August 2017 Development Paper

MariEMS Learning Material – Technical Upgrade and Retrofit

This is the 13th compilation by Professor Dr Reza Ziarati on the work of the EU funded Erasmus + MariEMS' partners and material researched by Chief Engineer Mohammed Haque. The material is composed from Chapter 13 of the learning material.

13. Boilers and Steam System

13.1 Introduction

The steam system plays a major role in energy efficiency of certain ship types (such as steam driven LNG ships) and a medium role in ships such as oil tankers carrying liquid cargo that require cargo heating or there is a need for cargo transfer using steam driven pumps but also need to generate Inert Gas for cargo tank cleaning, purging or tank top ups. **Figure 13.1.1** shows typical level of fuel use in boilers as compared to main and auxiliary engines for a VLCC vessel.

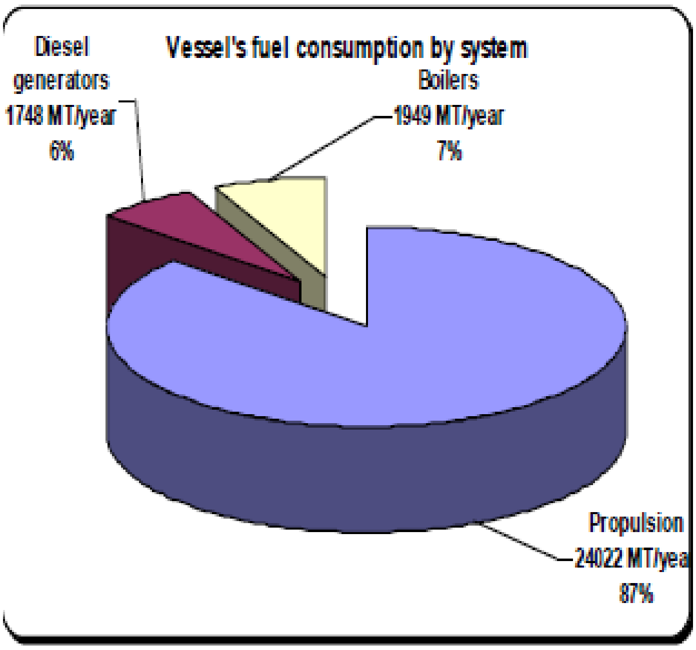

Figure 13.1.1 – Overall annual fuel consumption and boiler share [Bazari 2012]

Figure 13.1.2 from IMO 3rd GHG Study 2014 also reveals the level of energy use in marine boilers for the whole of international fleet.

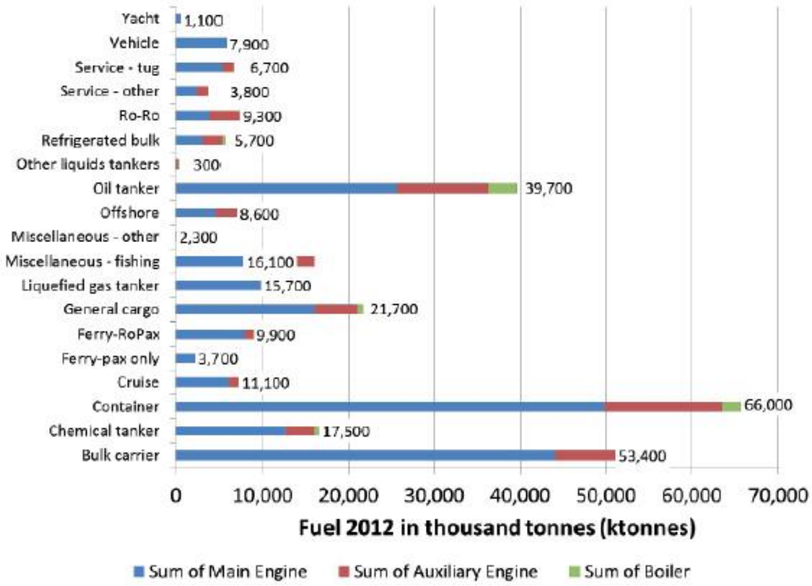

Figure 13.1.2 - Annual shipping fuel consumption per ship type and combustion system [Third IMO GHG Study 2014]

It can generally be stated that an overall average number of up to a maximum of 6% of shipping fuel consumption could be attributed to the use of boilers. As stated, for steam turbine propulsion ships such as steam LNG ships, more than 80% of energy use is due to boilers.

