JMR

Journal of Maritime Research, Vol. VIII. No. 2, pp. 3-12, 2011

ISSN: 1697-4840

STUDY OF POSSIBILITIES OF USING A STEAM PLANT TYPE "REHEAT" AND MIXED BOILERS OF COAL AND FUEL-OIL FOR THE PROPULSION OF BULKCARRIERS

C. Rodríguez[1,2], **F. Antelo** [1,3], **A. De Miguel**[1,4] and **J. Carbia**[1,5]

Received 30 July 2010; in revised form 15 August 2010; accepted 01 May 2011

ABSTRACT

This study aims to analyze the possibilities of using a steam turbine plant for propulsion of vessels for transporting coal; and they use the coal carried by themselves as fuel to propulsion system. The study analyze the operating cost of this system using as reference the crude oil prize because tha t is an international economic reference and the most merchant ships use heavy fuel oil as fuel for their propulsion.

Key words: Coal, steam turbine, reheated cycle, regeneration stages.

INTRODUCTION

One of the parameters that affect a greater or lesser extent, to determine the viability of propulsion plant are fixed operating costs, with fuel costs being one of the most important. So great may be its importance, depending on the type of vessel concerned, that a price increase might conflict with the possibility of operating in a competitive way (Economía y globalización, 2009). It is therefore essential to investigate how to reduce these costs when defining a project.

The marine fuel price is directly and proportionally linked to the crude oil price. Until 1973, the fuel cost was minimal and therefore the vessels did not have big ener-

[1] Universidade da Coruña, Paseo de Ronda, 51, 15011 A Coruña, Spain. [2] Doctoral student in the department "Enerxía e propulsión mariña". Email: carlosrv27@terra.es. Tel. 622297294. 3University professor in "Escuela técnica e superior de náutica e máquinas". Email: fantelog@udc.es. Tel. 686485685-4239. [4] Doctoral student in the department "Enerxía e propulsión mariña". Email: alberto.demiguel@udc.es Tel. 622247616-4316. [5] University profesor in "Escuela técnica e superior de náutica e máquinas". Email: carbia@udc.es. Tel. 615117572-4314.

gy-saving provisions. It was to achieve the engine power and operation simplicity and easy and cheap maintenance, rather than thermal and economic efficiency. Steam turbines were used in few stages, boilers without economizers, diesel engines burning marine diesel oil, designed with short strokes, simple turbochargers, and even non-supercharged engines, deck machinery working with steam, turbogenerators (Gourgoulis, 2010) also and a wide range of low energy efficiency equipment. Rising crude oil prices of the seventies led to the rapid abandonment of these systems onboard ships (see fig. 1).

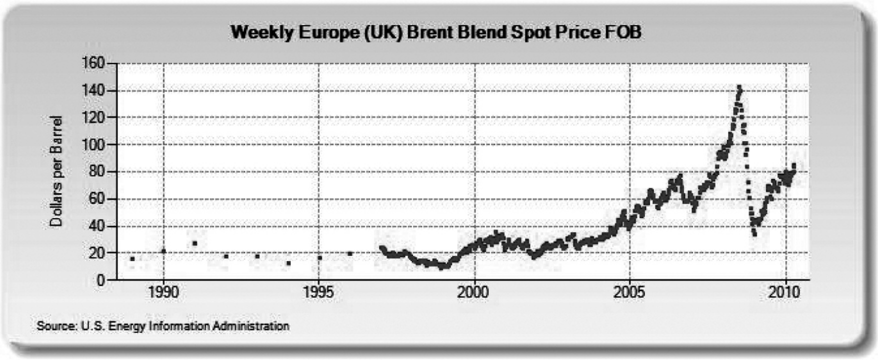

Fig. 1. The evolution of crude oil prices.

At the end of the seventies there was a fever of fuel saving in the main shipping companies in the world. With huge investments, the propulsion turbines were changed and replaced by diesel engines in many large container ships, some tankers, as well as some landmarks cruise ships such as the *Queen Elizabeth 2*. Many vessels powered by steam turbine were scrapped in advance and thereafter the tanker powered by diesel engines devoted in front of the steam engine.

In Spain, at the beginning of the eighties, an interesting experiment was made; two *Suezmax* tankers were cut and two *Capesize* bulk carriers too by the stern zone, then joining the stern of the steam-tankers in the bow of bulk carrier converted into bulk carriers to carry coal, with boilers that burst coal, coal carried by the ship. While the bulk carriers with diesel engine sterns were adequate to meet the maritime rules and regulations at that time and also pump chamber were renovated a segregated ballast tanks were installed (see fig. 2).

