January 2017 Development Paper

MariEMS learning Material - Ship-Board Operations and Energy Efficiency and references to Crew Responsibilities

This the second 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 Chapters 2, 5 and 6 represented as Part 1, 2 and 3 in the following article

Part 1

2. Introduction to Shipboard Roles and Responsibilities

2.1 Introduction

Like an office ashore, a ship is also equipped with some crew members with their ranks and role responsibility. Shipboard crews are an organised team of expertise like regimental forces who follows a chain of command in order to perform the vessel's day to day operations safely, efficiently and eco-friendly.

The crew team ranking and responsibilities are prescribed in an organogram where the main roles and responsibilities are structured in particular for those that have significant impact with regard to the shipboard energy management.

Training of ship-board staff on energy management activities are highlighted in various IMO guidelines and thus the initial effort by companies will include awareness raising and change of ship-board culture with regard to energy efficiency.

2.2 Shipboard Organisational Structure

The ship's crews are the personnel who sail on board a ship and are responsible for its operation, primarily when the ship is at sea (with some responsibility when at port). For the purpose of ship operation and traditionally, the crew of a commercial ship is divided into three departments:

- Deck department
- Engine department
- Catering (steward's) department.

Figure 2.2 shows some typical ship-board management organizational charts. A brief description of the important roles is given below.

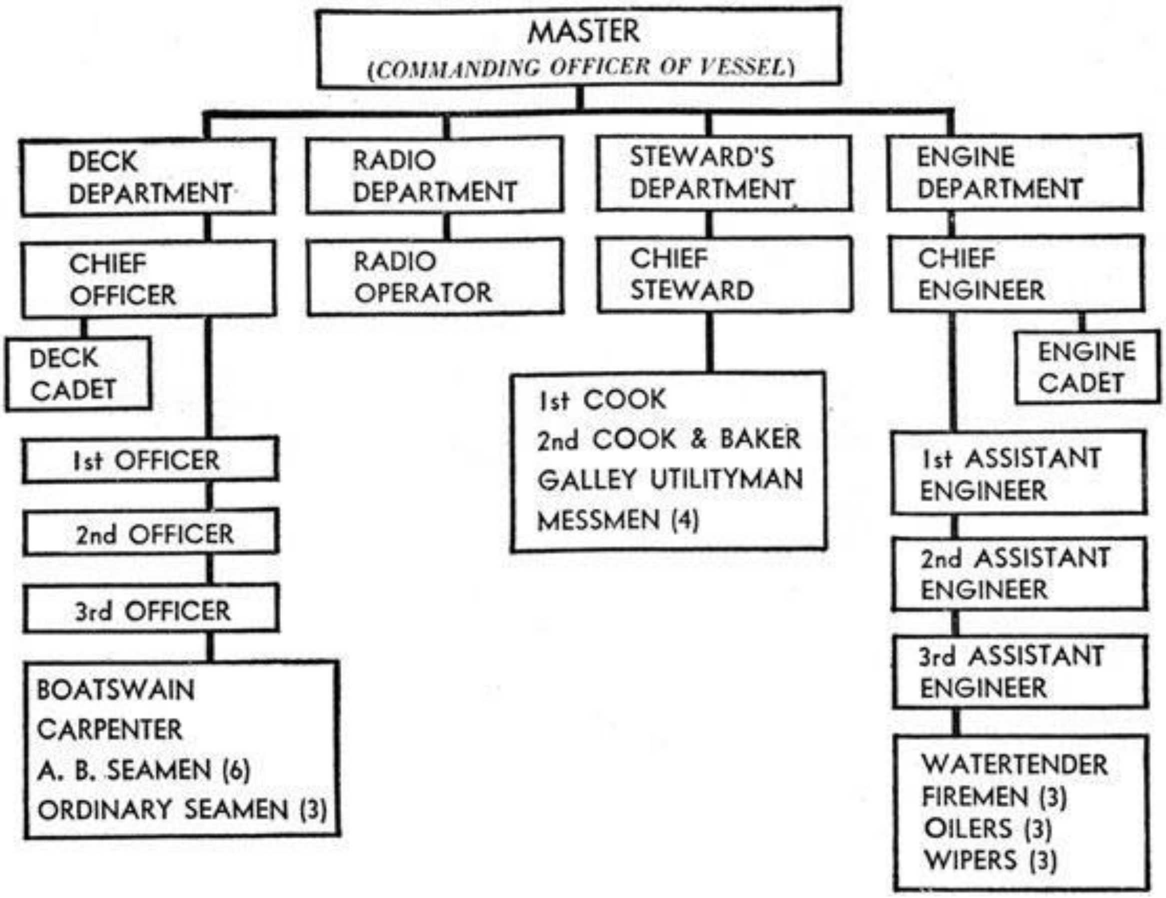


Figure 2.2 – Typical Shipboard Organogram with three main departments. The Radio Department is obsolete as a result of the implementation of GMDSS certificates to the Deck Officers.

The Master or more commonly the Captain is the ship's highest responsible officer, known as the supreme authority of the vessel acting on behalf of the ship's owner / operator or the manager. The Captain is legally responsible for the day to day management of the ship. His responsibility is to ensure that all the departments on board perform legally to the requirements of the ships' owner /operator or manager. Also, each shipboard department has a designated head who reports to the master. The deck department is headed by a Chief Officer. The engine department is headed by a Chief Engineer. He has other licensed engineers to assist him with engine room watch and the performance of maintenance and repair activities in the engine room.

The Chief Steward is the head of the catering department. He assists the captain in dealing with embarkation (entering a port) and disembarkation (leaving a port) formalities and other administrative tasks, if necessary. Additionally, in ports, he will take care of ordering and supervising the delivery of provisions and galley supply and distribution and is in charge of crew wages, etc. The above roles and their level of engagement will vary from one ship type to another.

Deck Department

Chief Officer: The Chief Officer is the head of the deck department. He is second-in-command after the ship's master. The Chief Officer's primary responsibilities are the vessel's cargo operations, its stability and supervising the deck crew. The Chief Officer is responsible for the safety and security of the ship, as well as the welfare of the crew on board. The Chief Officer typically stands the 4-8 hours of navigation watch. Additional duties include ensuring good maintenance of the ship's hull, cargo gears, accommodations, the lifesaving and firefighting appliances. The Chief Officer also trains the crew and cadets on various aspects like safety, firefighting, search and rescue and various other contingencies.

Second Officer: The Second Officer is usually in charge of ship navigation with a position below Chief Officer and above Third Officer. He/she is the third-in-command, after the Master and Chief Officer. The second officer typically stands watch from 1200 to 1600 at noon and again from 0000 to 0400 in the nights.

Third Officer: The third officer primarily charged with the safety of the ship and crew. The Third officer generally serves as the ship's chief safety officer. The Third Officer is the next licensed position on board the vessel, as fourth-in-command.

2.3 Engine Department

The engineers on board ships are also called technical officers. They are responsible for keeping the machinery maintained and operational. Today, ships are complex systems that combine a lot of technology within a small space. This includes not only the engines and the propulsion system, but also for example, the electrical power supply, devices for loading and discharging, garbage incineration and fresh water generators. Additionally, more and more environmental protection technologies, fuel treatment systems and cargo conditioning devices are used on board ships. The upkeep of all these are in the hands of engine department staff.

Chief Engineer: The Chief Engineer on a commercial vessel is the official title of an Engineer qualified to manage and oversee the technical department of the vessel. The qualification for this position is the Marine Engineer Class 1. The Chief Engineer is responsible for all operations and maintenance of all engineering equipment throughout the ship. He reports directly to the Captain on all issues related to technical dept.

Second Engineer: The Second Engineer is the officer responsible for supervising the daily maintenance and operation of the engineering systems. He or she reports directly to the Chief Engineer. The Second Engineer is second in command in the engine department after the ship's Chief Engineer. The person holding this position is typically the busiest engineer on-board the ship, due to the supervisory role this engineer plays and the operations duties performed. Operational duties include responsibility for the refrigeration systems, main engines and any other equipment not assigned to the third or fourth engineers.

Third Engineer: The Third Engineer is junior to the second engineer in the engine department and is usually in charge of boilers, fuel, auxiliary engines, condensate, and feed systems. This engineer is typically in charge of bunkering, if the officer holds a valid certificate for fuel transfer operations.

Fourth Engineer: The Fourth Engineer is junior to the third engineer in the engine department. The most junior certificated marine engineer of the ship, he or she is usually responsible for electrical, sewage treatment, lube oil, bilge, and oily water separation systems. Depending on usage, this person usually stands a watch. Moreover, in some companies the fourth engineer may assist the third officer in maintaining proper operation of the lifeboats.