13.2 Overview of a Ship's Steam System

In commercial ships, the steam system normally includes the following equipment:

- Auxiliary boilers
- Exhaust gas economisers

As the names imply, the exhaust gas economiser is a waste heat recovery system that recovers heat from exhaust of main or auxiliary engines and thus does not use fuel. The more the second system is used, the less will be a need for use of the auxiliary boilers, thus good maintenance and operating conditions of exhaust gas economiser should always be regarded as part of energy saving in the steam system. **Figure 13.2.1** shows a typical steam system for a ship.

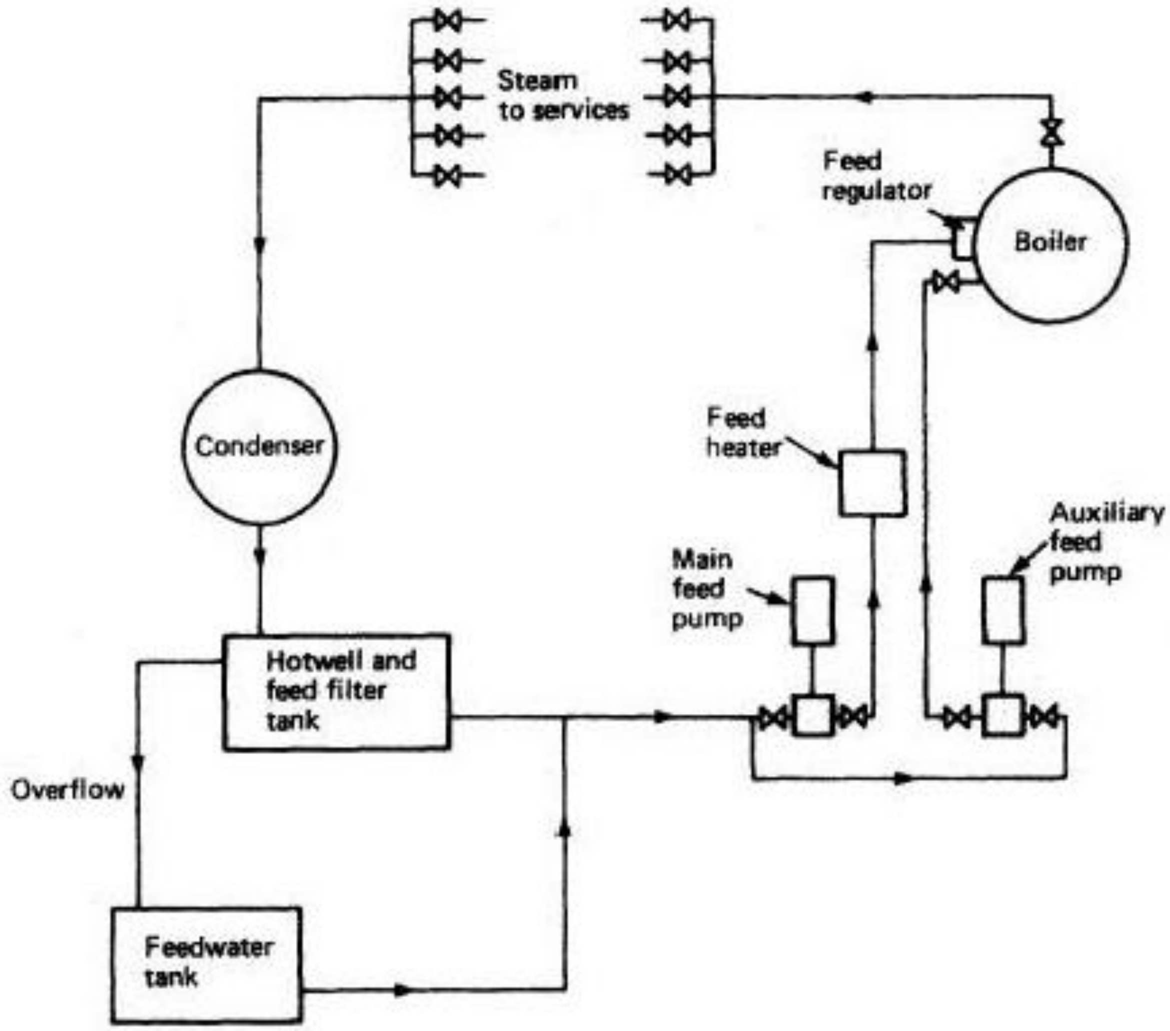

Figure 13.2.1 – A typical auxiliary boiler steam system configuration [Machinery Spaces.com]

For the sake of presenting the energy efficiency case, the ship-board steam system will be divided into the following parts:

- **The auxiliary boilers**: This is where the steam is produced using fuel.
- **The exhaust gas economiser**: This is where the steam is produced via waste heat recovery.
- **The steam distribution system**: This refers to steam piping system and relevant instruments and devices used for steam controls.
- **Steam end-use**: This refers to all the steam consuming systems such as steam turbines, fresh water generators, steam heaters, etc.