Currently, the thermal efficiency of a diesel engine is much greater than that obtained with a steam turbine cycle (Turbine cycle information, 2009). However, the engines are not able to consume solid fuels such as coal, which is cheaper than crude oil products and it has a more stable price (also the estimated reserves of both fuels are very different with a view to long-term future (Fossil fuel information, 2009)). That is why a ship using coal as fuel could be profitable today, and with opportunities to

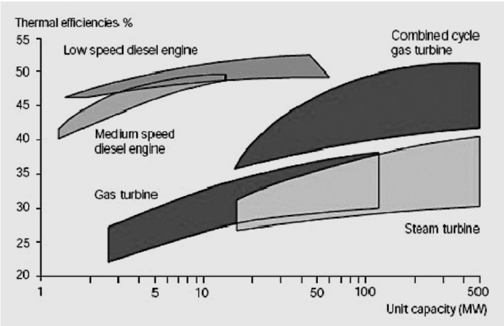

Fig. 2. Different vessels powered system with its efficiencies (MAN Diesel & Turbo).

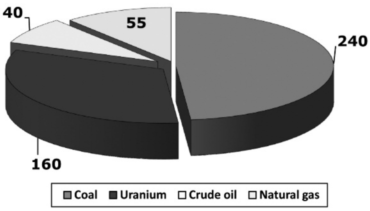

Fig. 3. Estimated years of each fossil fuel reserves.

improve their profitability in the future if crude oil prices continue to rise.

A suitable vessel for installing the propulsion steam turbines using coal as fuel would be a bulk carrier type Capesize for transporting coal, which would use part of the cargo as fuel (see fig. 3).

CURRENT STATUS

With regard to merchant vessels with engines of power ratings above 15,000 kW, the two-stroke diesel engine is used almost always and no other alternatives being considered.

Although the steam turbine is very reliable and requires almost no maintenance, it depends on boilers which need regular maintenance; usually double boilers are installed to improve reliability.

However, the thermal efficiency of this type of system is about 30%. In contrast, other alternatives such as internal combustion engines have efficiencies of 45% to 50%, which make them, therefore, in a huge opportunity to save fuel by changing the propulsion system. Despite this difference, the system of steam turbine propulsion remained the preferred solution for its reliability, and L.N.G. vessels are among the larger ones that still employ this form of propulsion.

The type of propulsion plant also influences, as gas turbines and steam are generally used to operate at near maximum power, while diesel engines should not be used to operate at over 90% of rated power. For this reason, the maximum continuous power installed on a ship with diesel powered exceeds that of other similar vessels but with steam turbine powered. The engine operating area often coincides with the lowest specific fuel consumption. In addition, the projection for the service life of components, recommendations for surveys and maintenance and service intervals are usually based on operation area.

The largest engine rooms are the slow diesel engine, but its large space makes up that they be directly coupled to the propeller without reduction gears. The engine room with steam turbines are also very voluminous, especially if it is compared the diesel engines and steam turbines engines room to small propulsion power. For this reason they are especially interesting for high power, over the range of diesel power.

The steam plant can improve its efficiency through the cycle with reheat and regeneration. The steam turbine plants are generally optimized for a given power and as a result, its power ranges are usually close to their design capabilities (in practice there is no limitation to the maximum power of steam turbines, as it happens with diesel engines). The steam is generally obtained through boilers with burners, which can consume the worst quality fuel oil (natural gas can also be used). With the low fuel prices and lower consumption of lubricating oil, for a time it was possible to compensate its worst specific consumption compared to other types of propulsion plants.

Slow diesel engines have the highest thermal efficiencies, but it seems they are reaching the limits of evolution and improvements are not expected. Slow diesel engines are specifically designed for vessel propulsion and are more tolerant of low quality of heavy fuel oil than the medium speed engines (normally 4 strokes). Their qualities of economy are quite competitive and their simplicity facilitates automation. The maintenance costs are lower than in medium-speed diesel engines. The specific fuel consumption is also better in the slow diesel engines and residual heat is more readily usable.

PLANT COST

Bear in mind that when making the selection of the propulsion machinery, three types of costs should be evaluated: initial costs (price of the plant, installation costs, etc.), variable costs (fuel, maintenance, crew...) potential costs (derived from the reliability and availability expected).

In general, in a merchant ship the operating costs (fuel costs, crew and maintenance required) are the primary consideration when evaluating the candidates to select the propulsion plant, while the initial costs have a relative importance.

