment	Function	No. Item	Functional Failure	Failure Mode	Causes	Failure Characteristic	Local Effect	End Effect	Consequence Category	Severity	Current Likelihood	Current Risk	Failure Detection/Corrective Measures
By Pass Valve	To equalize the steam pressure between the boiler and the steam system when main steam valve is closed below 16 kg/cm²	8.1	No steam flow from steam drum	Overheat loss	Generated steam leakage	Random failure	No steam generated	System shut down	Loss of Containment	Critical	Probable	High	No steam flow detected. Flow meter sends signal to control system to shut down the system automatically. General analysis required.
		8.2	Bypass valve is unable to be fully opened or closed	Valve damage occurence	Clogging, corrosion or any other strange objects	Random failure, Wear-out failure	Steam flow interference	Lower efficiency	Safety	Major	Remote	Medium	Lower steam flow detected by flow meter that sends signal to control system to show the alarm.
		8.3	By-pass valve is open while main steam valve is opened at 16 kg/cm²	Mechanical damage or input signal error	Valve components damage and error in signal transmission	Random failure	Underpressure	No effect of interest	Safety	Minor	Improbable	Low	No additional actions required
Safety Valve	To prevent the boiler from over pressure at 18 kg/cm²	9.1	Unable to automatically open when the steam pressure is at 18 kg/cm² or above	Mechanical damage or input signal error	Valve components damage and error in signal transmission	Random failure, Wear-out failure	Overpressure	System shut down	Safety	Catastrophic	Occasional	High	Higher pressure detected by pressure gauge sends signal to control system to show the alarm. Feed water supply and burner performance needs to check immediately.
		9.2	Unable to automatically close when the steam pressure is below 18 kg/cm²	Mechanical damage or input signal error	Valve components damage and error in signal transmission	Random failure, Wear-out failure	Underpressure	System shut down	Safety	Catastrophic	Occasional	High	Valve spring indicates out of order. System shut down required. Broken components replacement must be done immediately according to the standard procedure implied.
Temperature Gauge	To measure the temperature of the feed water and steam.	10.1	No indicator work	Mechanical damage	Broken gauge's components	Random failure, Wear-out failure	Unknown temperature	Monitoring disturbance	Loss of Containment	Major	Remote	Medium	External temperature gauge required. Down time as system on low duty period or periodical maintenance check required.

LAMPIRAN 4 – FMECA WORKSHEET

Equipment	Function	No. Item	Functional Failure	Failure Mode	Causes	Failure Characteristic	Local Effect	End Effect	Consequence Category	Severity	Current Likelihood	Current Risk	Failure Detection/Corrective Measures
		10.2	Unable to display proper measurement	Mechanical damage	Dirty, oily, vapourity and broken components	Random failure	Not significant	No effect of interest	Safety	Minor	Improbable	Low	No additional actions required
Pressure Gauge	To measure the pressure of the feed water and steam.	11.1	No indicator work	Mechanical damage	Broken gauge's components	Random failure, Wear-out failure	Unknown pressure	Monitoring disturbance	Explosion	Major	Remote	Medium	Additional pressure gauge required. Down time as system on low duty period or periodical maintenance check required.
		11.2	Unable to display proper measurement	Mechanical damage	Dirty, oily, vapourity and broken components	Random failure	Not significant	No effect of interest	Safety	Minor	Remote	Low	No additional actions required
Scum Valve	To remove floating impurities (scum) from the water surface	12.1	Unable to remove the scum	Not appropriate scum removal	Bad quality feed water, tools and operations	Random failure	Low quality feed water	Under performance	Safety	Major	Occasional	Medium	No scum removed tends to lower feed water quality. Manual removal may apply to the feed water supply
		12.2	Unable to open or close	Mechanical damage	Valve screw or plat cap damage.	Random failure, Wear-out failure	Low quality feed water	Lower efficiency	Safety	Major	Remote	Medium	Down time as system on low duty period or periodical maintenance check required.
Water Level Gauge	To check the feed water level in the water drum	13.1	Wrong water level display	Mechanical damage	Needle calibration required	Random failure	Unknown water level	No effect of interest	Safety	Minor	Remote	Low	No additional actions required
		13.2	Chocked water/steam side	Foreign object clogging	Corrosion and slag inclusion may occur	Random failure	Unknown water level	Monitoring disturbance	Loss of Containment	Major	Remote	Medium	Down time as system on low duty period or periodical maintenance check required.
		13.3	Stuck ball	Lack of possition	Ball wire loosen and crack possibility.	Random failure	Unknown water level	Monitoring disturbance	Loss of Containment	Major	Remote	Medium	Down time as system on low duty period or periodical maintenance check required.
		13.4	Breakage of glass	Mechanical damage	Thermal shock, overheating and life time factor	Random failure, Wear-out failure	Unknown water level	No effect of interest	Loss of Containment	Minor	Remote	Low	No additional actions required

LAMPIRAN 4 – FMECA WORKSHEET

Equipment	Function	No. Item	Functional Failure	Failure Mode	Causes	Failure Characteristic	Local Effect	End Effect	Consequence Category	Severity	Current Likelihood	Current Risk	Failure Detection/Corrective Measures
Blow Down Valve	To remove sludge or sediments from the boiler.	14.1	Unable to open or close	Mechanical damage	Valve screw or plat cap damage.	Random failure, Wear-out failure	Low quality feed water	Lower efficiency	Safety	Major	Remote	Medium	Down time as system on low duty period or periodical maintenance check required.
		14.2	Unable to remove the sludge	Under required feed water and operation mode	Bad quality feed water, tools and operations	Random failure	Builds up within the tank	No effect of interest	Safety	Minor	Remote	Low	No additional actions required
	To prevents steam/water flow into an empty boiler by mistake	15.1	Steam/water flow into an empty boiler by mistake	Lack of possition	Valve mechanism error in operation	Random failure	No steam generated	System shut down	Explosion	Major	Remote	Medium	Flow meter detection on abnormal flow out of steam cycle requires system shut down by control system.
Sample Valve	To take the feed water sample	16.1	Unable to open or close	Mechanical damage	Valve screw or plat cap damage.	Random failure, Wear-out failure	Low quality feed water	Monitoring disturbance	Safety	Major	Remote	Medium	Down time as system on low duty period or periodical maintenance check required.
		16.2	Leaking valve seat	Mechanical damage	Valve spring is clogged and broken seals may occur	Random failure	Feed water flashing and high velocity erosion	Monitoring disturbance	Loss of Containment	Major	Remote	Medium	Lower feed water flow detected by flow meter sends signal to control system to display the current real-time condition alarm.
Feed Water Valve	To close automatically the feed water supply if the water drum is fully loaded at 10 m^3	17.1	Unable to open or close automatically when water drum is fully loaded at 10 m^3	Mechanical damage or input signal error	Solenoid valve is out of order as its electricity problems or actuators fail to operate. Sensors may send error input transmitted data.	Random failure, Wear-out failure	No or less feed water supply to the water drum affects to steam production capacity	Overfired	Safety	Major	Remote	Medium	Manual actions required to open or close the valve while water drum is fully loaded that is shown in the level alarm display. Late actions may cause overpressure in the boiler, system shut down manually is also recommended for this case to prevent further failures.

