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Design Study of High Performance Steam Propulsion System for LNG Carrier

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ABSTRACT

This paper was discussed the current possibility technology can be used to design a high performance steam propulsion system for an LNG carrier. The propose system was designed based on the available technology for marine industry. The technical performance analysis was carried out to evaluate the improvement of the system. Economic performance for this system was also discussed in paper. The sensitivity analysis used for the economic performance analysis was made by varying the relative system initial cost and fuel price to cover several possible economic conditions to operate LNG Carrier.

KEY WORDS:*Steam turbine, propulsion system, LNG Carrier.*

NOMENCLATURE

LNG	Liquefied Natural Gas
BOG	Boiled Off Gas
MCR	Maximum continuous rating

1.0 INTRODUCTION

Previously, the steam propulsion system is the main power plant used for LNG carrier. This is because of the flexibility of the steam plant in fuel selection which brings advantage to the shipping company to utilize the boiled gas from the cargo tank. However, the steam propulsion plant is currently facing competition with new technologies such as dual-fuel diesel engine, boiled-off gas reliquefied system and diesel electric system.

The disadvantages of conventional steam propulsion system for LNG vessel are lower efficiency, high fuel consumption and long startup time if compared to other types of propulsion systems. As a result, the weaknesses of steam propulsion system for LNG carriers need to be improved for survival in the market. The reason to improve the plant is the ability of the steam plant to burn both heavy fuel and boiled off gas together during operating with high system reliability [1].

2.0 ULTRA STEAM TURBINE PLANT CONCEPT

The Ultra Steam Turbine Plant is the type of reheat plant with the working pressure above the critical pressure. The plant is developed by Mitsubishi Heavy Industries, MHI to recover the market share and exploits the new markets. Previously, the marine steam plants are operated at the steam condition at turbine inlet around 60 bars and 510^{0}C. However, the steam power plants for land application are able to operate with supercritical pressure and the steam temperature with 600^{0}C [2]. The maturity of the land steam plant is motivating the company to develop the new higher efficiency steam plant for marine application.

The Ultra Steam turbine plant which is developed currently have the steam condition with the pressure 100 bar and 560 ^{0}C. The new steam plant is a reheat-regenerative cycle. The Ultra Steam Turbine Plant is equipped with reheat boiler and one intermediate pressure turbine for the regenerative cycle to improve the efficiency. As investigated by MHI, the new Ultra Steam turbine plant is able to achieve the 12% plant efficiency improvement compared to previous conventional steam plant [1].

In conventional marine steam plants, the steam flow is flowing from the boiler to the high pressure turbine, and then passes to the low pressure turbine. However, for the new Ultra Steam Turbine Plant, the steam flow is flowing from boiler to high pressure turbine, then back to the reheater before sending to the intermediate pressure turbine. The steam exits from the intermediate pressure turbine will send to the low pressure turbine for the last state expansion [3].

The system improvement also resulted from the new design of reheat boiler and steam turbine itself as seen in the Ultra Steam Turbine Plant concept which is currently developed by Mitsubishi Heavy Industries. The reheat boiler used in the Ultra Steam Turbine Plant is equipped with the separated Reheater and Dual Furnace type for improve the protection and reliability for the Reheater. By this design, the Reheater and the furnace are located at the outlet of combustion gas where gas temperature is low. During the operation, the Reheater Burner can be stopped if there is no steam flow or extremely low steam flow conditions occur.

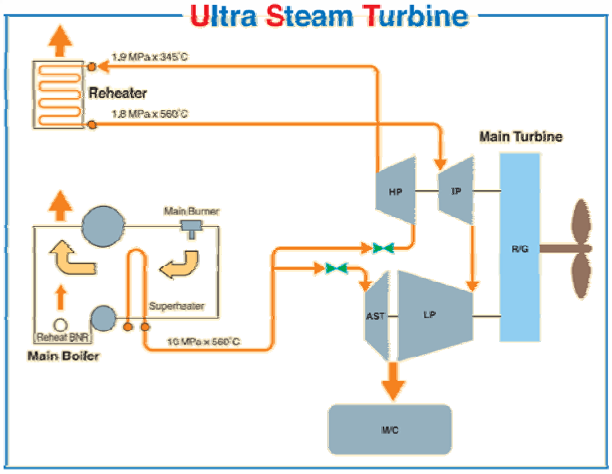

Figure 1: One line drawing for Ultra Steam Turbine plant [4]

The new plant is working at higher pressure and temperature, therefore the new design for the steam turbine also developed by the steam plant manufacturer. The turbine rotor and casing are designed for operating at temperature 560^0C with the latest material. The reliability of the material is proven by the land use steam turbine. The 3-dimensional stationary turbine blade for reaction stages lead to improve of turbine efficiency. The improvement in turbine efficiency claimed by the manufacturer is 22 to 23% for the new design turbine [4].