2.4 Steward's Department

Chief Steward: The Chief Steward directs and assigns personnel that do functions such as preparing meals, cleaning and maintaining officers' quarter, and managing the stores. The Chief Steward also does other activities such as overtime and cost control records, and may requisition or purchase stores and equipment. Other additional duties may include taking part in cooking activities. The

Chief Steward is assisted by a chief cook and his/her assistant cooks, mess men and assistant stewards.

2.5 Shipboard Activities for Energy Efficiency

Considering the above description, all ship crews have certain degree of roles to play on ship energy efficiency. Each crewmember's role is different to achieve the same goal. For example:

The Master, being overall in charge, has a significant impact on all aspects of ship operation including planning, execution, controls and evaluations. The Master in particular could influence significantly all ship operational issues. Without Master's full awareness and drive, ship energy management is unlikely to succeed on-board ships. Areas that Master could significantly impact are those related to ship operational aspects such as voyage management, weather routing, just in time arrival and so on. The Master has the authority to reroute the vessel at more convenient and cost saving way as well as he has the decision making capacity to reduce the vessel speed to complete a voyage at much lower fuel consumption but without making significant delays. The master's management skill has significant implications for ship energy efficiency. So, a ship's Master could have the highest influence for an energy efficient ship operation than any other ship-board staff.

The Chief Officer plays significant roles on the cargo and loading/unloading operations, ballast management operations, trim optimisation and aspects of hull and propeller condition and maintenance, etc. In this regard, all detailed operational issues are handled by Chief Officer and in this way he/she exerts a lot of influence on various ship activities including energy and environmental management. Good communications between Chief Officer and Chief Engineer would provide a more optimised operation between deck department requirements and engine department efficiency and maintenance requirements. Based on this, the Chief Officer is the second most important person on deck department that could influence the overall ship energy efficiency.

The Chief Engineer being in overall charge of technical aspects of ship engineering systems and machinery operations where the fuel is consumed and energy generated, could play a major role on technical issues including the condition and performance of engines and various machinery and the way they are utilised. The Chief Engineer normally carries out most of the machinery condition assessment activities, engine record logs and reporting and communications with Master and Chief Officer. The Chief Engineer is the competent person to calculate the optimum output of an engine with the minimum fuel consumption and he has the expertise to control air emission at the same time. By virtue of having the full picture of all engineering system, Chief Engineer is the most important person on-board in terms of energy efficiency implementation and execution.

The Second Engineer, by virtue of being the most engaged person in the engine department on day to day operation and maintenance of various systems, has the second most important role in engine department in ensuring that all machinery are in optimal working condition and performance as well as their usage are limited to requirements.

The other officers and crew members also play vital roles to maintain energy efficiency on board. The watch keepers keep the bare minimum machineries in operation to save energy. They can monitor the auxiliary engine loads and can decide if parallel running of multiple engines is good for economy at all. They can monitor the main engine load and inform the Chief Engineer for necessary action. Similarly, the deck officers can monitor the vessel trim, weather condition etc. to manipulate the best energy efficient option.

2.6 References:

1. http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Air%20pollution/M4%20energy%20management%20onboard%20final.pdf viewed on 18th Oct 2016.

2. http://www.marineinsight.com/careers-2/a-guide-to-merchant-navy-ranks/ viewed on 18th Oct 2016.

Part 2

2. Shipping Operations Overview

2.1 Introduction

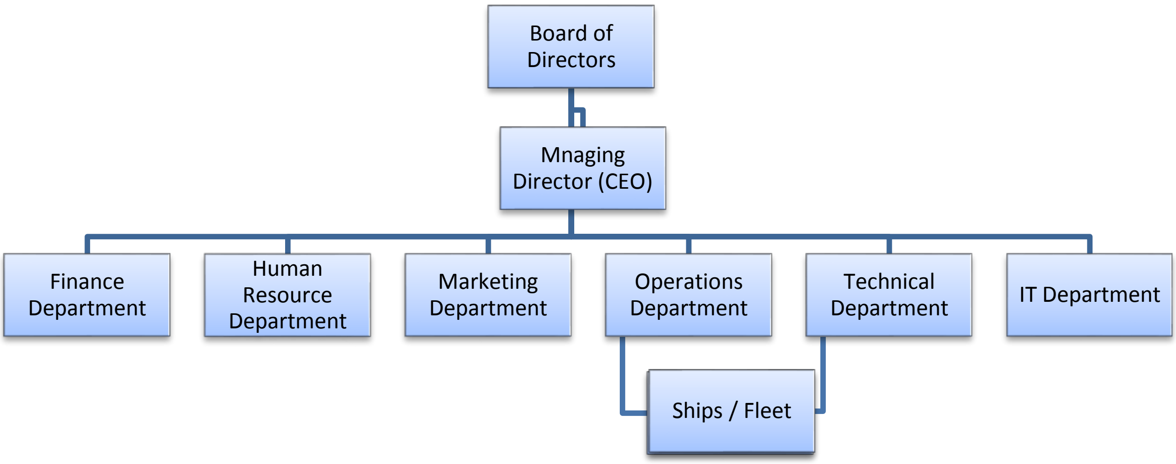
This section provides an overview of fleet management issues and discusses how to implement sustainable fleet management practices that leads to environmental protection and reduces transport costs. The purpose of a sustainable management of a fleet is to:

- Reduce accidents and associated risks and costs through improved navigation performance, and fleet health and safety responsibilities.
- Reduce overall fleet costs including fuel costs.
- Reduce fleet environmental impacts including reduction in air emissions such as carbon dioxide (CO_2) emissions.
- Adopt efficient voyage planning techniques to reduce distance sailed, minimise exposure to adverse sea conditions and make more efficient use of the fleet.
- Adopt new, energy efficient ship technologies and low carbon fuels through fleet renewal planning that are most appropriate for a sustainable operation.
- Support corporate sustainability goals, for example, under ISO 14001 and other environmental best practice.
- Provide a competitive edge by demonstrating economics and environmental credentials of the company's ship operations to its clients.

The material presented herein is mainly those from Barnhart et al 2007 that has been reformulated to suit the case for ship energy efficiency. Additional literatures are also provided for further reading on the subject. The aim is not to provide a detailed account of shipping business and its operations management aspects but to familiarise the trainee with main aspects of the industry that would influence the energy efficiency of shipping operations. The topics discussed herein that directly relate to ship energy efficiency and CO_2 reductions are then further discussed in other sections of this module.

2.2 Shipping Company Structure

The structure of a shipping company is determined primarily by the nature of the trade in which it operates and by the size of its activities. For example, the structure of a tramp operator will



generally be different from that of a much larger liner company. Irrespective of the size of the company, its structure should be designed to permit good and fast decision-making. An example of typical departments that a shipping company may have is shown in **Figure Part 2 2.2**

Figure Part 2 2.2: Typical organisation of a shipping company

Of the departments shown in Figure 5.2, the operations department and technical department are relevant to this training course.

Operations department (fleet management): This is the most important department for a shipping company. The main job of this department is to maximise the economic and safe deployment of the ships via a number of activities including planning and scheduling, i.e. deciding where to send the ships and when. A significant level of coordination is done by this department. Coordination is essential, not only with other internal departments but also with the ships, charterers, ports, agents, etc.

Technical Department: As the name implies, this department's main responsibility is to keep the ships in a seaworthy and good maintenance conditions. It is in charge of ships' maintenance and repairs including overhauls, technical repairs, routine maintenance, new building projects, etc.

2.3 Importance of Communications between Departments

One of the issues observed most of the time is the lack of optimal organisational communications between various departments that lead to waste of energy. For example, communication between deck and engine departments is essential for machinery use optimisation. In an effective ship-board energy efficiency programme, the collaboration and communications between all departments need to be enhanced. This may be achieved via consideration of energy efficiency at daily meetings and relevant ship-board work planning for reduction of electricity, compressed air, fresh water, etc. use.

The Engine and Deck department can jointly make an electricity consumption plan in the morning meeting where they can exchange information as how many cargo cranes will be operating throughout the day and at what rate the ballasting operation is required. The Engineers would then decide on load demand if a parallel operation of two generators is essential. For ballast operation a variable motor speed devise may be put into operation if the full capacity of the ballast pump is not required. Similarly, catering department can inform engine department in advance the usage of hot plates in order for the engineers to make an energy demand plan.

It is always a very good energy saving method to run one generator at full load rather than running two at half load. Therefore, it is essential to maintain a very good communication between the departments to know how much would be the load demand for the day and number of generators to run in order to optimise the energy efficiency.