Figure 13.2.2 shows a typical arrangement for such components.

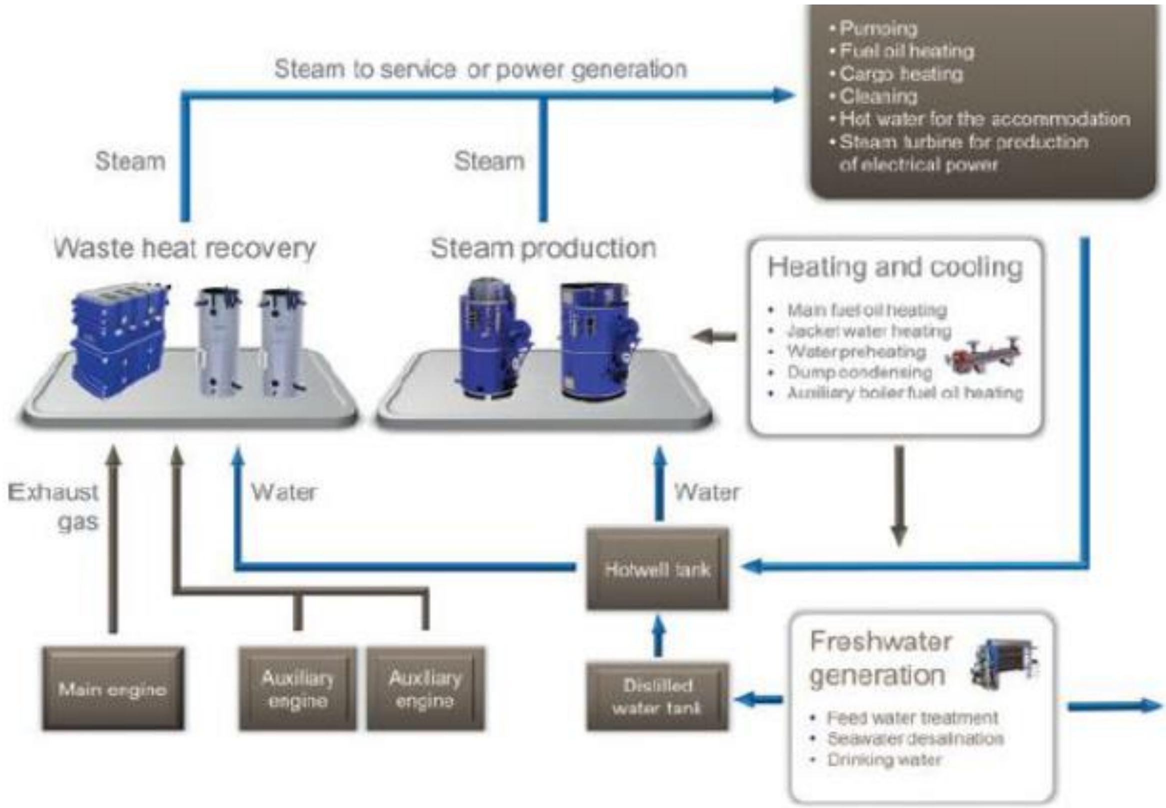

Figure 13.2.2 – Overall ship-board steam system [Alfa Laval]

13.3 Boiler Energy Efficiency Measures

Figure 13.3.1 shows typical energy efficiency characteristics of a boiler that is normally specified by boiler manufacturer. As can be seen, the boiler efficiency is a factor of its load.

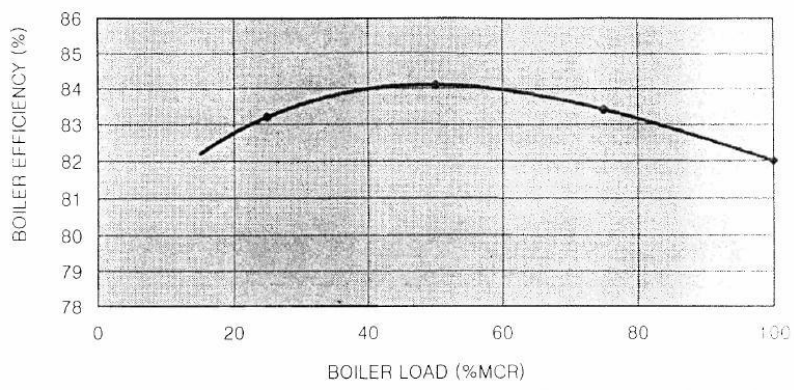

Figure 13.3.1 – Boiler efficiency characteristics

In operation, the efficiency tends to be lower than the above design values. There is a number of major areas that need to be managed in order to keep the auxiliary boiler at its highest energy efficiency levels as signified by **Figure 13.3.1**.