In the new plant design, the efficiency of the plant had been improved about 15% in fuel consumption, and 15% decrease in the emissions such as NOx, SOx and CO2. The reliability and safety for the plant is able to maintain in high level as well as conventional steam plant to provide the extremely long plant life. MHI is claimed that the plant is possible to operate more than 40 years and high flexibility in fuel selection [3].

3.0 HIGH PERFORMANCE STEAM PROPULSION SYSTEM STUDY

The design involves both the main propulsion system and auxiliary power system. This project is focused on the method to improve the plant efficiency for conventional steam power plant for LNG carrier. The conventional steam plant will be reconstructed and components of the steam plant are replaced with more efficient component in order to achieve the target.

The design considers criteria as below:

i. Increase operating pressure.
ii. Increase operating temperature.
iii. Reheat system for steam plant.
iv. Regenerative system for steam plant.
v. System power distribution method.
vi. Estimate the estimate the new system performance.
vii. Replace the new available main steam plant components

3.1. Assumption for Design and Technical Analysis

Assumptions are impossible to avoid in design works. This is because the actual design condition varies from time to time. The design assumptions applied in this project is as mentioned earlier, which governs the operating condition for the new system. However, the specification and the performance of the designed system only can be achieved if the real operating condition meets with the design assumption.

The design of the new high performance steam propulsion system is based on the assumptions below:

i. The seawater temperature always maintained at 29^0C.
ii. The sea surface condition is always calm.
iii. The size for system component can be determined by empirical method if the suitable power rating is not available in the market.
iv. The efficiency of the steam plant components can be determined by statistical methods.
v. The heat loss from steam/water inside the pipe assumed to be small and can be neglected.
vi. The efficiency of the plant is constant for its whole life span.
vii. The vessel will only operate at normal working condition for its life span.
viii. Corrosion never occurs in the system for the whole life span.
ix. The calorific value of the burning fuel, heavy fuel oil and boiled off the gas always maintained in same value.
x. The economizer is considered as the part of the boiler and heat recovery from economizer is involved in calculating the thermal efficiency and boiler efficiency.

3.2. Design Requirement for New System based on Basis Ship

System design requirement refer to the target which must be achieved for the system. It is the limitation of the system in operation. The performance of the system must be within the limitation to avoid designing an over-engineered product. Hence, the design requirement for the new high performance steam power plant is as below:

i. The main propulsion system must able to produce 26 800kW at MCR condition and 24 120kW at normal service condition.
ii. The maximum power produced by auxiliary steam generator must be around 2900kW.
iii. The auxiliary power supply must be adjustable.

iv. The system must be able to utilize the boiled off gas from the cargo tank and use it to produce the power for main and auxiliary system.
v. The emergency power rating must follow the requirement of ship classification society, normally 10% of total auxiliary power.
vi. The system working condition must achieve critical temperature and critical pressure condition to enable the system to work at higher efficiency.
vii. The endurance of the ship must be the same as the basis ship.
viii. The new system should be installable into the engine room of basis ship.

The system must able to work in the tropical weather environment and operate efficiently under the predetermined seas water temperatures.

3.3. Design of Main Propulsion System and Auxiliary System

The main propulsion system should be able to generate the 26 800 kW as stated in design requirement. In this steam plant propulsion system, the working steam enter the steam turbine inlet at a pressure of 9.8 MPa and temperature of 555 ^{0}C. Two regenerative cycles extract the steam at steam pressure of 2 MPa and 0.4887 MPa. The one stage reheat cycle resuperheating the steam at steam pressure 2 MPa.

Besides, the auxiliary steam drive generator system must be able to generate the maximum power as much as 2900 kW. The operating pressure range of the system is from 18.7 kPa to 9.8 MPa. The auxiliary steam turbine is driven by the steam generate from main boiler.

The specification of the high performance steam plant for main propulsion system and auxiliary system are shown as Table 1.