LAMPIRAN 4 – FMECA WORKSHEET

Equipment	Function	No. Item	Functional Failure	Failure Mode	Causes	Failure Characteristic	Local Effect	End Effect	Consequence Category	Severity	Current Likelihood	Current Risk	Failure Detection/Corrective Measures
		17.2	Leaking valve seat	Mechanical damage	Valve spring is clogged and broken seals may occur	Random failure	High velocity erosion of the feed water	Lower efficiency	Loss of Containment	Major	Occasional	Medium	Lower feed water flow detected by flow meter sends signal to control system to display the current real-time condition alarm.
Outletbox	To remove the flue gas from the furnace to the open air via ship exhaust system (funnel) at 394°C and 43,969 kg/h.	18.1	Flue gas is unable to flow out	Ducting leakage, broken valve and no flue gas generated	External influence on ducting leakage, wear-out valve to open and firing problems occured	Random failure	Exhaust system blockage	System shut down	Explosion	Critical	Occasional	High	Exhaust gas from furnace is unable to flow out. Higher pressure in the boiler detected by pressure gauge that sends signal to control system to shut down.
		18.2	Flowing flue gas is below 43,969 kg/h	Under required firing performance and operation mode	Burner is under performance or feed water supply interference	Random failure	Underpressure	No effect of interest	Safety	Minor	Improbable	Low	No additional actions required
		18.3	Flowing flue gas is above 43,969 kg/h	Over required firing performance and operation mode	Burner is higher than its standard performance	Random failure	Overpressure	Overfired	Safety	Major	Remote	Medium	Overcapacity flue gas may cause explosion needs to control under the specified requirements. Exhaust ducting system needs to check for any blockages possibilities or leakages.
		18.4	No flue gas flow from outletbox	Lack of combustion	Lower performance of burner in firing	Random failure	Less firing from furnace	Overfired	Explosion	Major	Occasional	Medium	Firing performance in the furnace needs to check according to exhaust gas production that flows along the outletbox.
Furnace Drain Valve	To remove the combustion dust from the furnace.	19.1	Unable to open or close	Mechanical damage	Valve screw or plat cap damage.	Random failure, Wear-out failure	Low quality feed water	Under performance	Safety	Major	Remote	Medium	Down time as system on low duty period or periodical maintenance check required.

LAMPIRAN 4 – FMECA WORKSHEET

Equipment	Function	No. Item	Functional Failure	Failure Mode	Causes	Failure Characteristic	Local Effect	End Effect	Consequence Category	Severity	Current Likelihood	Current Risk	Failure Detection/Corrective Measures
		19.2	Leaking valve seat	Mechanical damage	Valve spring is clogged and broken seals may occur	Random failure, Wear-out failure	High velocity erosion and corrosion	Lower efficiency	Loss of Containment	Major	Occasional	Medium	Lower feed water flow detected by flow meter sends signal to control system to display the current real-time condition alarm.
Air Heater	To make the inlet air temperature to the burner at 45°C	20.1	No heat out at all	Inlet air heating malfunction	Lower voltage or current as external cause while hot element plate failure as internal cause.	Random failure	Lower air temperature for burner air inlet	Under performance	Loss of Containment	Major	Remote	Medium	Lower air temperature detected by thermal sensor that sends signal to control system and display the warning. Air heater performance and condition need to check and repair if it is broken.
		20.2	Air leakage	Lack of combustion	Crack in several strain points may occur the leakage	Random failure	Lower air capacity for burner air inlet	Lower efficiency	Loss of Containment	Major	Occasional	Medium	Lower air flow at burner air inlet indicates air supply interferences that is detected by flow meter sensor. It sends signal to control display and show the alarm
		20.3	The inlet air temperature to the burner is above 45°C	Overheat loss	Higher firing performance of burner	Random failure	Not significant	No effect of interest	Safety	Minor	Remote	Low	No additional actions required
		20.4	The inlet air temperature to the burner is below 45°C	Overheat loss	Lower firing performance of burner	Random failure	Not significant	No effect of interest	Safety	Minor	Remote	Low	No additional actions required
Membrane Walls	To create a gastight construction for tube banks.	21.1	Crack damage	Mechanical damage and construction	Sudden expansion of steam pressure or thermal shock may occur for long term	Random failure, Wear-out failure	Steam exposure	System shut down	Loss of Containment	Catastrophic	Probable	High	Boiler steam leakage detected by pressure gauge sends signal to control system to shut down.

LAMPIRAN 4 – FMECA WORKSHEET

Equipment	Function	No. Item	Functional Failure	Failure Mode	Causes	Failure Characteristic	Local Effect	End Effect	Consequence Category	Severity	Current Likelihood	Current Risk	Failure Detection/Corrective Measures
		21.2	Corrosion	Plate fractures related to corrosion rate	Less zinc anode applied and bad quality of the feed water also the treatment system	Random failure, Wear-out failure	Major impact on structural integrity	Lower efficiency	Loss of Containment	Major	Occasional	Medium	Visual inspection needs to do as periodically condition monitoring program and classify the severity of current condition to make decision.
	To make the cooling effect as high as possible in the furnace.	22.1	No cooling effect in the furnace	Overheat loss	Bad insulation and wall plate clogging as sedimentation of fluids contaminants	Random failure	Overheating	Lower efficiency	Explosion	Major	Remote	Medium	Overheating may occurs as higher walls temperature make higher temperature and pressure of generated steam. Insulation and clogging check needs to apply according to this case periodically.

LAMPIRAN 5

MAINTENANCE TASK SELECTION

LAMPIRAN 5 – MAINTENANCE TASK SELECTION WORKSHEET

Functional Failure	*Failure Mode*	*Failure Char.*	*Hidden/ Evident*	*Effects*		*Risk Characterization*			*Task Selection*			
				Local	*End*	*Severity*	*Current Likelihood*	*Current Risk*	*Proposed Action(s)*	*Projected Likelihood*	*Projected Risk*	*Disposition*
No flame appeared	1. No fuel and air supply	Random failure, Wear-out failure	Evident	Difficulties on boiler start	System shut down	Catastrophic	Remote	Medium	1. Check fuel pipe work for any leakage 2. Check flanges, joints and connections for leakages 3. Check the manual valves are operating properly 4. Check there is no leakage from any part of the valve 5. Ensure the fuel supply pump is changed to standby and all parameters are in normal operating range	Remote	Medium	

LAMPIRAN 5 – MAINTENANCE TASK SELECTION WORKSHEET

Functional Failure	*Failure Mode*	*Failure Char.*	*Hidden/ Evident*	*Effects*		*Risk Characterization*			*Task Selection*			
				Local	*End*	*Severity*	*Current Likelihood*	*Current Risk*	*Proposed Action(s)*	*Projected Likelihood*	*Projected Risk*	*Disposition*
	2. No fire generated from stoker	Random failure, Wear-out failure	Evident	Boiler fails to start	System shut down	Critical	Frequent	High	1. Check and clean the burner nozzle 2. Check the atomization of fuel in the workshop. If the atomization is poor even after cleaning the nozzle, replace it with a new one 3. Clean the electrodes with electro-cleaner solution 4. Check electrodes for damages 5. Check the condition of ceramic insulation of the electrodes for any damage 6. While performing maintenance, ensure not to change angle of the electrodes with respect to the nozzle as it may cause problems in ignition, instability and building up of carbon deposits	Occasional	Medium	