2.4 Ship Types

Ships come in a variety of sizes. The size of a ship is measured by its weight carrying capacity (deadweight) and by its volume carrying capacity (gross tonnage). Cargo with low weight per unit of volume fills the ship's volume before it reaches its weight capacity. Deadweight (DWT) is the weight carrying capacity of a ship in metric tons. That includes the weight of the cargo, as well as the weight of fuels, lubricating oils, supplies, and anything else on the ship. Gross Tons (GT) is the volume of the enclosed spaces of the ship in hundreds of cubic feet.

Ships come also in a variety of types. Tankers are designed to carry liquids in bulk. The larger ones carry crude oil while the smaller ones usually carry oil products, chemicals, fruit juices and other liquids. Bulk carriers carry dry bulk commodities such as iron ore, coal, grain, bauxite, alumina, phosphate and other minerals. Some of the bulk carriers are self-discharging. They carry their own unloading equipment and are not dependent on port equipment for unloading their cargo. Liquefied Natural Gas (LNG) carriers carry refrigerated natural gas under very low temperatures.

Container ships carry standardized containers in which packaged goods are stowed. General cargo vessels carry in their holds and above deck all types of goods, usually packaged ones. These vessels often have multiple decks or floors. Since handling general cargo is labour intensive and time consuming, general cargo has been containerized during the past decades, thus reducing the time that these ships spend on port cargo operations from days to hours.

Refrigerated vessels or reefers are designed to carry cargos that require refrigeration or temperature controlled cargos like fish, meat, etc. but can also carry general cargo. Roll-on–Roll-off (Ro–Ro) vessels have ramps for trucks and cars to drive on and off the vessel. Other types of vessels are ferries, passenger ships, fishing vessels, service/supply vessels, barges, research ships, dredgers, naval vessels and other special purpose vessels. Some ships are designed as combination of the above types, e.g., ore-bulk-oil, general cargo with refrigerated compartments, passenger and Ro–Ro vessels and so on.

2.5 Cargo Types and Characteristics

Ships carry a large variety of cargos. The cargos may be manufactured consumer goods, unprocessed fruits and vegetables, processed food, livestock, intermediate goods, industrial equipment, processed materials and last but not least all different types of raw materials such as crude oil and minerals.

These goods may come in a variety of packaging such as boxes, bags, drums, bales and rolls or may be unpackaged or even in bulk. Sometimes cargoes are unitized into larger standardized units such as pallets, containers or trailers. Generally and in order to facilitate more efficient cargo handling, goods that are shipped in larger quantities are shipped in larger handling units or in bulk. During the last decades, packaged goods that required multiple manual handlings and were traditionally shipped by liners have been containerized into standard containers. Containerization of such goods facilitates efficient mechanized handling of the cargo, and thus saves time and money.

In addition, goods that are shipped in larger quantities are usually shipped more often in larger shipment sizes. Cargoes may require shoring on the ship in order to prevent them from shifting during the passage and may require refrigeration, controlled temperature or special handling while on board the ship. Different goods may have different weight density, thus a ship may be regarded as full either by weight or by volume or by another measure of capacity.

2.6 Ports

Ships operate between ports. Ports are used for loading and unloading cargo as well as for loading fuel, fresh water, other supplies and discharging waste. Ports impose physical limitations on the dimensions of the ships that may call in them (ship draft, length and width), and charge fees for their services. Sometimes ports are used for trans-shipment of cargo among ships, especially when the cargo is containerised. Major container lines often operate large vessels between hub ports and use smaller vessels to feed containers to/from spoke ports. In many countries, ports authorities that are in overall charge of regulating ports are different from those authorities that are in charge of regulating shipping.

Port operations involve a great many players, both at management level and at operational level. The management of ports also varies from one country to the other. The port as a physical entity is managed by a port authority in which the public authorities may or may not be a stakeholder. In addition, depending on the size of the port, any number of enterprises may be located within its perimeter. **Figure Par 2 2.6.1** offers an overview of the various market players within a port, indicating who provides services to whom. The diagram confirms that shipping companies rely on services provided by third parties (e.g. pilots, towage services, ship repairers, provisioning, waste reception facilities, and bunkering companies) that are somehow but not fully associated with a port.

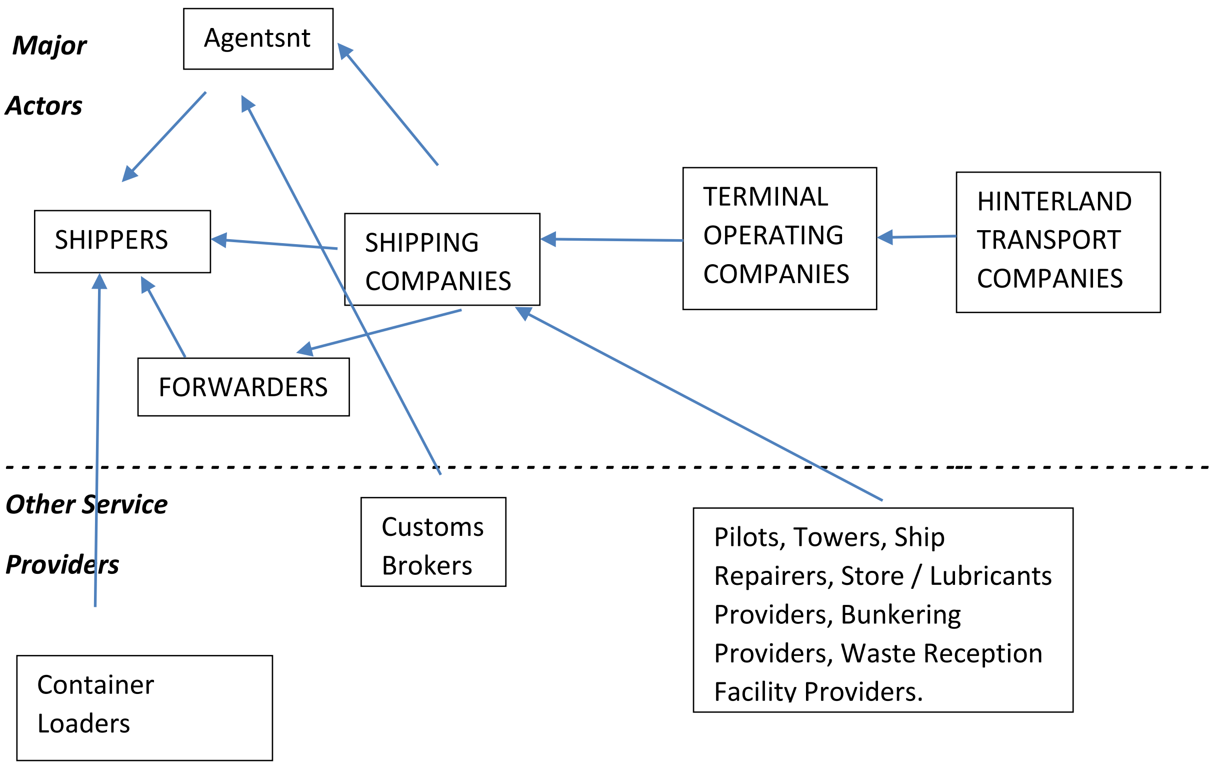


Figure Part 2 2.6.1 – Schematic of major players in port-related activities [Meersman, Van de Voorde and Vanelslander]

The large number of parties involved in port activities, each of which pursues its own objectives, gives rise to a considerable degree of diversity, both within the port and between ports. Hence, a generalised comparison between ports may not be fully possible. Moreover, the situation is further complicated by the fact that different ports often work under different economic, legal, social and tax regimes just because they are regarded as part of national entities in each country. Thus ports are to a large extent different from international shipping that is mostly regulated by IMO rather than by national-specific regulations that applies to ports [Hilde Meersman, et al].

The issues of governance, control and ownership are critical to any discussion of environmental management in ports. The vast majority of harbours are characterized by privately owned dock facilities and in these instances, control of property and operations lie with each private property owner.

Ports and air emissions

On the environmental side, one of the main issues that ports are facing is local air quality. This is caused due to air pollutants; rather the CO_2 emission that is the main topic of this training course. As most of activities relating to reduction of air pollutants have impacts on CO_2 emissions, in this module, the emphasis will be on all air emissions rather than simply CO_2.

In port areas, air emissions and energy consumptions are primarily due to ships. However, there are other equipment and facilities that use energy or contribute to air emissions to port areas. These are for example:

- Cargo loading and unloading devices.
- Trucks and other land-based transportation units such as locomotives.
- Buildings and energy needed for these building.
- Harbour crafts that provide additional services to port and shipping companies.