Table 1: Main propulsion system and auxiliary system specification

System	Main Propulsion	Auxiliary
Power Rating, kW	26 800 (MCR) 24 120 (Normal)	2 900
Heat Input, kJ/kg	2992.74	3262.12
Work Output, kJ/kg	1135.71	1149.75
Thermal efficiency, %	37.95	35.25
Specific Steam Consumption (kg/kW.h)	3.17	3.13
Steam Flow Rate (kg/s)	24.31 (MCR) 21.45 (Normal)	2.52

3.4. System Fuel Consumption analysis

The fuel consumption is depending on the power consumption of the ship and the boiler efficiency. From the manufacture document, it's shown that the boiler efficiency is 88.5% based on the higher heating value of the fuel. The fuel consumption was estimated for MCR condition and normal condition in this project. In both of the working condition, fuel consumption at 100% heavy fuel oil consumption and combination of boiled off gas and fuel gas was calculated as shown in Table 3.

The amount boiled off gas evaporated from the cargo tank is directly depending to cargo tank size, tank-filling ration, boil off rate and density of the liquidity natural gas [5]. The formula used to calculate the boiled off gas was provided by Oscar and Abel at the paper title “Izar BOG Reliquefaction systems for Marine Application” is shown as below:

$$BOGinhour = \frac{CargoSpace \times tankfillingratio \times Boiloffrate \times LNGdensity}{24} \quad (1)$$

Table 2: Technical specification for selected LNG Carrier

Criteria	Data
Cargo Volume	137585 m^3
Tank-filling ratio	98.5%
Boil off rate	0.15%
Estimate LNG density (Assume pure methane)	425 kg/m^3
HHV for BOG (kcal/kg)	13270
BOG rate (kg/hr)	3599.78
Energy supply by BOG (kJ/s)	55518.29

The specific fuel consumption was evaluated in both the MCR condition and normal working condition. The fuel consumption calculated from previous part is used to evaluate the fuel consumption performance here. The specific fuel consumption can be calculated based on following formula.

$$Specificfuelconsumption = \frac{Fuelconsumptionrate}{totalpowergenerated} \quad (2)$$

Below is the specific fuel consumption at ship working conditions:

Table 3: Specific fuel consumption at MCR and normal operating condition

Condition	MCR		Normal	
	100% fuel oil	BOG+fuel oil	100% fuel oil	BOG+fuel oil
Power Generated (kW)	29700		27020	
Energy Supply (kW)	90864.32		82646.97	
Fuel consumption (Tonnes/hour)	7.605	2.96	6.92	2.27
Specific fuel consumption (g/kW.h)	256	100	256	84

The specific fuel consumption at 100% fuel oil burning is same for both MCR condition and normal condition because the losses in both situations are assumed to be equal in the project. However, at (BOG + fuel oil) burning condition, the specific fuel consumption for normal operating condition is lower because the power demand at this condition is lower. As a result, the extra fuel required to supply to achieve demand is lesser compared to MCR condition. In general, the system fuel consumption can be improved since the specific fuel condition in any condition is lower than previous conventional steam plant.

3.5.Overall System Efficiency

The overall system efficiency can be calculated by comparing the total power generated by system to total energy supplied to the system. Both the main propulsion system and auxiliary system is taken in to consideration in the calculation of overall system efficiency. This is because both the systems share same boiler to obtain energy to work.

Since the system losses at normal working condition and MCR condition are assumed to be same, the overall system efficiency at both the conditions should be the same. In this analysis, the overall system efficiency was calculated based on normal working condition as follows. The energy supply at normal working condition is as calculated at section 4.5.3. The required energy supply is 82714.60 kW. Also, the power that can be produced by main system and auxiliary system is 24120 kW and 2900 kW accordingly.

$$Overallefficincy, \eta_o = \frac{totalsystempoweroutput}{totalpowerinput} \times 100 \qquad (3)$$

$$Overallefficincy, \eta_o = \frac{24120 + 2900}{82646.97} \times 100$$

$$= 32.70\%$$

3.6.Improvement on System Technical Performance

From the technical analysis, the performance of the high performance steam plant has improved compared to the conventional steam plants. The overall efficiency of the proposed main propulsion plant is 33% and 31% for the auxiliary system. At this efficiency, the overall fuel consumption of the designed system is 6.92 Tonnes/hour compared to 7.86 Tonnes/hour for the conventional steam plants.