LAMPIRAN 5 – MAINTENANCE TASK SELECTION WORKSHEET

Functional Failure	*Failure Mode*	*Failure Char.*	*Hidden/ Evident*	*Effects*		*Risk Characterization*			*Task Selection*			
				Local	*End*	*Severity*	*Current Likelihood*	*Current Risk*	*Proposed Action(s)*	*Projected Likelihood*	*Projected Risk*	*Disposition*
Unstable flame	1. Fuel and air supply interference	Random failure	Evident	Difficulties on boiler start	Underfired	Critical	Remote	Medium	1. Clean and inspect the heavy oil filters provided in the line 2. Ensure pneumatic/ solenoid valves installed before pilot and main burner are working correctly 3. Ensure the fuel supply pump is changed to standby and all parameters are in normal operating range 4. Ensure all the line filters are clean	Remote	Low	
Flame temperature is above 394°C	1. Overflow fuel supply	Random failure	Evident	Overheating	Overfired	Critical	Probable	High	1. Check the fuel pump motor RPM. 2. Check all valves in fuel line. 3. Reset fuel set point to the default.	Occasional	Medium	

LAMPIRAN 5 – MAINTENANCE TASK SELECTION WORKSHEET

Functional Failure	*Failure Mode*	*Failure Char.*	*Hidden/ Evident*	*Effects*		*Risk Characterization*			*Task Selection*			
				Local	*End*	*Severity*	*Current Likelihood*	*Current Risk*	*Proposed Action(s)*	*Projected Likelihood*	*Projected Risk*	*Disposition*
Flame temperature is below 394°C	1. Overflow air supply	Random failure	Evident	Lower boiler performance	Underfired	Critical	Occasional	Medium	1. Check the air fan motor RPM.2. Check all valves in air supply line.3. Reset all air supply set point to the default.	Remote	Low	
No heat to feed water in water drum	1. Not working burner	Random failure	Evident	No generated steam	System shut down	Critical	Probable	High	1. Ensure the fan inlet is kept clean off all deposits and obstructions 2. Make sure the burner register is kept clean 3. Check the air passage to register for deposits and dust 4. Ensure flame stabilizer is inspected and kept clean from carbon deposits 5. Flame stabilizer should be checked for heat corrosion	Occasional	Medium	
Feed water temperature is above 95°C	1. Over performance burner	Random failure	Evident	Overpressure	Overfired	Critical	Probable	High	Set the burner performance to the default	Occasional	Medium	

LAMPIRAN 5 – MAINTENANCE TASK SELECTION WORKSHEET

Functional Failure	*Failure Mode*	*Failure Char.*	*Hidden/ Evident*	*Effects*		*Risk Characterization*			*Task Selection*			
				Local	*End*	*Severity*	*Current Likelihood*	*Current Risk*	*Proposed Action(s)*	*Projected Likelihood*	*Projected Risk*	*Disposition*
	2. Under normal feed water level	Random failure	Evident	Lower steam pressure	Under performance	Catastrophic	Occasional	High	Condition monitoring required to feed water supply.	Occasional	Medium	
Feed water temperature is below 85°C	1. Under performance burner	Random failure	Hidden	Poor air-fuel mixture	Underfired	Major	Remote	Medium	Set the burner performance to the default	Remote	Medium	
	2. Over normal feed water level	Random failure	Evident	Higher steam capacity	Overfired	Critical	Probable	High	Condition monitoring required to feed water supply.	Occasional	Medium	
No feed water collected from feed water supply	1. Feed water supply interference	Random failure, Wear-out failure	Evident	No feed water supply	System shut down	Catastrophic	Probable	High	Clean the feed water supply section monthly	Occasional	Medium	
Fully loaded faster than one hour	1. Over performance feed water supply	Random failure	Evident	-	No effect of interest	Minor	Remote	Low	No additional actions required	Remote	Low	
Fully loaded slower than one hour	1. Under performance feed water supply	Random failure	Evident	Longer time to provide steam	Under performance	Major	Remote	Medium	No additional actions required	Remote	Low	

LAMPIRAN 5 – MAINTENANCE TASK SELECTION WORKSHEET

Functional Failure	*Failure Mode*	*Failure Char.*	*Hidden/ Evident*	*Effects*		*Risk Characterization*			*Task Selection*			
				Local	*End*	*Severity*	*Current Likelihood*	*Current Risk*	*Proposed Action(s)*	*Projected Likelihood*	*Projected Risk*	*Disposition*
No steam generated flow from water drum	1. Blockage on tubes	Random failure, Wear-out failure	Hidden	Interference on generated steam	System shut down	Major	Probable	High	Clean and remove the blockages along the tubes at least for every 500 running hours	Occasional	Medium	
	2. Lower or no feed water in water drum	Random failure, Wear-out failure	Evident	Lower feed water supply	System shut down	Major	Remote	Medium	No additional actions required	Remote	Low	
Steam temperature below 203.35°C	1. Under performance burner	Random failure	Evident	Poor air-fuel mixture	Underfired	Major	Remote	Medium	No additional actions required	Remote	Low	
	2. Higher feed water level	Random failure	Evident	-	No effect of interest	Minor	Remote	Low	No additional actions required	Remote	Low	
	3. Overheat loss	Random failure	Hidden	Steam exposure	Under performance	Critical	Occasional	High	Insulation check monthly and annual replacement	Remote	Medium	

LAMPIRAN 5 – MAINTENANCE TASK SELECTION WORKSHEET

Functional Failure	*Failure Mode*	*Failure Char.*	*Hidden/ Evident*	*Effects*		*Risk Characterization*			*Task Selection*			
				Local	*End*	*Severity*	*Current Likelihood*	*Current Risk*	*Proposed Action(s)*	*Projected Likelihood*	*Projected Risk*	*Disposition*
Steam temperature above 203.35°C	1. Over performance burner	Random failure	Evident	Overpressure	Overfired	Critical	Probable	High	1. Feed water supply check2. Burner firing performance check3. Steam drum temperature and pressure check	Occasional	Medium	
No steam collected from tube banks	Overheat loss	Random failure	Evident	Lower steam flow to steam drum	Under performance	Major	Occasional	High	1. Feed water supply check 2. Burner firing performance check 3. Steam drum temperature and pressure check	Remote	Medium	
Steam pressure below 16 kg/cm²	Under pressure	Random failure, Wear-out failure	Evident	No steam generated	System shut down	Critical	Probable	High	1. Feed water supply check 2. Burner firing performance check 3. Steam drum temperature and pressure check	Occasional	Medium	
Steam pressure above 16 kg/cm²	Over pressure	Random failure	Evident	Lower steam supply to service	Lower efficiency	Minor	Remote	Low	No additional actions required	Remote	Low	