Under this, the most common types of plants used in the propulsion of merchant ships are:

- Slow diesel engines, are those with the highest price.
- Steam plants have a high cost for low powers, but they are more profitable when the power is higher

STEAM POWER PLANTS IN VESSELS

The steam turbine plant still has advantages in certain areas such as marine propulsion system, but its main weakness is that its overall efficiency is relatively low.

Mitsubishi Heavy industries ltd "MHI"has proposed a reheat turbine plant, "UST plant" (Ultra steam turbine information, 2009), in that the global efficiency is improved over 15% compared to conventional steam turbine plant, "CST plant," and can rival with diesel propulsion systems "DFE / DRL" in the total plant cost, including in this cost the sum of the initial costs, operating costs and maintenance costs.

The main points of difference between the plants "UST" and "CST" are:

- Implementation of reheating of the steam.
- The application of higher pressure and higher temperature of steam.
- The introduction of the latest technologies to improve the internal efficiency of the turbines.

The success of the plant depends mainly on the group UST turbine propulsion with reheated steam (UST turbine). The group is composed of a high pressure turbine, intermediate pressure turbine and low pressure turbine with an astern turbine incorporated in the casing of the low pressure turbine. The group will be arranged to drive the propeller through a gearbox and tail shaft line.

KEY FEATURES OF UST TURBINES

The most significant feature of the UST turbine is the remarkable improvement of efficiency that can be achieved with adequate security in all the modes of operation considered. The high reliability, easy maintenance, and operation are kept the same as in conventional CST plant.

The main features including those listed above are:

- **Security**. Superior creep resistance, no leaks of steam in the flanges and joints.
- **Quality of life**. Low vibration noise.
- **Maintenance**. No consumable parts, extremely low maintenance costs, easy refurbishment.
- **Lifetime**. Robust design with large safety margins, with a long life expectancy.
- **Turbine Performance**. About 25% improvement of steam consumption compared to CST.
- **Reliability**. Proven design based on reheat turbine used in ground facilities.

The turbine performance improvement expected, as mentioned above, it is more than 12% in specific fuel consumption (SFC). That performance change is due to changes in steam plant conditions from CST to UST; the application of reheating cycle and increasing the turbine internal efficiency.

The turbine internal efficiency increasing is based on the latest technology manufacturing, that which has already been tested by MHI with reheat turbines on shore and the expected results were found by them. The UST turbine is set and optimized for marine use and the performance and efficiency proposed have been validated empirically and methodically.

THE NEWEST TECHNOLOGIES USED TO IMPROVE THE INTERNAL EFFICIENCY OF THE UST TURBINE

As mentioned above, more than 12% improvement in fuel consumption (FOC) can be achieved through the implementation of the UST turbine, its associated boiler and steam plant.

- **Improved condition of steam to UST turbine**. Approximately 2% improvement in specific fuel consumption (FOC).
- **Implementation of reheat cycle**. Approximately 8% improvement in specific fuel consumption (FOC).
- **Improved internal efficiency of the turbine**. About 2% improvement in specific fuel consumption (FOC).

To achieve the greatest improvement in specific fuel consumption (FOC) is absolutely necessary to improve internal efficiency in the UST turbine. The following points are used to optimize performance of UST turbine.

a) Optimization based on the diameter of the turbine rotor (HR / T).
b) Optimizing the number of turbine stages and the steam pressure of each extraction.
c) **Implementation of ISB with Multi-seal blade.**
d) Optimization of the angle of the nozzle at high pressure stages (HP).
e) Development of the last stages Curtis (Control) with a much higher efficiency for UST steam conditions.
f) Implementation of 3-D Rateau nozzles.
g) Implementation of 3-D stationary blades in LR reaction stages.
h) Implementation of blades with small non stationary-losses.
1) Optimization of a guide for exhaust flow (LR / T).

PROPULSION PLANT WITH DIESEL ENGINE OF 200,000 DWT BULK-CARRIER

The propulsion is through a fixed-pitch propeller (and thus an axes line), driven by a two-strokes diesel engine of high performance.

The main engine is MAN engine, model 7S80ME-C7. It is a slow diesel engine, two-stroke, which has a crosshead and incorporates modern electronic control system, which also has advantages for fuel consumption.

ALTERNATIVE PROPULSION PLANT WITH REHEATED STEAM

In this study we will build on the use of a UST steam plant, with reheated steam at high pressure, commercialized by Mitsubishi Heavy Industries ltd.