13.3.2 Fouling of surface

The boiler main function is to generate steam at correct pressure and temperature and with best energy efficiency. Optimal energy efficiency means optimal transfer of fuel energy to boiling water via various boiler pipes and heating surfaces. Aspects that could lead to a reduced rate of this heat transfer include:

- Fouling of boiler tubes and heat transfer surfaces on the gas side
- Fouling or scaling of boiler tubes on the water side.

The above will normally translate into a less heat transfer from gas and more heat retention by the exhaust gases as they leave the boiler. Thus high boiler outlet exhaust gas temperature could be a good indication of such fouled conditions. To remedy the case, maintenance practices should include boiler's soot blowing, de-scaling, good water, combustion adjustments (to reduce soot formation) and son on.

For this purpose, the heat transfer areas of the boiler must be monitored. The soot blowing of the boiler must be done regularly as build-up of soot acts like an insulator and reduces the heat transfer rate. The same goes for the build-up of scale in the water tubes. The stack temperature must be monitored regularly and any increase in it means that heat recovery is not optimum. High increases of exhaust gas temperature beyond those experienced after the last cleaning would indicating build-up of fouling and would require another cleaning action.

13.3.3 Optimum hot well temperature and blow-down levels

There is a hot well (see **Figure 13.2.1**) that collects all the condensates from steam system end-users plus where water treatment and cleaning may take place. It is from hot-well that the feed water is supplied to the boiler. Hot well temperature must be maintained at temperature specified by manufacturers. A low temperature (e.g. below 80°-85°C) will cause colder feed water to enter the boiler thus increasing the fuel cost due to the need for more heating for evaporation. An overheated hot well may cause evaporation of water at the suction of feed pump (e.g. cavitation) and cause vapour lock in the feed pump and loss of suction. For heat retention in the hot well to keep temperature higher, heat losses due to poor insulation can be reduced. Also, control of make-up water is important as excessive need for make-up water will be indicative of leak in the steam system as well as more heating for make-up water that is normally at low temperature.

The blow down of the boiler is required for controlling the amount of dissolved solids as a result of evaporation and impurity of make-up water or addition of other chemical. Blow down must be calculated and done after measuring the level of dissolved water. In some cases, the engineers blow down the boiler excessively, thus not only loose hot water, but also increase the need for make-up water and make-up water generation.

13.3.4 Excessive combustion air

In order to burn the fuel, air needs to be supplied to the boiler. The excess air unused in the combustion gets heated and then discharged through the chimney. This is waste of energy. Thus, any excess air that is not needed for combustion will cause energy loss as it will take away heat from boiler and discharge to the atmosphere, thus normally should be avoided.

Boilers normally have certain amount of optimal excess air and the air input must be adjusted to this level. It signifies a balance between combustion efficiency and amount of air supplied. Excessive "excess air" is identified in the form of either high O_2 concentration or low concentration of CO_2 in the boiler exhaust gas. These two parameters thus need to be monitored as part of controlling boiler excess air thus its energy efficiency. **Figure 13.3.4** shows the boiler efficiency as a function of CO_2 concentration. As can be seen, it is desirable to maximise the CO_2 concentration in the exhaust gas for best efficiency. As indicated, the optimum level would normally be specified by the manufacturer.