LAMPIRAN 5 – MAINTENANCE TASK SELECTION WORKSHEET

Functional Failure	*Failure Mode*	*Failure Char.*	*Hidden/ Evident*	*Effects*		*Risk Characterization*			*Task Selection*			
				Local	*End*	*Severity*	*Current Likelihood*	*Current Risk*	*Proposed Action(s)*	*Projected Likelihood*	*Projected Risk*	*Disposition*
No steam flow from steam drum	No steam collected from steam drum	Random failure	Evident	Overpressure	Overfired	Major	Occasional	Medium	1. Feed water supply check 2. Burner firing performance check 3. Steam drum temperature and pressure check	Remote	Medium	
Valve is unable to be fully opened	Valve damage occurence	Random failure	Evident	No steam generated	System shut down	Critical	Probable	High	Monthly condition check and valve mechanism test	Occasional	Medium	
Valve is open while steam pressure is below 16 kg/cm²	Mechanical damage or input signal error	Random failure, Wear-out failure	Evident	Steam flow interference	Under performance	Major	Remote	Medium	No additional actions required	Improbable	Low	
Valve is unable to be fully closed	Mechanical damage or input signal error	Random failure	Evident	Underpressure	No effect of interest	Minor	Improbable	Low	No additional actions required	Improbable	Low	

LAMPIRAN 5 – MAINTENANCE TASK SELECTION WORKSHEET

Functional Failure	*Failure Mode*	*Failure Char.*	*Hidden/ Evident*	*Effects*		*Risk Characterization*			*Task Selection*			
				Local	*End*	*Severity*	*Current Likelihood*	*Current Risk*	*Proposed Action(s)*	*Projected Likelihood*	*Projected Risk*	*Disposition*
Valve is close while steam pressure is above 16 kg/cm²	Mechanical damage or input signal error	Random failure, Wear-out failure	Evident	Oversupply service steam	Lower efficiency	Major	Occasional	Medium	1. Check the input signal2. Clean and remove any contaminants monthly3. Corrosion prevention by applying coating at least for a year	Remote	Medium	
No steam flow from steam drum	Overheat loss	Random failure	Evident	Overpressure	No effect of interest	Minor	Remote	Low	No additional actions required	Remote	Low	
Bypass valve is unable to be fully opened or closed	Valve damage occurence	Random failure	Evident	No steam generated	System shut down	Critical	Probable	High	1. Check the input signal 2. Clean and remove any contaminants monthly 3. Corrosion prevention by applying coating at least for a year	Occasional	Medium	
By-pass valve is open while main steam valve is opened at 16 kg/cm²	Mechanical damage or input signal error	Random failure, Wear-out failure	Evident	Steam flow interference	Lower efficiency	Major	Remote	Medium	No additional actions required	Improbable	Low	

LAMPIRAN 5 – MAINTENANCE TASK SELECTION WORKSHEET

Functional Failure	*Failure Mode*	*Failure Char.*	*Hidden/ Evident*	*Effects*		*Risk Characterization*			*Task Selection*			
				Local	*End*	*Severity*	*Current Likelihood*	*Current Risk*	*Proposed Action(s)*	*Projected Likelihood*	*Projected Risk*	*Disposition*
Unable to automatically open when the steam pressure is at 18 kg/cm² or above	Mechanical damage or input signal error	Random failure	Evident	Underpressure	No effect of interest	Minor	Improbable	Low	No additional actions required	Improbable	Low	
Unable to automatically close when the steam pressure is below 18 kg/cm²	Mechanical damage or input signal error	Random failure, Wear-out failure	Evident	Overpressure	System shut down	Catastrophic	Occasional	High	1. Clean and remove any dust or crust for at least every month 2. Screw and spring ov valve replacement at 12000 running hours 3. Performance test at least every 3 months	Remote	Medium	
No indicator work	Mechanical damage	Random failure, Wear-out failure	Evident	Underpressure	System shut down	Catastrophic	Occasional	High	1. Clean and remove any dust or crust for at least every month2. Screw and spring ov valve replacement at 12000 running hours3. Performance test at least every 3 months	Remote	Medium	

LAMPIRAN 5 – MAINTENANCE TASK SELECTION WORKSHEET

Functional Failure	*Failure Mode*	*Failure Char.*	*Hidden/ Evident*	*Effects*		*Risk Characterization*			*Task Selection*			
				Local	*End*	*Severity*	*Current Likelihood*	*Current Risk*	*Proposed Action(s)*	*Projected Likelihood*	*Projected Risk*	*Disposition*
Unable to display proper measurement	Mechanical damage	Random failure, Wear-out failure	Evident	Unknown temperature	Monitoring disturbance	Major	Remote	Medium	No additional actions required	Remote	Low	
No indicator work	Mechanical damage	Random failure	Evident	Not significant	No effect of interest	Minor	Improbable	Low	No additional actions required	Improbable	Low	
Unable to display proper measurement	Mechanical damage	Random failure, Wear-out failure	Evident	Unknown pressure	Monitoring disturbance	Major	Remote	Medium	No additional actions required	Remote	Low	
Unable to remove the scum	Not appropriate scum removal	Random failure	Evident	Not significant	No effect of interest	Minor	Remote	Low	No additional actions required	Remote	Low	
Unable to open or close	Mechanical damage	Random failure	Evident	Low quality feed water	Under performance	Major	Occasional	Medium	Check the valve condition weekly	Remote	Medium	
Wrong water level display	Mechanical damage	Random failure, Wear-out failure	Evident	Low quality feed water	Lower efficiency	Major	Remote	Medium	No additional actions required	Remote	Low	
Chocked water/steam side	Foreign object clogging	Random failure	Evident	Unknown water level	No effect of interest	Minor	Remote	Low	No additional actions required	Remote	Low	
Stuck ball	Lack of possition	Random failure	Evident	Unknown water level	Monitoring disturbance	Major	Remote	Medium	No additional actions required	Remote	Low	
Breakage of glass	Mechanical damage	Random failure	Evident	Unknown water level	Monitoring disturbance	Major	Remote	Medium	No additional actions required	Remote	Low	

LAMPIRAN 5 – MAINTENANCE TASK SELECTION WORKSHEET

Functional Failure	*Failure Mode*	*Failure Char.*	*Hidden/ Evident*	*Effects*		*Risk Characterization*			*Task Selection*			
				Local	*End*	*Severity*	*Current Likelihood*	*Current Risk*	*Proposed Action(s)*	*Projected Likelihood*	*Projected Risk*	*Disposition*
Unable to open or close	Mechanical damage	Random failure, Wear-out failure	Evident	Unknown water level	No effect of interest	Minor	Remote	Low	No additional actions required	Remote	Low	
Unable to remove the sludge	Under required feed water and operation mode	Random failure, Wear-out failure	Evident	Low quality feed water	Lower efficiency	Major	Remote	Medium	No additional actions required	Remote	Low	
Steam/water flow into an empty boiler by mistake	Lack of possition	Random failure	Evident	Builds up within the tank	No effect of interest	Minor	Remote	Low	No additional actions required	Remote	Low	
Unable to open or close	Mechanical damage	Random failure	Evident	No steam generated	System shut down	Major	Remote	Medium	No additional actions required	Remote	Low	
Leaking valve seat	Mechanical damage	Random failure, Wear-out failure	Evident	Low quality feed water	Monitoring disturbance	Major	Remote	Medium	No additional actions required	Remote	Low	
Unable to open or close automatically when water drum is fully loaded at 10 m^3	Mechanical damage or input signal error	Random failure	Evident	Feed water flashing and high velocity erosion	Monitoring disturbance	Major	Remote	Medium	No additional actions required	Remote	Low	