Emissions in port areas are mainly those due to diesel engines and boilers. These air emissions include:

- Nitrogen Oxides (NOx): The main sources of NOx are diesel engines both for ships and other land-based trucks.
- Particulate Matters (PM): Again diesel engines are the main source of such emissions.
- Sulphur Oxides (SOx): These are due to burning of sulphur content of fuel.
- Some carbon monoxide and unburned hydrocarbons could also be emitted from ship engines if they are not properly tuned.

The amount and level of such emissions will depend on not only technologies used but also operational aspects of ships, the time they stay in port and other energy using machinery and facilities in port itself.

Emission reductions in the port area are typically focused on PM, SOx and NOx due to air quality health impacts. Controlling NOx, PM and SOx is the central focus for most national and regional regulatory agencies and therefore the same applies for ports as does to the shipping industry. GHGs emissions have recently been seriously addressed by regulatory agencies such as IMO, although in the port area, health effects and thus pollutants typically take the priority over GHG emissions.

In a discussion paper by International Transport Forum [Olaf Merk], it is claimed that shipping emissions in ports are substantial, accounting for 18 million tonnes of CO2 emissions (this is equivalent to burning of about 6 million tonnes of fuel oil), 0.4 million tonnes of NOx, 0.2 million tonnes of SOx and 0.03 million tonnes of PM10 (PM with size of less than 10 microns) in 2011. Around 85% of emissions come from containerships and tankers. Containerships have short port stays, but high emissions during these stays.

The same paper states that most of CO2 emissions in ports from shipping are in Asia and Europe (58%), but this share is low compared to their share of port calls (70%). European ports have much less emissions of SOx (5%) and PM (7%) than their share of port calls (22%), which can be explained by the EU regulation to use low sulphur fuels at berth. Future forecasts indicate that most of shipping emissions in ports are estimated to grow fourfold up to 2050. This would bring CO2-emissions from ships in ports to approximately 70 million tonnes in 2050 and NOx-emissions up to 1.3 million tonnes. Asia and Africa will see the sharpest increases in emissions, due to strong port traffic growth and limited mitigation measures.

The above indicates that various initiatives are needed to combat air pollution in ports. These will be discussed in this module with specific reference on CO2 emissions. Various ports have developed infrastructure, regulation and incentives that mitigate shipping emissions in ports. These instruments would need wider application in order for ship emissions in ports to be significantly reduced.

2.7 Shipping Segments

There are large numbers of ways by which the shipping business may be categorised or classified. One obvious one is by ship types. Accordingly, the ships could be segmented into tanker, bulker, container, etc. There are other methods of the shipping segmentation, two of which are briefly described.

2.7.1 Ship segments by geography of operation

Shipping routes may be classified according to their geographical characteristics as deep-sea, short-sea, coastal and inland waterways. Due to economies of scale in shipping, larger size vessels are employed in deep-sea trades between continents whereas smaller size vessels usually operate in short-sea and coastal routes, where voyage legs are relatively short. For example, smaller containerships are used on short-sea routes that feed cargo to larger vessels that operate on long deep-sea routes (referred to as feeders). Due to draft restrictions, inland waterways are used mainly by barges. Barges are used to move cargoes between the inland and coastal areas; often for trans-shipments to/from ocean-going vessels or to move cargoes between inland ports.

2.7.2 Shipping segments by operation

There are generally three basic modes of operation of commercial ships:

• **Liner operations:** Liners operate according to a published itinerary and schedule similar to a bus line. The demand for their services depends among other things, on their schedules / itineraries. Liner operators usually control container and general cargo vessels. Cruise industry, although not referred to as liner operations, usually follow the same model of operation.

• **Tramp operations:** Tramp ships follow the available cargoes similar to a removal van. Often tramp ships engage in contracts of affreightment (see following pages for full description). These are contracts where specified quantities of cargo have to be carried between specified ports within a specific time frame for an agreed payment per unit of cargo. Tramp operators usually control part of tankers and dry bulk carriers segments. Both liner and tramp operators try to maximize their profits per time unit.

• **Industrial operations:** Industrial operators usually own the cargoes shipped and control the vessels used to ship them either as owner or as a charterer. Their vessels may be their own or on a time charter. Industrial operators aim to minimize the cost of shipping for their cargo transport but generally operate within a wider company business framework, thus their approach to ship management may be different from those of the liner or tramp operators. Industrial operations relate to high volume liquid and dry bulk trades for large integrated companies such as oil, chemicals and ores corporations.

In shipping and in cases of excess fleet capacity, vessels may be chartered out (to other operators), laid-up or even scrapped. However, when liners reduce their fleet size, they normally would reshuffle their itineraries / schedules, which may result in reduced service frequency or withdrawal from certain markets. Industrial operators, who are usually more risk-averse and tend not to charter-out their vessels, size their fleet below their long-term needs, and complement it by short-term (time or voyage/spot) charters from the tramp segment.

Seasonal variations in demand and uncertainties regarding level of future demand, freight rates and cost of vessels affect the fleet size decision. However, when the trade is highly specialised (e.g. LNG carriers), no tramp market exists and the industrial operator must assure sufficient shipping capacity through long-term commitments and contracts. The ease of entry into the maritime industry is manifested in the tramp market that is highly private market and entrepreneurial. This market condition results in occasional long periods of oversupply of shipping capacity. This then leads to the associated depressed freight rates and vessel prices. However, certain market segments such as container lines pose large economies of scale and are hard to enter by the smaller players.

2.8 Ship/Fleet Planning

Ship / fleet planning problems are relatively complex as ships operate under a variety of operational conditions such as:

- A ship operates mostly in international trades which mean that they are crossing multiple national jurisdictions, with their own relevant issues.
- A ship represents a large capital investment that translates into high daily costs of capital, fuel costs, port dues, etc. Thus, it cannot remain idle and must be busy earning on a continuous basis.
- Ships have higher uncertainty in their operations due to their higher dependence on weather conditions and their operation in multiple jurisdictions and various ports.
- Although shipping may look to be the least regulated mode of transportation, there are significant legal, political, regulatory and economic aspects involved in maritime transportation.

Maritime transportation planning problems can be classified in the traditional manner according to the planning horizon into business, commercial and operational decision making levels.

2.8.1 Business planning

At the business level, aspects that relate to overall industry structure, status and future are being considered. These are cases such as:

- Market and trade selection,
- Network and transportation system design (including trans-shipment points),
- Fleet size and fleet mix decisions (type, size, and number of vessels),
- Port/terminal location, size, and design.
- Ship design and choice of ship technology.

The business planning aspect of shipping is not of direct interest in this course. At the commercial levels, most of topics of interest are more relevant and includes for example aspects such as:

- Fleet deployment (assignment of specific vessels to various trade routes),
- Ship routing and scheduling,
- Port and berth scheduling,
- Cargo operation scheduling,

At the operational level, operation management is conducted to optimally achieve the commercial requirements. These include for example:

- Voyage planning
- Ship speed selection and adjustments
- Ship loading operations
- Ship environmental/weather routing

Business decisions are long-term decisions that set the stage for commercial and operational ones. In maritime transportation business (strategic) decisions cover a wide spectrum, from the design of the transportation services to accepting long-term contracts. Most of the strategic decisions are on the supply side and these are: market selection, fleet size and mix, transportation system/service network design, maritime supply chain/maritime logistic system design and ship design. The above decisions are based on operational information and use of a variety of models.

Choice of ship size

The ship design covers a large variety of topics that are addressed by naval architects and marine engineers. They include structural and stability issues, materials, on-board mechanical and electrical systems, cargo handling equipment, and many others. Some of these issues have direct impact on the ship's commercial viability. Obvious examples for GHG emissions reduction purposes are decision making on ship size and ship speed.

The question of the optimal size of a ship arises when one tries to determine what is the best ship for a specific trade? The optimal ship size is the one that minimizes the ship operator's cost per ton of cargo on a specific trade route with a specified cargo mix; within all regulatory constraints. However, one should realize that in certain situations, factors beyond costs may dictate the choice of the ship size.

Significant economies of scale exist at sea (i.e. use of larger vessels); where the cost per cargo ton-mile decreases with increasing the ship size. These economies stem from the capital costs of the ship (design, construction, and financing costs), from fuel consumption, and from the operating costs (crew cost, supplies, insurance, and repairs). These costs per unit of cargo transport tend to reduce as the ship size increases.