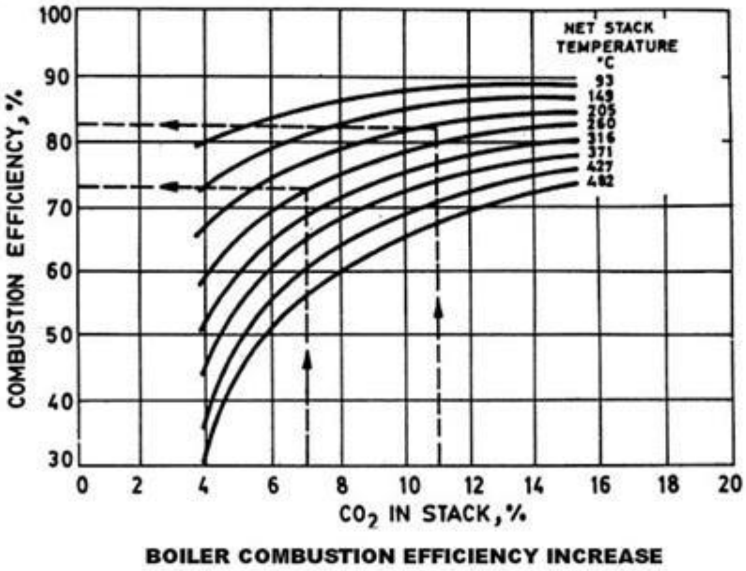

Figure 13.3.4 – Boiler efficiency as a function of CO_2 level in the exhaust gas [Mohit Sanguri

13.3.5 Exhaust gas economiser efficiency

The Exhaust gas economiser in a ship is like a huge heat exchange that exchanges heat between exhaust gases from engines to water and produces steam for the same purpose that auxiliary boilers produce steam. The revered energy and amount of steam generate by exhaust gas economiser is normally sufficient for routine ship-board steam requirements, thus normally a ship with exhaust gas economiser does not need to fire the boiler while in passage. As far as improving efficiency by avoiding the fouling on the gas side and water side, the same principles discussed under boiler applies.

The efficiency of an exhaust gas economiser can be improved by increased soot blowing frequency (once or twice a day while at sea). Recording the exhaust gas temperature difference and pressure drop can provide an indication of economiser cleanliness. Water washing should be scheduled into major repair periods. The exhaust gas economiser maintenance will not only improve energy efficiency but also reduce maintenance overall costs and reduce safety risks associated with soot fires. Occasionally use of fuel additives may improve the cleanliness of the economiser.

As for ship design, the maximum waste heat recovery is desirable. For exhaust gas economisers, the funnel stack temperature must be as low as possible but with sufficient margin to be above the dew point to avoid sulphur corrosion. Generally a funnel temperature of 165° to 195°C when using fuel oil is considered optimum.

13.3.6 Boiler efficiency and load factor

Like any other devices, the boiler energy efficiency is a factor of its load factor. **Figure 13.3.1** and also **Figure 13.3.6** show typical of such efficiencies.

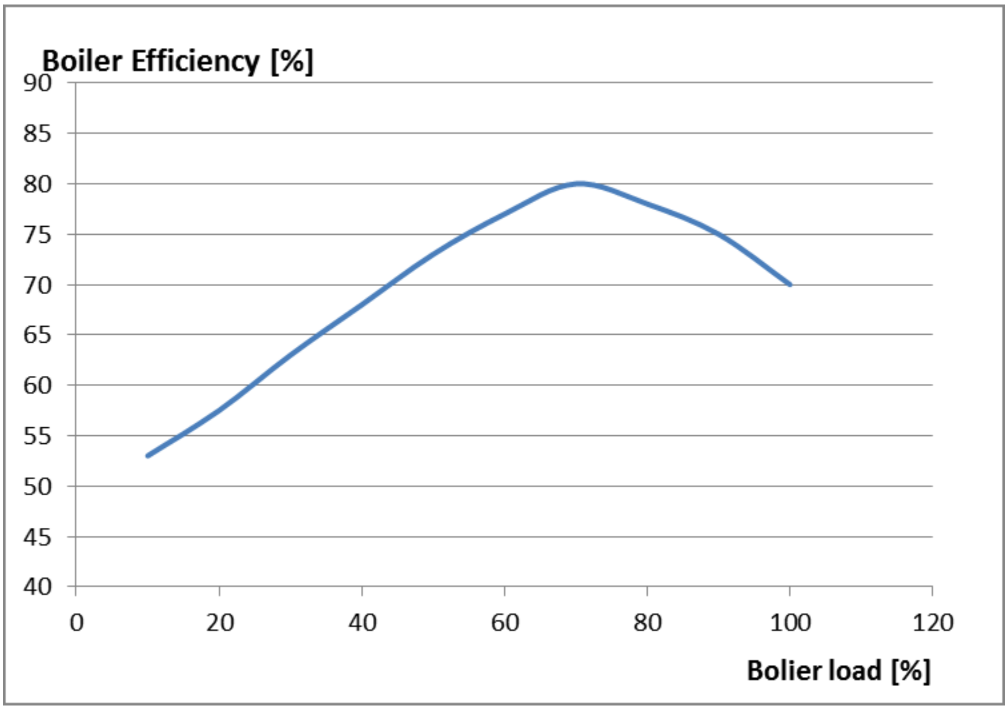

Figure 13.3.6 – Impact of load factor on efficiency

Accordingly, for this boiler the efficiency is highest at certain point and then drop off with changes in load. Thus boiler load management could be considered as one aspect of energy efficiency. **Figure 13.3.6** shows that at 70% load, the efficiency is 80% and at 30% load, the efficiency is 63%; a significant drop.