LAMPIRAN 5 – MAINTENANCE TASK SELECTION WORKSHEET

Functional Failure	*Failure Mode*	*Failure Char.*	*Hidden/ Evident*	*Effects*		*Risk Characterization*			*Task Selection*			
				Local	*End*	*Severity*	*Current Likelihood*	*Current Risk*	*Proposed Action(s)*	*Projected Likelihood*	*Projected Risk*	*Disposition*
Leaking valve seat	Mechanical damage	Random failure, Wear-out failure	Evident	No or less feed water supply to the water drum affects to steam production capacity	Overfired	Major	Remote	Medium	No additional actions required	Remote	Low	
Flue gas is unable to flow out	Ducting leakage, broken valve and no flue gas generated	Random failure	Evident	High velocity erosion of the feed water	Lower efficiency	Major	Occasional	Medium	Visual inspection along ducting line monthly	Remote	Medium	
Flowing flue gas is below 43,969 kg/h	Under required firing performance and operation mode	Random failure	Evident	Exhaust system blockage	System shut down	Critical	Occasional	High	1. Check the input measures daily 2. Clean and remove the crust or clogging at least twice a month 3. Performance test for every 3 months	Remote	Medium	
Flowing flue gas is above 43,969 kg/h	Over required firing performance and operation mode	Random failure	Evident	Underpressure	No effect of interest	Minor	Improbable	Low	No additional actions required	Improbable	Low	

LAMPIRAN 5 – MAINTENANCE TASK SELECTION WORKSHEET

Functional Failure	*Failure Mode*	*Failure Char.*	*Hidden/ Evident*	*Effects*		*Risk Characterization*			*Task Selection*			
				Local	*End*	*Severity*	*Current Likelihood*	*Current Risk*	*Proposed Action(s)*	*Projected Likelihood*	*Projected Risk*	*Disposition*
No flue gas flow from outletbox	Lack of combustion	Random failure	Evident	Overpressure	Overfired	Major	Remote	Medium	No additional actions required	Remote	Low	
Unable to open or close	Mechanical damage	Random failure	Evident	Less firing from furnace	Overfired	Major	Occasional	Medium	Routine check of the valve at daily	Remote	Medium	
Leaking valve seat	Mechanical damage	Random failure, Wear-out failure	Evident	Low quality feed water	Under performance	Major	Remote	Medium	No additional actions required	Remote	Low	
No heat out at all	Inlet air heating malfunction	Random failure, Wear-out failure	Evident	High velocity erosion and corrosion	Lower efficiency	Major	Occasional	Medium	1. Daily visual inspection 2. Clean and remove the dust or any contaminants monthly 3. Penetrant test application at least for annual inspection	Remote	Medium	
Air leakage	Lack of combustion	Random failure	Evident	Lower air temperature for burner air inlet	Under performance	Major	Remote	Medium	No additional actions required	Improbable	Low	
The inlet air temperature to the burner is above 45°C	Overheat loss	Random failure	Evident	Lower air capacity for burner air inlet	Lower efficiency	Major	Occasional	Medium	No additional actions required	Remote	Low	

LAMPIRAN 5 – MAINTENANCE TASK SELECTION WORKSHEET

Functional Failure	*Failure Mode*	*Failure Char.*	*Hidden/ Evident*	*Effects*		*Risk Characterization*			*Task Selection*			
				Local	*End*	*Severity*	*Current Likelihood*	*Current Risk*	*Proposed Action(s)*	*Projected Likelihood*	*Projected Risk*	*Disposition*
The inlet air temperature to the burner is below 45°C	Overheat loss	Random failure	Evident	Not significant	No effect of interest	Minor	Remote	Low	No additional actions required	Remote	Low	
Crack damage	Mechanical damage and construction	Random failure	Hidden	Not significant	No effect of interest	Minor	Remote	Low	No additional actions required	Remote	Low	

LAMPIRAN 5 – MAINTENANCE TASK SELECTION WORKSHEET

Functional Failure	*Failure Mode*	*Failure Char.*	*Hidden/ Evident*	*Effects*		*Risk Characterization*			*Task Selection*			
				Local	*End*	*Severity*	*Current Likelihood*	*Current Risk*	*Proposed Action(s)*	*Projected Likelihood*	*Projected Risk*	*Disposition*
Corrosion	Plate fractures related to corrosion rate	Random failure, Wear-out failure	Evident	1. Pinpoint penetration of metal2. Rusting of ferrous metals3. Pits can penetrate deep into the metal that can result in rapid failure of feed lines, economiser tubes and boiler tubes4. Ultimate failure of boiler metal, steam mains and condensate lines	System shut down	Catastrophic	Probable	High	1. Eliminating corrosive gases2. Removal of dissolved oxygen3. High PH value of boiler water4. Mechanical deaeration of boiler water5. Higher feed water temperature i.e. reduces its oxygen content.6. Chemical de-oxygenation by use of oxygen scavengers i.e. sodium sulphite7. Hot condensate return as it contains less O2 then feed water and also saves fuel.	Occasional	Medium	

LAMPIRAN 5 – MAINTENANCE TASK SELECTION WORKSHEET

Functional Failure	*Failure Mode*	*Failure Char.*	*Hidden/ Evident*	*Effects*		*Risk Characterization*			*Task Selection*			
				Local	*End*	*Severity*	*Current Likelihood*	*Current Risk*	*Proposed Action(s)*	*Projected Likelihood*	*Projected Risk*	*Disposition*
No cooling effect in the furnace	Overheat loss	Random failure, Wear-out failure	Evident	Major impact on structural integrity	Lower efficiency	Major	Occasional	Medium	1. Clean and remove any clogging or crusted contaminants at least twice in a month 2. Insulation replacement at least for 28000 running hours 3. Recoating for the steel plate for intermediate survey	Remote	Medium	

LAMPIRAN 6

SUMMARY OF MAINTENANCE TASK

LAMPIRAN 6 – SUMMARY OF MAINTENANCE TASK

Maintenance Category : A
Functional Group : Vessel Service
System : Heating
Sub System : Marine Boiler
Equipment Item : Burner

Task	*Task Type*	*Item No.*	*Risk*		*Frequency*	*Reference*	*Comments*
			Unmitigated	*Mitigated*			
Check the condition of nozzle for clogging	CM	1.1	Medium	Medium	Monthly	Anish Wankhede (2015)	If a blockage is found, clean it with a soft brush or scrubbing paper. Chemical liquids are not allowed in this case.
Check the atomization of fuel in the workshop	CM	1.1	High	Medium	Monthly	Anish Wankhede (2015)	If the atomization is poor even after cleaning the nozzle, replace it with a new one.
Clean the electrodes with electro-cleaner solution.	PM	1.1	High	Medium	Every 3 month	Anish Wankhede (2015)	Check electrodes for damages. Replace if it is broken.
Replace ceramic insulation of the electrodes.	PM	1.1	High	Medium	Annual	Anish Wankhede (2015)	Use cerachrome type only for ceramic insulation.
Check the solenoid valve controlling the fuel in the main burner	CM	1.1	High	Medium	Annual	Anish Wankhede (2015)	When the desired setting has been made, tighten jam nut and replace cover.
Check and clean the cup for hard deposits in rotary cup burner	PM	1.1	High	Medium	Every 3 months	Anish Wankhede (2015)	Consider replacing the rotary cup if it is perforated by deposits.
Clean all filters related to the burner	PM	1.2	Medium	Low	Every 2 weeks	Anish Wankhede (2015)	No chemical liquid allowed
Reset all set point for boiler supplies control system	OTC	1.3, 1.4	Medium	Low	Every 3 months	Anish Wankhede (2015)	Set to the default.