However, at port the picture is different and may not be in favour of economies of scale. Loading and unloading rates are usually determined by the land-side cargo handling equipment and available storage space. Depending on the type of cargo and whether the cargo handling is done by the land-side equipment or by the equipment on the ship (e.g., pumps, cranes), the cargo handling rate may be constant (i.e. does not depend on the size of the ship), or, for dry cargo where multiple cranes can work in parallel, the cargo handling rate may be approximately proportional to the length of the ship. Since the size of the ship is determined by its length, width, and draft, and since the proportions among these three dimensions are practically almost constant, the size of the ship is approximately proportional to the third power of its length. Therefore, in the better case, cargo-handling rates will increase proportional to the one-third power of the ship size. However, when the cargo is liquid bulk (e.g., oil) the cargo-handling rate may not be related to the size of the ship.

A ship represents a large capital investment that translates into a large cost per day. Port time is expensive and presents dis-incentives for large ship scales. Thus the time of port operations may cap the optimal size of ship. Generally, the longer a trade route is, the larger the share of sea-days in a voyage, then the larger the optimal ship size will be. Other factors that affect the optimal ship size are the utilization of ship capacity at sea, loading and unloading rates at the ports, and the various costs associated with the ship. On certain routes there may be additional considerations that affect the size of the ship, such as required frequency of service and availability of cargo.

Thus, the optimal ship size is a long-term decision that must be based on expectations regarding future market conditions. During the life of a ship, a lot of market volatility may be encountered. Freight rates may fluctuate over a wide range and the same is true for the cost of a ship. When freight rates are depressed, they may not even cover the variable operating costs of the ship, and the owner has very few alternatives. In the short run the owner may either reduce the daily variable operating cost of the ship by slow steaming, that results in significant reduction in fuel consumption, or the owner may layup the ship till the market improves.

Laying up a ship involves a significant set-up cost to put the ship into layup, and, eventually, to bring it back into service. However, laying up a ship significantly reduces its daily variable operating cost. When the market is depressed, owners scrap older ships. The value of a scrapped ship is determined by the weight of its steel (the "lightweight" of the ship), but when there is high supply of ships for scrap the price paid per ton of scrap drops.

In the shorter run, ship size may be limited by parameters of the specific trade, such as availability of cargoes, required frequency of service, physical limitations of port facilities such as ship draft, length, or width, and available cargo handling equipment and cargo storage capacity in the ports. In the longer run, many of these limitations can be relaxed if there is an economic justification to do so. In addition there are limitations of ship design and construction technology, as well as channel restrictions in canals in the selected trade routes.

Modern cargo handling equipment that is customized for the specific cargo results in higher loading and unloading rates, and shorter port calls. Such equipment is justified where there is a high volume of cargo. That is usually the case in major bulk trades; under such circumstances the optimal ship size becomes very large, far beyond the capacity of existing port facilities. In addition, with such large ships the frequency of shipments drops to a point where inventory carrying costs incurred by the shipper start playing a significant role. When one includes the inventory costs in the determination of the optimal ship size, that size is reduced significantly. The resulting ship sizes are still much larger than existing port facilities can accommodate, and thus the main limit on ship sizes is the draft limitation of ports. However, for a higher value cargo or for less efficient port operations, smaller vessel sizes are optimal. In short-sea operations, competition with other modes may play a significant role. In order to compete with other modes of transportation more frequent service may be necessary. In such cases frequency and speed of service combined with cargo availability may be a determining factor in selecting the ship size.

Fleet size and mix

One of the main strategic issues for shipping companies is the choice of an optimal fleet. This deals with both the type of ships to include in the fleet, their sizes and the number of ships of each size.

In order to support decisions concerning the optimal fleet of ships for an operator, very often include routing decisions. The objective of the strategic fleet size and ship mix problem is usually to minimize the fixed capital costs of the ships needed and the variable operating costs of these ships when in operation. In a commercial routing and scheduling problem, one usually minimizes only the operating costs of the ships. However, at the business (strategic) decision making level, the routing decisions and minimisation of operating costs is combined with minimization of the capital costs needed for the fleet.

Additionally, the fleet size and mix decisions have to be based on an estimate of demand for the transportation services. This need to be included in decision making model despite the fact that the demand forecast is highly uncertain.

2.8.2 Commercial planning

The commercial planning is concentrated on medium-term decisions and the focus of this level in maritime fleet operation is primarily on optimal routing and scheduling. In industrial shipping the cargo owner or shipper normally controls the ships' operations. Industrial operators try to ship all their cargoes at minimum cost. A tramp shipping company, on the other hand, may have a certain amount of contract cargoes that it is committed to carry and tries to maximize the profit from optional cargoes. During the last decades, there has been a shift from industrial to tramp shipping. Perhaps the main reason is that many cargo owners are now focusing on their core business and have outsourced other activities like transportation to independent shipping companies. From the shipper's perspective, this outsourcing has resulted in reduced risk.

Liner shipping differs significantly from the other two types of shipping operations; i.e. tramp and industrial. However, the liner shipping involves significant commercial decisions at different planning levels. The differences among the types of shipping operations are also manifested when it comes to routing and scheduling issues. One main issue for liners on the commercial planning level is the assignment of vessels to established routes or lines; this is referred to as "fleet deployment".

A focus on a fleet deployment problem where the shipping company utilize the different cruising speeds of the ships in the fleet is important. The routes are pre-defined, and each route will be sailed by one or more ships several times during the planning period. Each route has a defined common starting and ending port. A round-trip along the route from the starting port is called a voyage.

The demand is given as a required number of voyages on each route without any explicit reference to the quantities shipped. The fleet of ships is heterogeneous and it can be assumed that not all ships can sail all routes. Such a specification can incorporate needed ship capacity together with compatibilities between ships and ports. With information about the feasible ship-route combinations and the company's fleet mix, the relevant decisions on fleet deployment are taken. Of course, minimisation of cost and maximisation of profits is one main factor; however and in particular for liner operators, minimisation of fuel cost and thus reduction of fleet CO_2 emissions becomes an important decision making aspect at this level.

2.8.3 Routine (operation) planning

When the uncertainty in the operational environment is high and the situation is dynamic, or when decisions have only short-term impact, one resorts to short-term operational planning. This could happen in part of the tramp shipping segment that requires routine day to day decision making on best method of fleet deployment.

In certain circumstances, it is not practical to schedule ships beyond a single voyage. This happens when there is significant uncertainty in the supply of the product to be shipped, or in the demand for the product in the destination markets. The shipped product may be seasonal and its demand and supply may be affected by the weather. These factors contribute to the uncertainty in the shipping schedule. The shipper has to assure sufficient shipping capacity in advance of the shipping season, but does not know in advance the exact timing, quantities and destinations of the shipments. The shipper normally does not have return cargoes for the ships, so the ships are hired under contracts of affreightment or spot charters and generally do not return to load for a second voyage.

Based on product availability, demand projections, inventory at the markets and transit times, the shipper builds a shipping plan for the short term and has to decide to assign the planned shipments to the available fleet at minimal cost.

2.8.4 Speed selection and cruising speed

A ship can operate at a speed slower than its design speed and thus significantly reduce its fuel costs (see for example slow steaming in subsequent sections). However, a ship must maintain a minimal speed to assure proper steerage and safe operation of main engine, etc. For most cargo vessels the bunker fuel consumption per time unit is approximately proportional to the third power of the speed (the consumption per distance unit is proportional to the second power of the speed). Thus, reducing the speed by 20% reduces the fuel consumption (per time unit) by about 36%.

When bunker fuel prices are high the cost of bunker fuel may exceed all other operating costs of the ship. Thus there may be a strong incentive to steam at slower speed and reduce the operating costs. A fleet operator that controls excess capacity (e.g. line operators), can reduce the speed of the vessels and thus reduce the effective capacity of the fleet, instead of laying-up, chartering-out or selling vessels.

Often cruising speed decisions may be an inherent part of such fleet scheduling / planning decisions. Cruising speed decisions affect both the effective capacity of the fleet and its operating costs. Under a contract of affreightment, a ship operator commits to carry specified amounts of cargo between specified loading port(s) and unloading port(s) at a specific rate over a specific period of time for an agreed upon revenue per delivered unit of cargo.

The term fleet deployment is usually used for ship scheduling problems associated with liners as discussed earlier. In such cases and because the vessels are essentially assigned to routes that they will follow repeatedly; the deployment decisions (including speeds) are medium to longer term decisions. On the other hand, tramp and industrial operators usually face shorter term ship scheduling problems. A set of cargoes has to be carried by the available fleet, and if the fleet has insufficient capacity, some cargoes may be contracted out. The cruising speed of the vessels in the available fleet can be an important factor in fleet scheduling decisions.