Operating the boiler at low load is thus inefficient. Avoiding low load boiler operation will depend on ship type, number of boilers and where the steam is used. Generally, if there are two auxiliary boilers on a ship, they must not run in parallel if one can supply the whole steam demand; unless safety issues dictates the need for such a parallel operation case.

13.4 Steam Distribution System Energy Efficiency Measures

The steam distribution system maintenance makes a significant contribution to energy efficiency in steam system. Measures to consider include:

- Steam loss through open bypass valves
- Steam loss through failed open steam traps
- Heat loss through un-insulated or improperly insulated piping and equipment.

To determine if your ship could benefit from a steam distribution system maintenance program, normally steam lines and steam traps surveys need to be done at regular intervals. The inspection activities will include steam pipes, insulation, traps, steam supply/discharge on or around heat exchange devices etc. Fundamental to such inspections is the collection of good data. Aspects to consider include:

Reduce steam leakage: As part of day routines, checks should be made for steam leaks. The steam leaks should be rectified as soon as observed.

Heat loss due to inadequate insulation: The boiler and steam lines along with condensate return to the hot well must be well insulated. Over a period of time insulation is damaged or worn out. Any analysis by thermography or any other thermal measurement system could identify the hot spots. Improvement of damaged insulation due to repair work must be done. All these will reduce the heat losses from the system thus improve energy efficiency.

Steam trap losses: Steam traps are used to discharge condensate once it is formed, thus the main function is to prevent live steam from escaping and to remove air and non-condensable gases from the line. However it is a largely neglected part of the steam distribution system. Steam traps that are stuck open allow live steam to escape thus resulting in loss of heat and also increasing the load of the condenser. Steam trap that is stuck shut results in reduced capacity of the equipment it is being supplied to. Overall, steam traps must be checked at planned intervals to show their good working conditions.

13.5 Steam End-Use Energy Efficiency Measures

Steam end-use could vary according to ship types. The main users of steam include:

- Steam-driven cargo pumps in tankers.
- Steam driven ballast pumps
- Cargo heating
- Fuel storage, treatment and condition system
- Fresh water generation especially in cruise ships
- HVAC system in particular in cruise ships

Every efforts should be made to economies on steam-end use as this would eliminate the need for extra steam generation thus very effective in energy saving.

13.5.1 Cargo heating planning and optimisation

In some ships, the cargo requires cooling to maintain quality; e.g., refrigerated or frozen cargo. With other cargoes such as special oil products, special crude oils, heavy fuel oils, etc. may require heating in particular in winter and cold climate regions. Some of this heat required can be supplied by exhaust gas economiser. However, in many cases an additional auxiliary boiler is needed to supply sufficient steam. Steam from exhaust gas is generally sufficient to heat the heavy fuel oil that is used on most ships; in port, however, steam from an auxiliary boiler may be needed. For cargo heating purposes and in order to reduce fuel consumption and the heating costs, a voyage-specific cargo heating plan should be developed by the shipboard team with support from operation department at head office. For a proper plan, the following should be considered:

- Vessel tank configuration.
- Whether deck heater or tank heating coils are provided.
- Number of heating coils and surface areas.
- Cargo details including specific heat, pour point, cloud point, viscosity, and wax content.

- Weather en-route including ambient air and sea water temperatures.
- Estimated heat loss and drop in temperatures.
- Recommended return condensate temperatures.
- Estimated daily heating hours and consumption.

Various parameters such as daily air/sea temperatures, weather, cargo temperatures at three levels, steam pressures, return condensate temperature, actual against estimated consumptions and temperatures are discussed between shipboard team and head office. The heating plan should be reviewed and revised appropriately throughout the voyage.