The models of UST steam plant marketed currently by Mitsubishi Heavy Industries Ltd, and are the most suitable for use in the propulsion of 200,000 dwt bulk carrier, would be the MR36-II model, that with 26 MW would remain a little below the specified power, and the following model MR40-II with 30 MW would remain a little above the required power (see fig. 4).

Although the specified power for the bulk carrier does not exactly match the power rating given by these models, the important thing is that the power is within the range

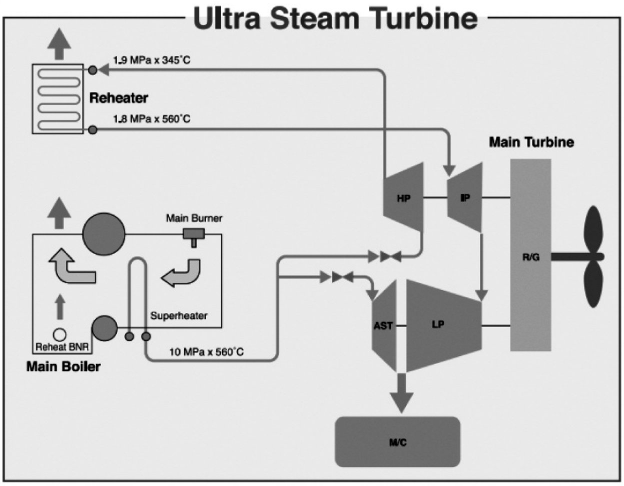

Fig. 4. Scheme of Mitsubishi UST plant (Mitsubishi Heavy Industries ltd).

of powers available. and the possibility of a specific adaptation for each application would be feasible and of this way to optimize fuel consumption for each vessel.

For the practical implementation of this project, the issue referring to steam turbines would have no difficulty, because the steam turbines issue could be solved by contacting of steam plant manufacturers and acquiring the most appropriate model for each vessel. However, the steam generators (Gourgoulis, 2010) using coal as fuel would represent the biggest challenges of this project so as to carry out their practical realization.

Currently, the use of steam generators that have coal as an energy source only has practical application in power stations on shore. Wherefore suitable steam generators should be developed for marine applications, as well as transportation, feeding and preparation coal facilities to the boilers, which must be designed for the use onboard of this kind of vessels. The use of steam generators from shore facilities would be a good starting point for developing marine boilers suitable for this application.

The steam generators installed in the ship should be at least two units (two large units and a smaller third assistant would be an optimal solution), and would be needed to take the possibility of burning coal and H.F.O. at the same time. The dual boilers would be needed to support and to compensate irregularities and distortions in the supply of coal, to make faster the manoeuvring of load change and both start and stop processes.

The determination of the steam generator system more suitable to install in the vessel exceeds the scope of this study, even though it is also a technology that should be developed specifically for this type of vessel that is currently absent.

On the other hand, although we are aware of the technologies used on shore facilities, it must be taken into account that to adapt these for use at naval facilities may not be feasible, practical or economically viable.

The types of boilers used on shore facilities and likely to be used on ships could be:

- Boilers with pulverized coal furnace.
- Boilers with cyclone furnace.
- Boilers with fluidized bed combustion.

The boilers should have an advanced regulation and control system, so that the variation of the spraying of H.F.O. could normalize and stabilize the pressure and mass flow rate in the boiler if the coal supplies were altered. A pilot burner of H.F.O. should always be in place to adequately control the boiler.

The treatment system of coal, its transportation from the vessel`s holds to the engine room and the feeding in the boiler should be fully automated and designed according to specific operating conditions of vessels, such as movements in the sea, maximum heeling and redundancy. Pre-treatment of coal depends on the type of boiler used.

Another possibility to simplify the installation on the vessel would be buying coal ready for burning or installing on shore facilities near the cargo terminal where the treatment of coal is carried out to be used as fuel during the voyage. It would be necessary to do economic studies to select the best option. If a particular fleet of coal-powered vessel was available; the pre-treatment facility option on shore might take on greater importance.

The scheme of the steam plant made in this study is based on information from Mitsubishi UST installation

Electrical power can be generated in three ways, 1º by tail generator coupling in a PTO (power take off), 2º through the Turbine Auxiliary (AUX T.) 3º or through diesel generators. The cheapest way is producing electricity with the tail generator. In case that the tail alternator was connected, the specific fuel consumption of the installation is less than if it uses the auxiliary turbine, as the main turbine efficiency is higher.