In addition to cost and schedules, short-term cruising speed decisions should take into account also the impact of the destination port operating times. If the destination port is closed over the weekend (or at night) there is no point arriving there before the port opens. Thus reducing the cruising speed and saving fuel makes sense. In the case where cargo-handling operations of a vessel that started when the port was open continue until the vessel is finished, even after the port closes, it may be worthwhile to speed up and arrive at the destination port to start operations before it closes. There are a variety of tactics that may be used to take advantage of more appropriate vessel scheduling.

Voyage management: Voyage management refers to all ship management activities that lead to the optimal planning and execution of a voyage. To ensure best-practice voyage management, all aspects of planning, execution, monitoring and review of a voyage are included in this concept.

2.9 Maintenance Management

Numerous mechanical and electrical systems are installed on board a ship and they require maintenance. Proper maintenance of a ship has significant impact on overall technical performance and energy efficiency of the vessel.

A ship is usually scheduled once a year for maintenance in a port or a shipyard, and once every few years a ship is surveyed by its classification society in a shipyard. However, some maintenance is required between such planned maintenance periods. This includes both routine/preventive maintenance and repair of breakdowns (at least temporary repair until the ship reaches the next port). On-board maintenance is usually done by the crew, but the shrinking size of crews reduces the availability of the crew for maintenance work. A large ship may have less than two dozen seamen on board, and that includes the captain and the caterers. This limited crew operates the ship around the clock.

In order to facilitate maintenance, a ship must carry spare parts on board. The amount of spare parts is determined by the frequency of port calls and whether spares and equipment are available in these ports. Large and expensive spares that cannot be shipped by air, such as a propeller, may pose a special problem and may have to be prepositioned at a port or carried on board the vessel.

Ship maintenance operations and management are fundamental for energy efficient operation of its machineries and systems. Deterioration of ship systems' condition takes place due to normal wear and tear, fouling, miss-adjustments, long periods of operation outside design envelopes, etc. As a consequence equipment downtime, quality problems, energy losses, safety hazards or environmental pollution may result. The end outcome is a negative impact on the operating cost, profitability, customer satisfaction and probable negative environmental impacts. Thus good maintenance is in line with good performance and energy efficiency.

To facilitate good ship maintenance despite the lowering number of crews over time, decision support tools for condition monitoring are frequently used. Also, third party maintenance contracts could be made so that external specialised organisations look after important ship-board assets (e.g. engines). The increase in data communication between ship and shore is an enabling technology to provide support to ship-board staff by the shoe-based staff.

The planned maintenance is organised based on makers prescribed maintenance frequency and a set amount of spares is supplied to vessel prior to the scheduled maintenance date. A computer operated maintenance database is maintained on board and in the shore office synchronised to upkeep all the maintenance info and spare parts availability etc. including maintenance procedure.

The breakdown maintenance is performed upon failure of a component or a machinery. Though this procedure is cost saving but in the long run it may pose the vessel to undue delays and uncertainty of the schedule.

The Condition monitoring is another kind of diagnosis system of the machineries by which a decision may be made if a maintenance should be carried out by feeling its' running condition eg. Vibration, load current, operation temperature etc. This is a cost saving procedure in respect to planned maintenance, and a maintenance requirement is assumed prior to a breakdown, however, the condition monitoring requires very highly skilled engineers to diagnose a fault.

2.10 Bunker Procurement

A ship may consume hundreds of tons of bunker fuel per day at sea and there may be significant differences in the cost of bunker fuel among bunkering ports. Thus one has to decide where to buy bunker fuel. Sometimes it may be worthwhile to divert the ship to enter a port just for loading bunker fuel. The additional cost of the ship's time has to be traded off with the savings in the cost of the fuel. Bunker procurement is overall a commercial decision making process but nevertheless it has large implications for routine operation decision making as well. Additional cost of ship diversion may not occasionally come into perspective due to split-incentive issues relating to who pays for what when it comes to ship costs. Bunker procurement not only involves operational considerations but also technical considerations.

Due to the increasing fuel price shipping businesses normally use Heavy Fuel Oil (HFO) that is of lowest quality and the cheapest in price amongst marine fuels and could be of poor quality if care is not exercised during procurement and use. Control of quality and quantity of fuels purchased and also on-board fuel treatment can provide significant benefits for safeguarding the machinery from damage but also in terms of energy efficiency.

For the optimum energy gain from a certain grade of fuel it has to be treated with appropriate chemical compound to improve its' combustion quality. For appropriate atomisation of the fuel it needs proper viscosity prior to injection to the combustion chamber. The viscosity is directly related to fuel temperature, therefore, it is of utmost importance to determine the injection temperature for that grade of fuel. This can be achieved either from the bunker delivery note or by lab test of the fuel.

2.11 Reference and further reading

1. IMO Train the Trainer (TTT) Course on Energy Efficient Ship Operation [Viewed on 29th Oct 2016]

Available from http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/IMO-Train-the-Trainer-Course.aspx

Part 3

2. Ship-Board Energy Efficiency Measures

2.1 Introduction

The energy efficiency measures relating to ship's operation/commercial management have been widely argued and shown that these kinds of measures are not fully under the control of ship staff, thus the issue of communication and coordination between ship, shore office, charterer, shipper, etc. are under consideration to manage the ship's operation energy efficiently.

For a complete success in energy efficiency management, measures have to be taken to a large extend and primarily to the hands and under the control of the ship-board staff (although not all of them by 100%). They could be the subject of ship's in-passage activities for energy efficiency. An overview of major aspects of shipboard activities that impacts the ship's fuel consumption coming under this category are briefly introduced first and then fully described in other sections of this chapter.

2.2 Optimised Ship Handling

Optimum trim: Most ships are designed to carry a designated amount of cargo at a certain speed for certain fuel consumption. The same applies to ballast operations. Whether loaded and unloaded, for such conditions, normally there exists a ship trim that minimises the propulsion power, thus main engines' fuel consumption. In fact, for any given draft there is one optimum trim that gives minimum ship resistances. In some ships, it is possible to assess optimum trim conditions for fuel efficiency continuously throughout the voyage. Setting the ship trim is to a large extent in the hand of shipboard staff although loading, operational and navigational constraints may limit the full extent of proper use of this energy efficiency measure.

Optimum ballast: Ships normally carry ballast water to ensure ship's stability and safety. Normally, ballast levels should be adjusted taking into account the requirements to meet ship stability, steering aspects of the ship and optimum trim. This does not necessarily mean carrying lots of ballast water all the time. This unnecessarily increases the ship displacement that directly increases fuel consumption. Thus there is an optimum ballast condition that needs to be achieved through good cargo planning as well as voyage planning. Therefore optimising the ballast levels for energy efficiency within the framework of ship stability, safety, steer-ability and optimum trim can be regarded as an energy efficiency measure.

Optimum use of rudder and autopilot: There have been large improvements in automated heading and steering control systems technologies. Whilst originally developed to make the bridge team more effective, modern autopilots can achieve much more. An integrated navigation system can achieve significant fuel savings by simply reducing the distance sailed "off track". The principle is simple; better course control through less frequent and smaller corrections will minimize losses due to rudder resistance. In some cases, retrofitting of a more efficient autopilot to existing ships could be considered.

2.3 Optimised Propulsion Condition

Hull maintenance: Hull fouling always happens in ships. The rate of hull fouling will depend on a number of factors such as quality of paint, ship service speed, periods of idle /waiting and ship geographical area of operation. Hull resistance can be optimized by new advanced coating systems, possibly in combination with hull cleaning at certain intervals. Regular in-water inspection of the condition of the hull is recommended. Consideration may be given to the possibility of timely full removal and replacement of underwater paint systems to avoid the increased hull roughness caused by repeated spot blasting and repairs over multiple dry dockings.

Propeller cleaning: Propeller cleaning and polishing or even appropriate coating may significantly increase fuel efficiency. The need for ships to maintain efficiency through in-water hull and propeller cleaning should be recognized and facilitated by port States.

Main engine maintenance: Marine diesel engines have a very high thermal efficiency (~50%). This is the best efficiently currently available on the market and is the main reason why diesel engines are unrivalled in shipping. The high efficiency is due to the systematic minimisation of heat and mechanical loss of such engines and improved performance parameters that has taken place over many decades. In particular, the new breed of electronic controlled engines can provide efficiency gains with wider flexibility for example for slow steaming. To keep these engines in optimal condition and performance, they need to continuously undergo on-board condition and performance monitoring. Maintenance in accordance with manufacturers' instructions in the company's planned maintenance schedule will also maintain efficiency. The use of engine's condition monitoring can be a useful tool to maintain high efficiency.

2.4 Boilers and Steam System

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 6.4.1 shows typical level of fuel use in boilers as compared to main and auxiliary engines for a VLCC vessel.