Table 4: The comparison between the specific fuel consumption and specific lubricating oil consumption

Propulsion System	Specific Fuel Consumption (g/kWh)	Specific Lub.oil Consumption (g/kWh)
Conventional steam plant	290	0
High performance steam plant	256	0
Dual fuel diesel electric	190	0.8
Gas Turbine	207	0

(Source for all specific lubricating oil consumptions and specific fuel consumption for duel fuel diesel engine and gas turbine: Attachment for diploma thesis "Techno-economic Evaluation of Various Energy Systems for LNG Carriers", 2006[6])

From the comparison in Figure 4, the improvement was achieved for high performance steam plants; however, the performance of this designed system is still lower than dual fuel diesel engines and gas turbines. This is because the specific fuel consumption of the proposed system is estimated 25% higher than dual fuel diesel electric systems. Further improvement is required to increase the competitiveness of the steam propulsion plants.

4.0 ECONOMIC PERFORMANCE ANALYSIS

The cost involved in the LNG Carrier can be separated into two main types which are building costs and operating costs. For building cost, it is involved material, fabrication, design and other charge. From the study, the building cost occupies about 2/3 of the life cycle costs and operating costs occupies another 1/3 of life cycle costs [7].

The operating cost which is estimated around 1/3 to life cycle cost. It consist the component of ship owner's cost, sailing costs and cargo costs. In ship owner's costs, it involves the costs for personnel, stores, maintenance and repair, insurance and overheads. The percentage of the ship owner's cost to the overall operating cost is around 43%. Besides that, the largest part of the operating cost is sailing costs, the sailing costs involved fuel and lubricating oil cost also port cost. If the ship is required to pass through a canal, the canal cost is considered as a component of sailing cost. From the previous record, it is estimated that the sailing cost is 46% of the total operating costs. The remaining 11% of the overall operating cost is cargo costs. The cargo costs are mainly composed of commissioning costs and stevedoring costs. The cargo costs are assumed will not affected by routing either.

From a review of a journal paper entitled "Some Economical Aspects of the Routing of Ships", it was found that the percentage of each operating cost component by relative to overall operating costs can be shown in the Figure 2.

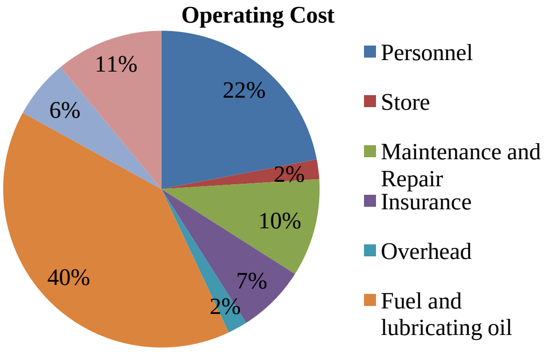

Figure 2: The component of operating cost and its component percentage[8]

The economic analysis and the sensitivity analysis are performed based on the assumptions below:

i. The charter rate is constant in this analysis.
ii. The cargo owner is chartering the LNG Carrier by voyage charter.
iii. The initial cost for high performance steam propulsion system is relative to the initial cost for conventional steam propulsion system.
iv. The initial cost of the ship other than the propulsion system and its propulsion supportive system is same for both proposed system and conventional steam propulsion system.

v. Maintenance cost is assumed in percentage relative to the LNG Carrier initial cost and the number of services required yearly for both LNG Carriers is constant for its life span.
vi. The total operating cost of high performance steam propulsion LNG Carrier and conventional steam propulsion LNG Carrier is the summation of fuel cost, repair maintenance cost and other operating cost.
vii. The operating cost other than maintenance cost and fuel cost is assumed same for both the conventional steam propulsion system and high performance steam propulsion system.
viii. The operating cost other than maintenance cost and fuel cost is assumed 50% of total operating cost for conventional steam plant.
ix. The fuel cost for both the conventional steam propulsion LNG Carrier and high performance steam propulsion LNG Carrier is relative to its fuel consumption rate and the fuel price.
x. The salvage value for both LNG Carrier can be calculated based on the depreciation rate.
xi. Ownership of the LNG Carriers is assumed to be of a Malaysian Company and the depreciation rate in Malaysia is selected.
xii. The service route of the LNG Carrier is same for its life span.
xiii. The cargo capacities of the LNG Carriers are same for both the propulsion systems.

The purpose of sensitivity analysis which been carried out in this project is to analyze the change of system economic performance when the economic condition is changed. A few variables of sensitivity analyses were selected in this project to compare both conventional steam propulsion system and new high performance Steam Propulsion system. Initial cost is altered to measure the change of initial cost to system economic performance. The economic performance was estimated for the conventional steam propulsion LNG Carrier by referring to the publish journal paper. The economic performance for the conventional steam propulsion LNG Carrier is shown as follows.