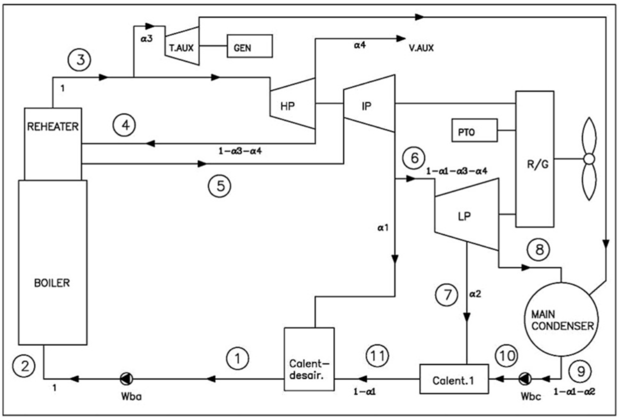

Fig. 5. Scheme of Rankine cycle with reheat and two bleedings.

The auxiliary steam extraction (V. AUX) is used to supply the ship’s services using steam for its operation. Keep in mind that most steam consumers are pre treatment heavy fuel oil equipment and at this facility it consumes mostly coal, so we have less mass of fuel-oil to heat, which could have reduced the amount of auxiliary steam, of this way the installation efficiency would improve.

In the diagram below we can see the Rankine cycle with reheat and two extractions of the facility that we have set (see fig. 5-7).

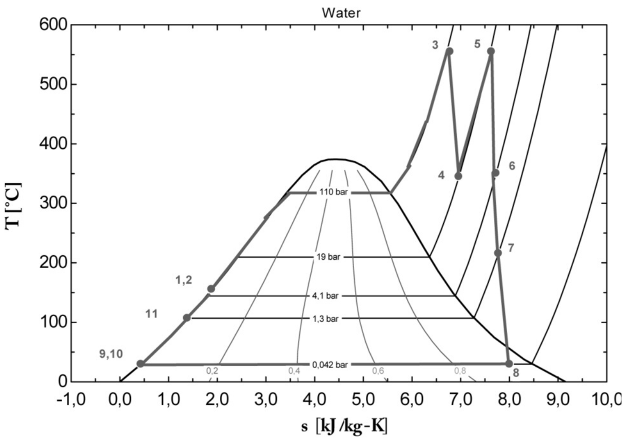

Fig. 6. Rankine Diagram with reheat in UST steam plant.

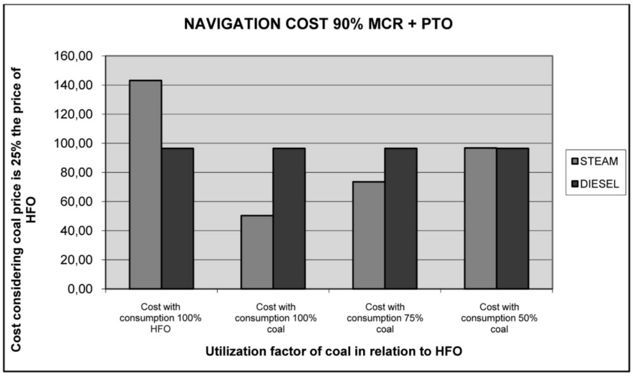

Fig. 7. Costs sailing at 100% of MCR+PTO, considering coal price 25% of crude oil price.

CONCLUSIONS

- It is expected that crude oil and natural gas prices experience a strong upward trend with respect to current prices.
- The use of steam cycle using coal as fuel based its reason for being in the huge price difference between coal and crude oil, which is expected, tends to increase in the future.
- It is a good solution to diversify the fuel sources to maritime sector, one almost exclusively dependent on crude oil for its operation.
- Small quantities of coal used can lead to big savings of money, due to the huge price difference between the two fuels.

REFERENCES

Economía y globalización. Online information. http://blogs.ua.es/miqueltari/2010/04/24/evolucion-precio-petroleo/ [Accesed 17 April 2009]

D. Gourgoulis (2010) Troubleshooting of marine steam turbo electro generators using engine control room simulator. *Journal of maritime research*, Vol. VII No I pp.13-26.

Turbine cycle information. Online information http://www.manbw.com [Accesed 23 April 2009]

Turbine cycle information. Online information www.wartsila.com [Accesed 23 April 2009]

Turbine cycle information. Online information http://www.mhi.co.jp/en/ [Accesed 23 April 2009]

Turbine cycle information. Online information http://www.khi.co.jp/index_e.html [Accesed 23 April 2009]

Fossil fuel information. Online information http://en.wikipedia.org/wiki/Fossil_fuel [Accesed 27 April 2009]

Ultra steam turbine. Online information. http://www.mhi.co.jp/en/products/expand/ultra_steam_turbine.html [Accesed 27 April 2009]