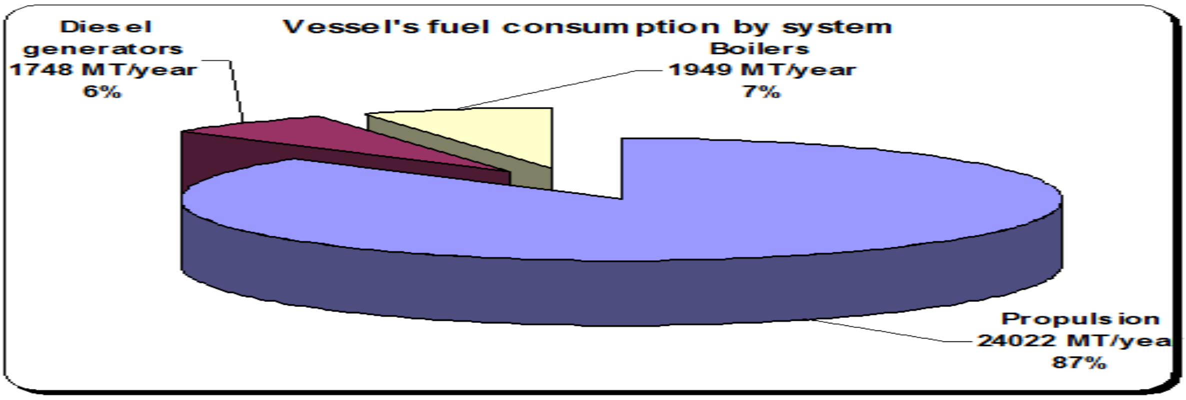


Figure Part 3 2.4.1 – Overall annual fuel consumption and boiler share [Bazari 2012]

In some ship types, boilers and steam are using significant amount of energy for either propulsion turbines or for other auxiliary services such as operation of cargo and ballast pumps, cargo heating, fuel oil treatment and conditions and so on.

Figure Part 3 2.4.2 from IMO 3rd GHG Study 2014 also reveals the level of energy use in marine boilers for the whole of international fleet.

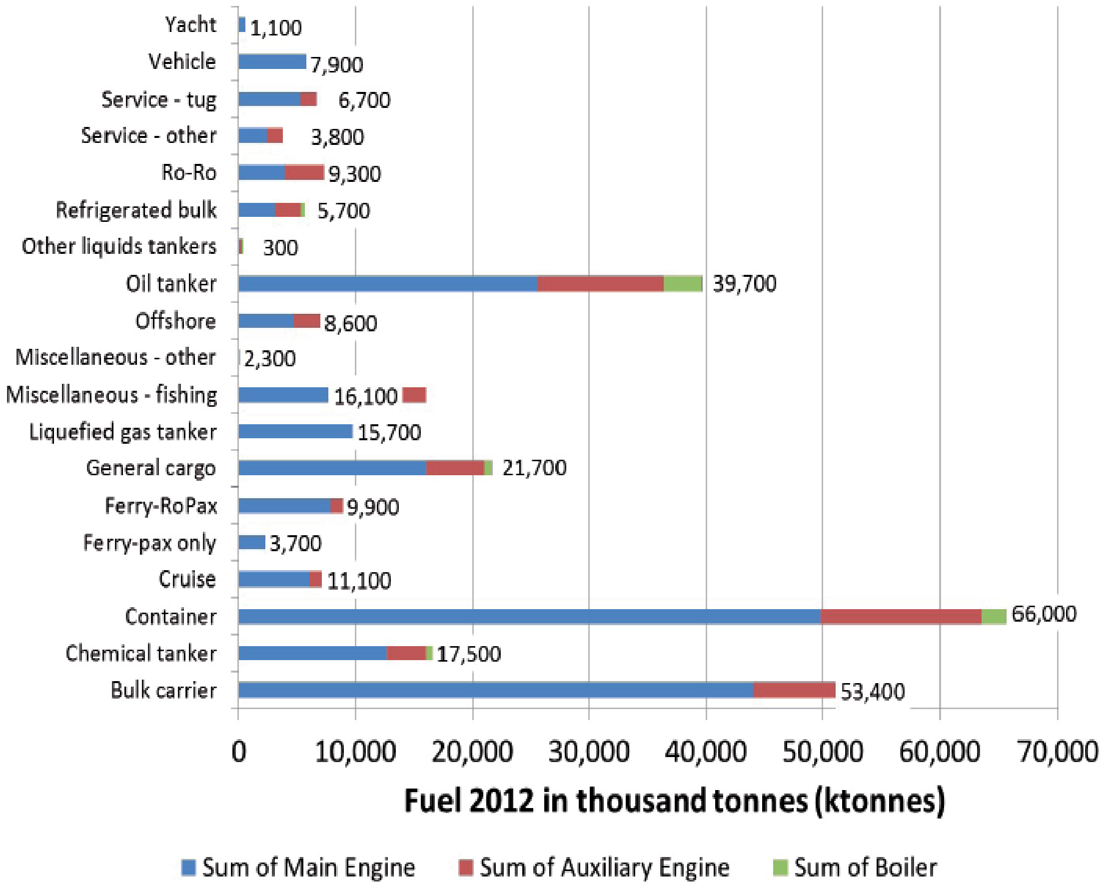


Figure Part 3 2.4.2 - Annual shipping fuel consumption per ship type and combustion system [Third IMO GHG Study 2014]

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.

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 6.4.3 shows a typical steam system for a ship.

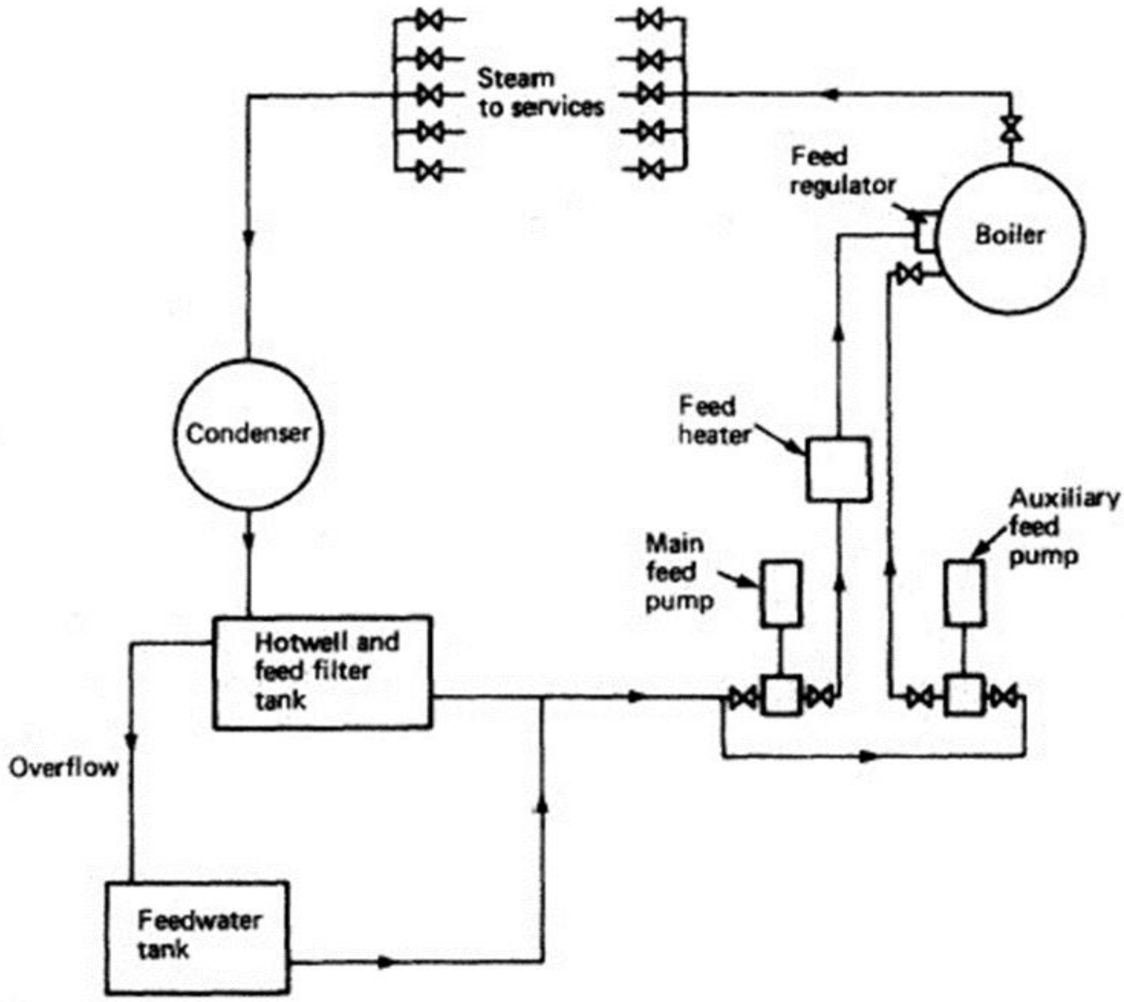


Figure Part 3 2.4.3 – A typical auxiliary boiler steam system configuration [Machinery Spaces.com]

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.