LAMPIRAN 6 – SUMMARY OF MAINTENANCE TASK

Maintenance Category : B
Functional Group : Vessel Service
System : Heating
Sub System : Marine Boiler
Equipment Item : Furnace

Task	*Task Type*	*Item No.*	*Risk*		*Frequency*	*Reference*	*Comments*
			Unmitigated	*Mitigated*			
Set the burner performance to the default	OTC	2.2, 2.3	High	Medium	Annual	J. Rupert (2016)	Follow the instruction of manufacturer recommendations
Check and clean the burner assembly and its related equipments	PM	2.1	High	Medium	Monthly	J. Rupert (2016)	Follow the instruction of manufacturer recommendations
Condition monitoring required to feed water supply.	CM	2.2	High	Medium	Daily	J. Rupert (2016)	Follow the instruction of manufacturer recommendations

Maintenance Category : B
Functional Group : Vessel Service
System : Heating
Sub System : Marine Boiler
Equipment Item : Water Drum

Task	*Task Type*	*Item No.*	*Risk*		*Frequency*	*Reference*	*Comments*
			Unmitigated	*Mitigated*			
Clean the feed water supply section monthly	PM	3.1	High	Medium	Monthly	D. Perrickson (2014)	Follow the instruction of manufacturer recommendations
Penetrant or magnetic particle test for all inner surface of tank	CM	3.2, 3.3	Medium	Low	Annual	D. Perrickson (2014)	Follow the instruction of manufacturer recommendations

LAMPIRAN 6 – SUMMARY OF MAINTENANCE TASK

Maintenance Category : B
Functional Group : Vessel Service
System : Heating
Sub System : Marine Boiler
Equipment Item : Generating Tube Banks

Task	*Task Type*	*Item No.*	*Risk*		*Frequency*	*Reference*	*Comments*
			Unmitigated	*Mitigated*			
Clean and remove the blockages along the tubes at least for every 500 running hours	PM	4.1	High	Medium	Monthly	K. Mandidi (2017)	Follow the instruction of manufacturer recommendations
Insulation check monthly and annual replacement	CM	4.2, 4.3	High	Medium	Annual	K. Mandidi (2017)	Follow the instruction of manufacturer recommendations

Maintenance Category : B
Functional Group : Vessel Service
System : Heating
Sub System : Marine Boiler
Equipment Item : Steam Drum

Task	*Task Type*	*Item No.*	*Risk*		*Frequency*	*Reference*	*Comments*
			Unmitigated	*Mitigated*			
Feed water supply and steam vessel check and cleaning	CM	5.1	High	Medium	Daily	D. Perrickson (2014)	Follow the instruction of manufacturer recommendations
Burner set to the default performance	OTC	5.2, 5.3	High	Medium	Annual	D. Perrickson (2014)	Follow the instruction of manufacturer recommendations

Maintenance Category : A
Functional Group : Vessel Service
System : Heating
Sub System : Marine Boiler
Equipment Item : Main Steam Valve

Task	*Task Type*	*Item No.*	*Risk*		*Frequency*	*Reference*	*Comments*
			Unmitigated	*Mitigated*			
Condition check and valve mechanism test	CM	6.1	High	Medium	Monthly	W. Ariesta (2015)	Personnel on board
Clean and remove any clogging contaminants	PM	6.2, 7.1	Medium	Low	Every 2 weeks	W. Ariesta (2015)	Personnel on board

LAMPIRAN 6 – SUMMARY OF MAINTENANCE TASK

Task	*Task Type*	*Item No.*	*Risk*		*Frequency*	*Reference*	*Comments*
			Unmitigated	*Mitigated*			
Visual inspection	PM	6.3, 7.2	Medium	Low	Weekly	W. Ariesta (2015)	Personnel on board

Maintenance Category : A
Functional Group : Vessel Service
System : Heating
Sub System : Marine Boiler
Equipment Item : By Pass Valve

Task	*Task Type*	*Item No.*	*Risk*		*Frequency*	*Reference*	*Comments*
			Unmitigated	*Mitigated*			
Check the input signal measurements	CM	8.1	Medium	Low	Daily	W. Ariesta (2015)	Personnel on board
Clean and remove any clogging contaminants	PM	8.2	High	Medium	Monthly	W. Ariesta (2015)	Personnel on board
Corrosion prevention by applying coating at least for a year	PM	8.3	High	Medium	Annual	W. Ariesta (2015)	Personnel on board

Maintenance Category : A
Functional Group : Vessel Service
System : Heating
Sub System : Marine Boiler
Equipment Item : Safety Valve

Task	*Task Type*	*Item No.*	*Risk*		*Frequency*	*Reference*	*Comments*
			Unmitigated	*Mitigated*			
Clean and remove any dust or crust	PM	9.1	High	Medium	Monthly	Aalborg Manual Guide	Personnel on board
Replacement of safety valve	PM	9.1, 9.2	High	Medium	2 years	Aalborg Manual Guide	Docking preparation
Screw and spring or valve replacement and performance test	PM	9.2	High	Medium	Annual	Aalborg Manual Guide	Personnel on board

LAMPIRAN 6 – SUMMARY OF MAINTENANCE TASK

Maintenance Category : A
Functional Group : Vessel Service
System : Heating
Sub System : Marine Boiler
Equipment Item : Temperature Gauge

Task	*Task Type*	*Item No.*	*Risk*		*Frequency*	*Reference*	*Comments*
			Unmitigated	*Mitigated*			
Clean and remove any clogging contaminants	PM	10.1	Medium	Low	Monthly	L. Minho (2011)	Personnel on board
Bimetal replacement	PM	10.2	Medium	Low	Annual	L. Minho (2011)	Personnel on board

Maintenance Category : A
Functional Group : Vessel Service
System : Heating
Sub System : Marine Boiler
Equipment Item : Pressure Gauge

Task	*Task Type*	*Item No.*	*Risk*		*Frequency*	*Reference*	*Comments*
			Unmitigated	*Mitigated*			
Clean and remove any clogging contaminants	PM	11.1	Medium	Low	Monthly	L. Minho (2011)	Personnel on board
Needle spring replacement	PM	11.2	Medium	Low	Annual	L. Minho (2011)	Personnel on board

Maintenance Category : A
Functional Group : Vessel Service
System : Heating
Sub System : Marine Boiler
Equipment Item : Scum Valve

Task	*Task Type*	*Item No.*	*Risk*		*Frequency*	*Reference*	*Comments*
			Unmitigated	*Mitigated*			
Clean and remove any clogging contaminants	PM	12.1	Medium	Low	Every 3 month	W. Ariesta (2015)	Personnel on board
Visual inspection	PM	12.2	Medium	Low	Daily	W. Ariesta (2015)	Personnel on board