The optimum temperature to which cargo should be heated for carriage and discharge largely depends on the following factors:

- **Pour point:** It is the lowest temperature at which the liquid will pour or flow under prescribed conditions. It is a rough indication of the lowest temperature at which cargo is readily pump-able. General principle is to carry cargo at 10^{o}C above pour point temperature.
- **Cloud point:** It is the temperature at which dissolved solids are no longer completely soluble, precipitating as second phase and is synonymous with wax appearance temperature. Once separated, it requires temperature over 80^{o}C to dissolve the wax. Cargo temperature should not be allowed to fall below the cloud point.
- **Wax content:** High wax crude tends to deposit sludge, and therefore require to be maintained at a higher temperature to prevent wax fall out.
- **Viscosity:** High viscosity oils do not necessarily deposit sludge and may be carried at lower than the discharge temperatures. However, for discharge purposes, the heating will be done to reduce the viscosity to acceptable levels for cargo pumps.
- **Ambient weather and sea conditions:** This will also influence the cargo carriage and discharge temperatures as these impacts the level of heat transfer from cargo tanks or fuel tanks.

The cargo heating plan would need to take into account the above parameter. As part of cargo heating planning, relevant instructions will be developed. Heating instructions should be reviewed after loading cargo, based on charterer requirement. Permission to carry and discharge the cargo at optimum temperatures should be requested from charterer or cargo owner. The heating plan should be made soon after loading cargo and reviewed/updated on daily basis considering the various factors that affect the heating and customer requirements.

A review of the heating log abstract with the following will help with better future planning and identifying the gaps:

- Actual vs. planned temperature
- Actual vs. planned fuel oil consumption
- Actual vs. planned heating hours

Vessels should complete the heating abstract (daily basis) after completion of each voyage and send it ashore along with the Cargo Heating Log, also identifying any gaps.

Figure 13.5.1 shows a typical cargo heating patterns graph.

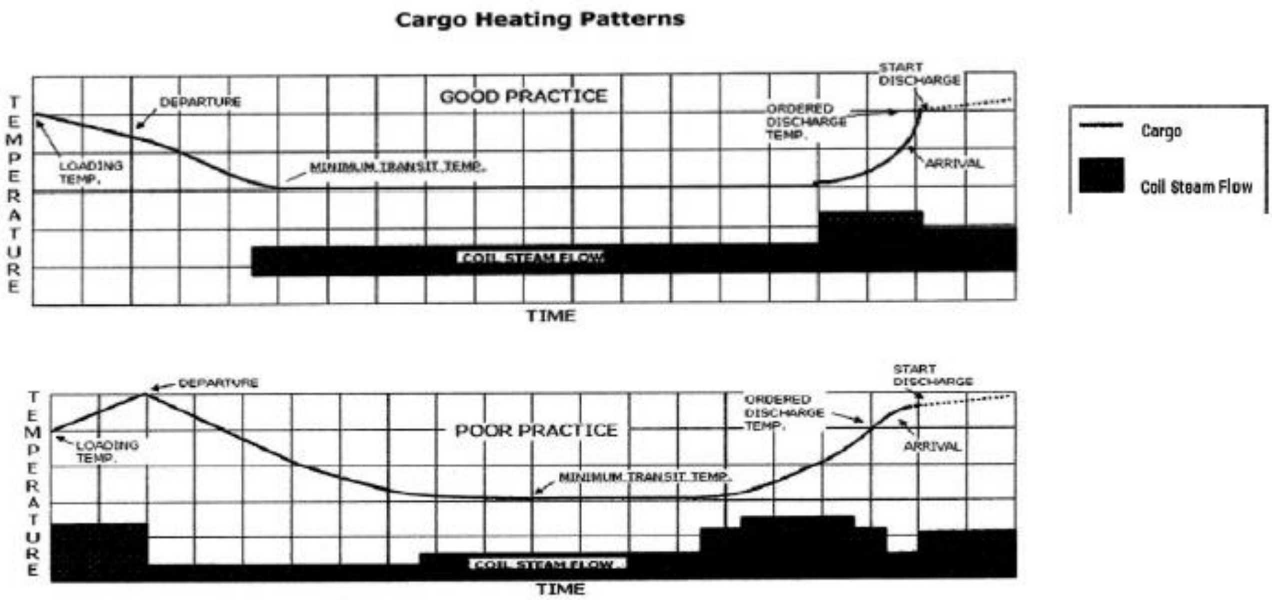

Figure 13.5.1 - Example of a cargo heating process [OCIMF 2011]

Operational control and best practice

For best practice cargo heating planning, the following should be noted:

- Vessels should have a greater understanding of the voyage manager/charterer's heating instructions.
- Seek the receiver/charterer's permission for allowable range of cargo temperatures.
- Avoid heating during adverse weather period.
- Create and follow the proper cargo heating plan to verify the effectiveness of actual heating progress.
- Closely monitor and analyse cargo heating reports. Monitor heating daily to address deviations from the heating plan.
- Do not heat for short frequent periods and running boiler at low loads.
- Follow the recommended condensate temperature and optimum boiler settings for efficient cargo heating. Heating instructions, accompanying the heating plan, should further highlight these points.
- Maintain efficient and good communication between the vessel and the voyage manager/charterer about the plan and execution.