Boiler energy efficiency measures:

Figure 6.4.4 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.

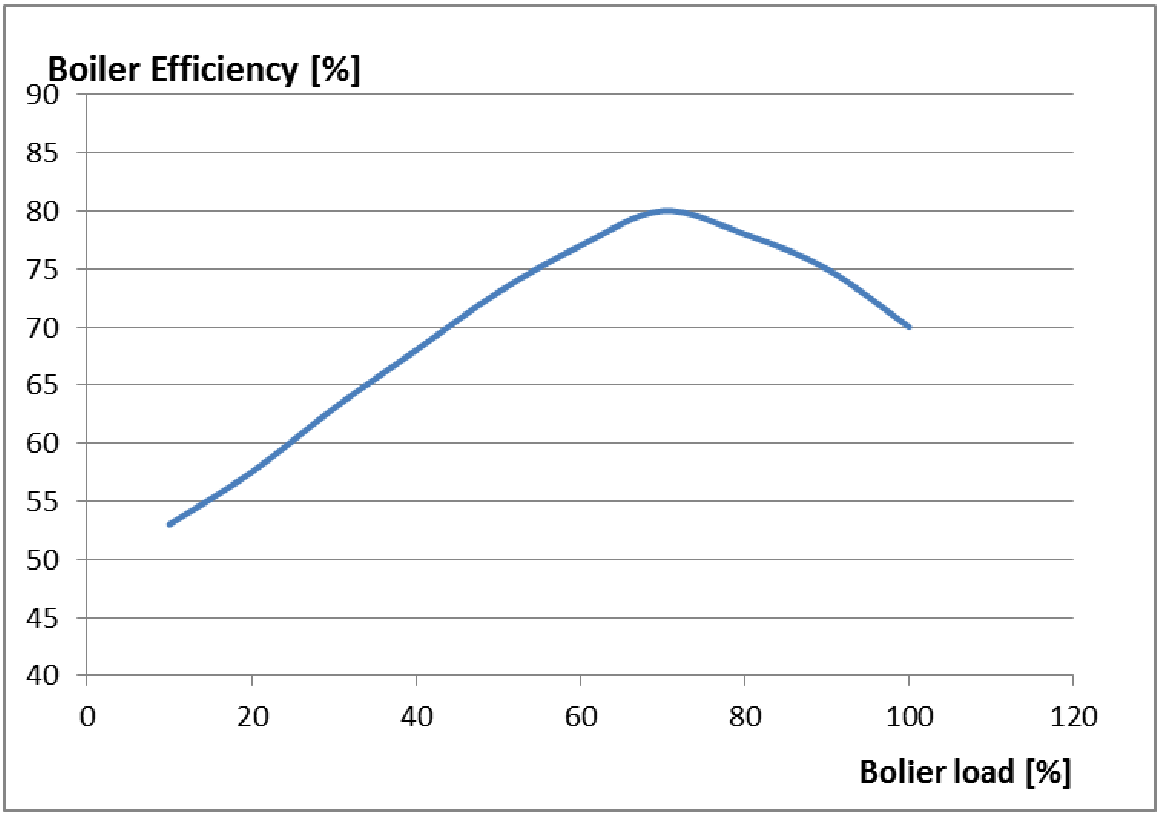


Figure Part 3 2.4.4 – Boiler efficiency characteristics

In operation, the efficiency tends to be lower than the above design values. There are 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 Part 3 2.4.4

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.

Optimum hot well temperature and blow-down levels:

There is a hot well 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 steam generation. 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.

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 Part 3 2.4.5 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.

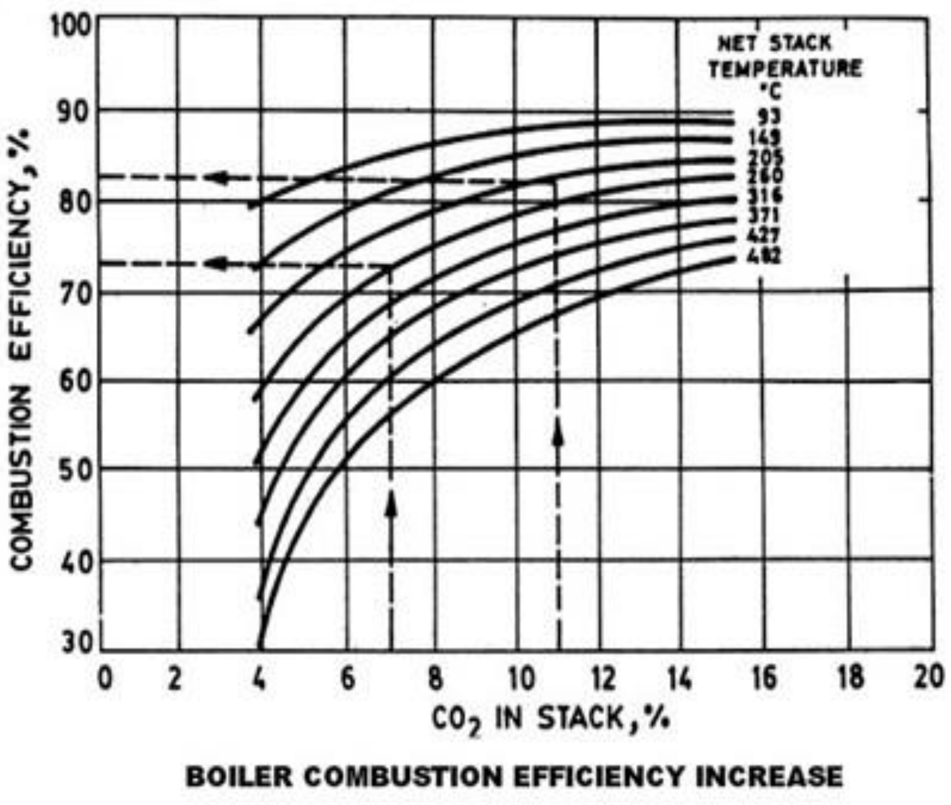


Figure Part 3 2.4.5 – Boiler efficiency as a function of CO_2 level in the exhaust gas [Mohit Sanguri]

Exhaust gas economiser efficiency:

The Exhaust gas economiser in a ship is like a huge heat exchanger 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^o to 195^{o}C when using fuel oil is considered optimum.

Boiler efficiency and load factor:

Like any other devices, the boiler energy efficiency is a factor of its load factor. Figure Part 3 2.4.4 shows typical such efficiencies.

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 Part 3 2.4.4 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.

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.

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.

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 enroute 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°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°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 10.8 shows a typical cargo heating patterns graph. Figure 10.8 - 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.

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.

Inert Gas Generation (IGG):

In various type 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 O2 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.

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 minimised.
- 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.

2.5 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. Mohit Sanguri, "Energy Conservation in Boilers and Making an Audit Report"

http://www.marineinsight.com/marine/marine-news/headline/energy-conservation-inboilers-and-making-an-audit-report/

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2. Bazari Z, 2012, "Ship Energy Efficiency – Developments and Lessons Learnt", Lloyd's Register, LRTA publication, November 2012. Viewed 1st Nov 2016.

3. Machinery Spaces.com "Feed systems for auxiliary boilers and steam turbines – operating principle", http://www.machineryspaces.com/feed-system.html, Viewed 1st Nov 2016.

4. Carbon Trust, 2012, "Steam and high temperature hot water boilers", Carbon Trust UK Publication, 2012. Viewed 1st Nov 2016.

5. Alfa Laval, "Efficiency in boilers and beyond",

http://www.alfalaval.com/globalassets/documents/industries/marine-andtransportation/marine/whr.pdf,

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6. "IMO train the trainer course material", developed by WMU, 2013. Viewed on 2nd Nov, 2016.

7. OCIMF 2011, "Example of a Ship Energy Efficiency Management Plan", submitted to IMO by Oil Companies International Marine Forum (OCIMF), MEPC 62/INF.10, April 2011. Viewed on 2nd

Nov, 2016.