Table 5: Cost and revenue for conventional steam propulsion LNG Carrier

Criteria	**Amount (USD)**
Total Initial Cost	170,300,000*
Propulsion and Auxiliary system Cost	32,500,000*
Operating Cost:	
Fuel Cost	33,147,840
Annual Maintenance Cost	8,515,000
Other Operating Cost	41,662,840
Salvage (10% Depreciation Rate for 20 years)	20,704,504
Annual Revenue	98,436,108

(Source: *Conference of Sigtto Panel Meeting at year 2003[9])

The Interest Rate of Return method is selected to compare the systems. Two factors for high performance steam propulsion LNG Carrier economic performance were varied for sensitivity analysis. The factors are system relative initial cost and fuel price. The relative initial cost for propulsion and auxiliary system is varying from 80% to 160% to the propulsion and auxiliary system for conventional steam propulsion LNG Carrier. For the fuel price, it is varying from 230 USD/Tonnes to 800 USD/Tonnes. The sensitivity analysis result assess by interest rate of return methods is shown as follow.

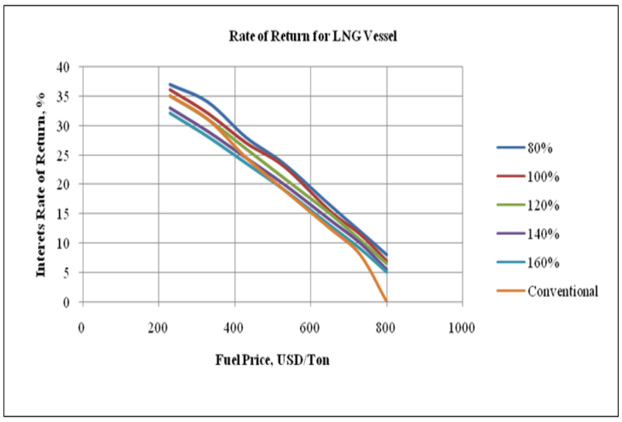

Figure 3: Comparison between Interest Rate of Return for conventional plant and high performance plant in relative initial cost

The purpose of internal rate of return is to analyze the return rate of the system in its whole life spend. From the analysis, the internal rate of return for both the conventional steam plant and high performance steam plant can be seriously affected by the fuel price. Analysis found that the increase of fuel price can cause a significant decrease in the rate of return. The effect of change in fuel price is larger for the LNG Carrier which is equipped with conventional steam plant compared to the high performance steam plant.

The conventional steam plant LNG Carrier will result in the same rate of return with a high performance steam plant with relative initial cost 120% if the fuel price is lower than 330 USD/Tonnes. If the fuel price exceeds 330 USD/Tonnes, the high performance steam plant with the initial cost 120% and lower has higher rate of return compared to conventional steam plant LNG Carrier.

When the fuel price more than 430 USD/Tonnes, the high performance steam plant with relative initial cost 140% to conventional steam plants can result in a better rate of return compared to the conventional steam plant LNG Carrier. The same situation apply to the high performance steam plant with the relative initial cost 160% to the conventional steam plant when the fuel prices higher than 530 USD/Tonnes.

The conventional steam plant LNG Carrier which has high fuel consumption rate is not suitable to work in the high fuel price condition. The increase of fuel price can cause the operating cost for conventional steam plant to increase more compare to proposed system. Therefore, the proposed system with lower fuel consumption rate can perform better in high fuel price condition. This advantage can reduce the effect of the increasing in initial cost to the system.

At the current situation, the fuel price is fluctuating within the range from 330 USD/Tonnesto 500 USD/Tonnes(From 2008 to 2012) and it may increase to a higher range in future. This situation will provide an opportunity for the high performance steam plant to dominate the LNG Carrier market, replacing the conventional steam plant LNG Carrier if the manufacturer is able to maintain the initial cost of high performance steam plant within 140% compared to conventional steam plant. Therefore, the proposed system is more competitive in future since the international fuel price is increasing from time to time.

5.0 DISCUSSION

5.1.Effect of Steam Working Pressure and Temperature to Thermal Efficiency

The improvement of thermal efficiency can be obtained by increasing the steam plant working pressure and temperature. Calculations of thermal efficiency at different working conditions have been carried out based on simple steam cycles. The assumptions for the calculations are as follows:

i. The steam exhaust temperature and pressure are the same.
ii. The losses at the turbine and boiler are neglected.
iii. The pump work is neglected.