Cargo heating may also benefit from the use of effective insulation. For example, using lagging on heating coil water / condensate return pipes as well as steam, thermal oil and hot-water lines on deck area. This could be significant energy saving option as it has been observed that some ships lack insulation of branch lines and cargo tanks. It is important that the insulation material is of good quality. A poor quality of insulation material is likely to rot or lose its effectiveness.

13.5.2 Steam for cargo discharge or ballast water operation

Certain ships such as large crude oil and product tankers as well as ships for the need for large ballast pump may use steam-driven turbines to drive the cargo and ballast pumps.

In these ships, extra boilers are operated to drive the cargo pump steam turbines as well as for inert gas generation. Cargo pump driven steam turbines are highly inefficient (with an overall efficiency of about 10-15%) and care should be exercised in their usage level.

During cargo discharging operations, vacuum should be maintained properly in the vacuum condenser. This will ensure better work transfer across the steam turbine thereby increasing output at the same boiler load. During cargo discharging operation, better coordination and planning must be maintained with the terminal personnel {loading master, terminal representative(s)} as also on board with deck and engine department so as to reduce idle firing period of main boilers; reducing unnecessary / prolonged cargo oil pumps' warm up period, idle running of inert gas plant etc.

13.5.3 Inert Gas Generation (IGG)

In various types of crude oil and product tankers, IG is needed for cleaning, purging and top of the cargo tanks for safety reasons. The IGG (Inert Gas Generation) system produces exhaust gas with minimal O_2 concentration for this purpose. The IGG operation resemble that of boilers and consumes fuel thus its management is required for saving energy. The IGG usage needs to be monitored to ensure that it is not used excessively. Also, optimising of the cargo tank cleaning, gas freeing and inspection intervals will reduce the usage of IGG system. When IGG system is used, the level of discharge to atmosphere (blow off of not needed IG) should be minimised via optimal operation of the system.

13.6 Shipboard Best Practice Guide

The need to maintain clean surfaces on all exhaust gas economiser and auxiliary boilers is emphasised. The differential pressure across the economiser and its gas inlet and exhaust temperatures should be constantly monitored and appropriate action taken if measurements are out of optimum range.

Additionally, steam traps are to be checked regularly for functionality and steam leaks are to be identified and stopped. Boiler control settings such as burner start/stop and water level setting for feed pump start/stop shall be chosen in a way to reduce energy consumption.

Cargo tank heating (if applicable) shall be carried out according to the specification of the cargo and control temperatures shall be set as low as possible. Also, fuel oil temperature in various storage tanks must be monitored and kept within acceptable limits.

For evaluation of insulation and steam traps, thermal imaging may be used as a tool.

To demonstrate compliance to the above guidelines, the following need to be carried out:

- Steam pipes insulation should be kept in good condition.
- Boiler insulation should be kept in good condition.
- Steam traps are to be checked regularly for functionality.
- Steam leaks are to be identified and stopped.
- Boiler pressure setting for burner start/stop is to be as wide as practicable.

- Cargo tank heating (if applicable) shall be carried out according to the specification of cargo and control temperatures shall be set as low as practicable.
- Fuel temperature in storage, settling ad supply tanks shall be monitored and kept at acceptable lower limits.

Other activities will include:

- Steam trap maintenance should be carried out regularly. Steam traps which are not working correctly may lead to the loss of an excessive amount of additional energy.
- All steam leakages to be minimized.
- Auxiliary boiler is to be used during anchorages and other relevant opportunities.
- Starting of auxiliary boilers too far in advance of intended use is to be avoided.
- Steam dumping when possible is to be avoided.
- Pipe/ valve lagging is to be maintained in good order to minimize heat loss.
- Steam tracing is to be used judiciously.
- Bunker tank heating is to be optimised.

13.7 References and further reading

The following list provides references for this section and additional publications that may be used for more in-depth study of topics covered in this section:

1. Sanguri M, "Energy Conservation in Boilers and Making an Audit Report" http://www.marineinsight.com/marine/marine-news/headline/energy-conservation-in-boilers-and-making-an-audit-report/ viewed Nov 2016.
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