LAMPIRAN 6 – SUMMARY OF MAINTENANCE TASK

Maintenance Category : A
Functional Group : Vessel Service
System : Heating
Sub System : Marine Boiler
Equipment Item : Water Level Gauge

Task	*Task Type*	*Item No.*	*Risk*		*Frequency*	*Reference*	*Comments*
			Unmitigated	*Mitigated*			
Clean and remove any clogging contaminants	PM	13.1, 13.2	Medium	Low	Monthly	L. Minho (2011)	Personnel on board
Sight glass and water level sensor replacement	PM	13.3, 13.4	Medium	Low	Annual	L. Minho (2011)	Personnel on board

Maintenance Category : A
Functional Group : Vessel Service
System : Heating
Sub System : Marine Boiler
Equipment Item : Blow Down Valve

Task	*Task Type*	*Item No.*	*Risk*		*Frequency*	*Reference*	*Comments*
			Unmitigated	*Mitigated*			
All the connected pipes must be unpressurised (0 bar) and at room temperature (20°C)	CM	14.1	Medium	Low	Monthly	W. Ariesta (2015)	Personnel on board
Inspection bore should be inspected for leakage of the medium	CM	14.2	Medium	Low	Every 3 month	W. Ariesta (2015)	Personnel on board
Screw and spring or valve replacement and performance test	PM	15.1	Medium	Low	Annual	W. Ariesta (2015)	Personnel on board

Maintenance Category : A
Functional Group : Vessel Service
System : Heating
Sub System : Marine Boiler
Equipment Item : Sample Valve

Task	*Task Type*	*Item No.*	*Risk*		*Frequency*	*Reference*	*Comments*
			Unmitigated	*Mitigated*			
Clean and remove any clogging contaminants	PM	16.1	Medium	Low	Monthly	W. Ariesta (2015)	Personnel on board
Screw and spring or valve replacement and performance test	PM	16.2	Medium	Low	Annual	W. Ariesta (2015)	Personnel on board

LAMPIRAN 6 – SUMMARY OF MAINTENANCE TASK

Maintenance Category : A
Functional Group : Vessel Service
System : Heating
Sub System : Marine Boiler
Equipment Item : Feed Water Valve

Task	*Task Type*	*Item No.*	*Risk*		*Frequency*	*Reference*	*Comments*
			Unmitigated	*Mitigated*			
Clean and remove any clogging contaminants	PM	17.1	Medium	Low	Every 2 weeks	W. Ariesta (2015)	Personnel on board
Screw and spring or valve replacement and performance test	PM	17.2	Medium	Low	Annual	W. Ariesta (2015)	Personnel on board

Maintenance Category : C
Functional Group : Vessel Service
System : Heating
Sub System : Marine Boiler
Equipment Item : Outletbox

Task	*Task Type*	*Item No.*	*Risk*		*Frequency*	*Reference*	*Comments*
			Unmitigated	*Mitigated*			
Insulation replacement	PM	18.1	High	Medium	Annual	S. Morrison (2009)	Docking preparation
Recoating for the steel plate	PM	18.2, 18.3	Medium	Low	2 years	S. Morrison (2009)	Docking preparation

Maintenance Category : A
Functional Group : Vessel Service
System : Heating
Sub System : Marine Boiler
Equipment Item : Furnace Drain Valve

Task	*Task Type*	*Item No.*	*Risk*		*Frequency*	*Reference*	*Comments*
			Unmitigated	*Mitigated*			
Clean and remove dust or any foreign objects	PM	19.1	Medium	Low	Weekly	W. Ariesta (2015)	Personnel on board
Visual inspection and penetrant test	CM	19.2	High	Medium	Monthly	W. Ariesta (2015)	Personnel on board

LAMPIRAN 6 – SUMMARY OF MAINTENANCE TASK

Maintenance Category : B
Functional Group : Vessel Service
System : Heating
Sub System : Marine Boiler
Equipment Item : Air Heater

Task	*Task Type*	*Item No.*	*Risk*		*Frequency*	*Reference*	*Comments*
			Unmitigated	*Mitigated*			
Visual inspection	CM	20.1	Medium	Low	Daily	M. Thiwari (2011)	Follow the instruction of manufacturer recommendations
Clean and remove the dust or any contaminants	PM	20.2	Medium	Low	Monthly	M. Thiwari (2011)	Follow the instruction of manufacturer recommendations
Penetrant test application	PM	20.3, 20.4	Medium	Low	Annual	M. Thiwari (2011)	Follow the instruction of manufacturer recommendations

Maintenance Category : C
Functional Group : Vessel Service
System : Heating
Sub System : Marine Boiler
Equipment Item : Membrane Walls

Task	*Task Type*	*Item No.*	*Risk*		*Frequency*	*Reference*	*Comments*
			Unmitigated	*Mitigated*			
Insulation replacement	PM	21.1	High	Medium	Annual	ASME BPVC	Dokcing preparation
Recoating for the steel plate	PM	21.2	Medium	Low	2 years	ASME BPVC	Dokcing preparation
Clean and remove any clogging or crusted contaminant	PM	22.1	Medium	Low	Every 2 weeks	ASME BPVC	Dokcing preparation

LAMPIRAN 7

WORKPACKAGE

LAMPIRAN 7 – WORKPACKAGE

Maintenance Schedule	
Burner	
Interval	Done by
Monthly	Mechanic
Following these recommended steps should help operators reduce problems with boiler burner. Here is a brief check list: 1. Check the condition of nozzle for clogging 2. Check the atomization of fuel in the workshop	
Interval	Done by
Annual	Mechanic
Following these recommended steps should help operators reduce problems with boiler burner. Here is a brief check list: 1. Replace ceramic insulation of the electrodes 2. Check the solenoid valve controlling the fuel in the main burner	
Interval	Done by
Every 3 Month	Mechanic
Following these recommended steps should help operators reduce problems with boiler burner. Here is a brief check list: 1. Clean the electrodes with electro-cleaner solution 2. Check and clean the cup for hard deposits in rotary cup burner 3. Reset all set point for boiler supplies control system	
Interval	Done by
Every 2 Weeks	Mechanic
Following these recommended steps should help operators reduce problems with boiler burner. Here is a brief check list: 1. Clean all filters related to the burner	

Maintenance Schedule	
Furnace	
Interval	Done by
Monthly	Mechanic
Following these recommended steps should help operators reduce problems with boiler burner. Here is a brief check list: Check and clean the burner assembly and its related equipments	

LAMPIRAN 7 – WORKPACKAGE

Maintenance Schedule	
Water Drum	
Interval	Done by
Annual	Mechanic
Following these recommended steps should help operators reduce problems with boiler burner. Here is a brief check list: Penetrant or magnetic particle test for all inner surface of tank	

Maintenance Schedule	
Generating Tube Banks	
Interval	Done by
Annual	Mechanic
Following these recommended steps should help operators reduce problems with boiler burner. Here is a brief check list: 1. Clean and remove the blockages along the tubes 2. Insulation replacement	

Maintenance Schedule	
Steam Drum	
Interval	Done by
Monthly	Mechanic
Following these recommended steps should help operators reduce problems with boiler burner. Here is a brief check list: Feed water supply and steam vessel check and cleaning	

Maintenance Schedule	
Main Steam Valve	
Interval	Done by
Monthly	Mechanic
Following these recommended steps should help operators reduce problems with boiler burner. Here is a brief check list: 1. Condition check and valve mechanism test 2. Clean and remove any clogging contaminants	

LAMPIRAN 7 – WORKPACKAGE

Maintenance Schedule	
By-pass Valve	
Interval	Done by
Monthly	Mechanic
Following these recommended steps should help operators reduce problems with boiler burner. Here is a brief check list: 1. Corrosion prevention by applying coating 2. Clean and remove any clogging contaminants	

Maintenance Schedule	
Safety Valve	
Interval	Done by
Every 2 years	Mechanic
Following these recommended steps should help operators reduce problems with boiler burner. Here is a brief check list: 1. Both replacement 2. General test and cleaning	

Maintenance Schedule	
Temperature Gauge	
Interval	Done by
Monthly	Mechanic
Following these recommended steps should help operators reduce problems with boiler burner. Here is a brief check list: 1. Visual inspection and performance test 2. Clean and remove any clogging contaminants	

Maintenance Schedule	
Pressure Gauge	
Interval	Done by
Monthly	Mechanic
Following these recommended steps should help operators reduce problems with boiler burner. Here is a brief check list: 1. Visual inspection and performance test 2. Clean and remove any clogging contaminants	

LAMPIRAN 7 – WORKPACKAGE

Maintenance Schedule	
Scum Valve	
Interval	Done by
Monthly	Mechanic
Following these recommended steps should help operators reduce problems with boiler burner. Here is a brief check list: 1. Corrosion prevention by applying coating 2. Clean and remove any clogging contaminants	

Maintenance Schedule	
Water Level Gauge	
Interval	Done by
Annual	Mechanic
Following these recommended steps should help operators reduce problems with boiler burner. Here is a brief check list: 1. Sight glass and water level sensor replacement 2. Clean and remove any clogging contaminants	

Maintenance Schedule	
Blow Down Valve	
Interval	Done by
Monthly	Mechanic
Following these recommended steps should help operators reduce problems with boiler burner. Here is a brief check list: 1. Corrosion prevention by applying coating 2. Clean and remove any clogging contaminants	

LAMPIRAN 7 – WORKPACKAGE

Maintenance Schedule	
Sample Valve	
Interval	Done by
Monthly	Mechanic
Following these recommended steps should help operators reduce problems with boiler burner. Here is a brief check list: 1. Corrosion prevention by applying coating 2. Clean and remove any clogging contaminants	

Maintenance Schedule	
Feed Water Valve	
Interval	Done by
Monthly	Mechanic
Following these recommended steps should help operators reduce problems with boiler burner. Here is a brief check list: 1. Corrosion prevention by applying coating 2. Clean and remove any clogging contaminants	

Maintenance Schedule	
Outletbox	
Interval	Done by
Monthly	Mechanic
Following these recommended steps should help operators reduce problems with boiler burner. Here is a brief check list: 1. Visual inspection and penetrant test 2. Clean and remove dust or other foreign objects	

LAMPIRAN 7 – WORKPACKAGE

Maintenance Schedule	
Furnace Drain Valve	
Interval	Done by
Monthly	Mechanic
Following these recommended steps should help operators reduce problems with boiler burner. Here is a brief check list: 1. Visual inspection and performance test 2. Clean and remove dust or other foreign objects	

Maintenance Schedule	
Air Heater	
Interval	Done by
Monthly	Mechanic
Following these recommended steps should help operators reduce problems with boiler burner. Here is a brief check list: 1. Visual inspection and penetrant test 2. Clean and remove dust or other foreign objects	

Maintenance Schedule	
Membrane Walls	
Interval	Done by
Annual	Mechanic
Following these recommended steps should help operators reduce problems with boiler burner. Here is a brief check list: 1. Insulation replacement 2. Recoating for the steel plate	

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BIODATA PENULIS

Bagas Somporn Supriadi Putra yang merupakan penulis laporan tugas akhir (skripsi) ini lahir di Tulungagung, 15 Maret 1995 dari orang tua yang bernama Supriadi dan Sumiati. Penulis merupakan anak pertama dari dua bersaudara yang memiliki adik laki-laki bernama Bramestu Adikusuma. Penulis menempuh pendidikan dimulai dari SDN Kwangsan (lulus tahun 2007) kemudian melanjutkan ke SMPN 1 Sedati (lulus tahun 2010) lalu ke SMKN 3 Buduran jurusan Teknik Instalasi Permesinan Kapal (lulus tahun 2013). Setelah lulus SMK, penulis sempat bekerja selama 6 bulan di PT Fuboru Indonesia pada pertengahan tahun 2013 sebagai teknisi *maintenance* sebelum melanjutkan pendidikan ke perguruan tinggi dengan mengambil program studi Diploma III (D-3) Jurusan Teknik Permesinan Kapal di Politeknik Perkapalan Negeri Surabaya (PPNS) pada tahun 2014 dan lulus pada tahun 2017 dengan pujian (*cum laude*).

Setelah lulus dari PPNS kemudian penulis diterima sebagai *drafter* di PT Merak Jaya Beton pada tahun 2017 selama kurang lebih 6 bulan sebelum melanjutkan pendidikan sarjana (S-1) di Departemen Teknik Sistem Perkapalan Fakultas Teknologi Kelautan Institut Teknologi Sepuluh Nopember (ITS) Surabaya pada tahun 2018. Di samping menjalani aktifitas sebagai mahasiswa, saat ini penulis juga bekerja sebagai *waiter* di rumah makan "Kedai Pak Pri". Selain pernah bekerja di bidang teknik, penulis juga pernah bekerja di bidang lainnya yakni diantaranya pernah bekerja di bidang keuangan sebagai asisten konsultan sekuritas di PT Kontak Perkasa Futures selama 3 bulan pada bulan Maret hingga bulan Mei tahun 2015 dan pernah juga bekerja di bidang pendidikan sebagai asisten pimpinan outlet lembaga bimbingan belajar Ayo Cerdas Indonesia (ayocerdas.com) juga selama 3 bulan pada bulan November tahun 2017 hingga bulan Januari tahun 2018.

Selain menempuh ilmu di bidang akademik, penulis juga akfif di berbagai organisasi yang membangun karakter yang kuat dan sebagai wadah untuk bersosialisasi serta menumbuhkan kerja sama dalam mewujudkan suatu visi dan gagasan. Di antara organisasi tersebut adalah Pasukan Pengibar Bendera Pusaka (PASKIBRAKA) Kabupaten Sidoarjo tahun 2011 sebagai anggota, komunitas musik independen *"Fighting Forward"* (LAMBRIO) Sidoarjo tahun 2012 hingga 2015 sebagai anggota, Komunitas Tahajjud Berantai (KUTUB) Sidoarjo tahun 2015 hingga sekarang sebagai anggota, *Local Guide Community* Google Maps™ Indonesia tahun 2016 hingga sekarang sebagai anggota dan karang taruna Generasi Kav Bumi Sedati (GEKA) Sidoarjo tahun 2019 hingga sekarang sebagai ketua.

MOTTO: *"Allah does not burden a soul beyond that it can bear."*