From Figure 6.1, the thermal efficiency will increase when the steam plant working temperature and pressure are increased. The parabolic curves show that the improvement in thermal efficiency becomes lower when the working pressure increases. From the comparison, the high performance steam propulsion system which is designed to work at 10 MPa, 560 ^{0}C obtains the improvement of thermal efficiency of 3% compared to conventional steam propulsion systems.

However, improving the thermal efficiency by increasing the working pressure and temperature has its limitation. The first limitation is the material strength. If the pressure in the system is higher than the allowable stress of the material, it can cause immediate failure to the system and its components.

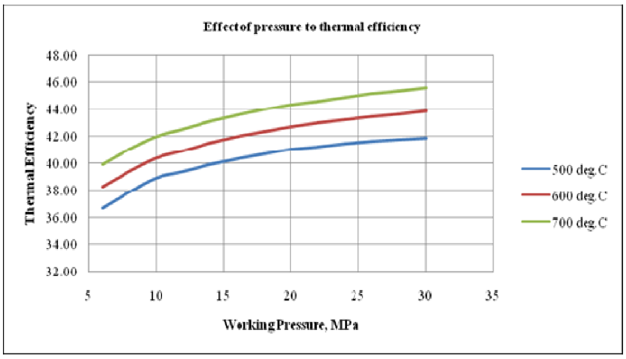

Figure 4: Thermal efficiency for the steam plant at different steam inlet pressure and temperature

Besides, by increasing the working temperature, it will cause a decrease of the allowable stress for the material. Currently, steel alloy is selected to construct the marine boiler and turbine. The strength of cast steel will decrease significantly when the temperature increases over the normal working range of the material. This factor limits the steam plant manufacture to increase the working temperature of steam plant to improve the thermal efficiency.

In order to overcome low component strength, the thickness of the components can be increased. By increasing the components' thickness, the strength of the components at different temperatures can be increased directly. However, this method can cause the weight and the size of the system to increase and the cargo space for the LNG Carrier to be reduced. In addition, increasing the thickness of the components can cause the initial cost of the system to increase since more materials are required to build the system.

The materials used for the components of the proposed system have been upgraded by the manufacturer. For turbine, Cr.Mo.V Steel is selected to construct the component [4]. For boiler components, the steam drum is construed by using steel grade ASTM A299 Gr.A. The material for the tube is LR grade 460 Carbon-Steel and LR grade 410 Carbon-Steel [10].

However, the working temperature for this high performance steam propulsion system is limited to 560 ^{0}C. At this temperature, the allowable stress of the materials is decreased almost half of it compared to its allowable stress at room temperature. Again, from the figure above, if the temperature is increased to 660 ^{0}C, the allowable stress is not enough to sustain the working pressure. At this condition, the steam plant is not safe to be operated although the thermal efficiency can be increased.

From published papers, improvement of the steam plant thermal efficiency by increasing working temperature and pressure is available currently. Creep strength for new alloys was fully studied to replace the ferrite alloys [11]. The new alloys such as nickel alloys have higher creep strength compared to ferrite alloys at high temperatures. This allows the plant designer to increase the working temperature and pressure. In addition, some of the mentioned material were used to constructed inland steam plant for generate electricity.

The inland steam plant is able to work at higher temperature and pressure compare to marine steam plant. Currently, modern inland steam plants are working at an ultra-critical condition where the pressure and temperature are 26Mpa and 610 ^{0}C [12]. At this working condition, the inland steam power plant is able to work with higher efficiency compared to marine steam plants. The strict weight and safety considerations in the marine industry restrict the industry from applying the same technology as the inland steam plant applied. By improving the technology, higher class materials can be created and this will increase the possibility of the marine steam plant to work at higher temperature and pressure to achieve better plant efficiency.

5.1.Improvement of Economic Performance

The economic analysis was carried out mainly focusing on the operating cost. From the analysis, it is assumed that 50% of the LNG Carrier's operating cost is the fuel cost and maintenance cost. Both the fuel cost and maintenance cost depend on the system performance. Another 50% of the operating cost such as insurance cost, port cost and crews cost are assumed same for both high performance steam propulsion LNG Carriers and conventional steam propulsion LNG Carriers.

From the analysis, the high performance steam propulsion LNG Carrier has lower annual fuel cost compared to the conventional steam propulsion LNG Carrier. However, the maintenance cost for the designed system is estimated higher since the cost of the components is higher. In general, the total operating cost of the high performance steam propulsion LNG Carrier is lower compared to conventional steam propulsion LNG Carriers. The increase of the system efficiency led to the improvement of economic performance for the new designed system.

From the analysis, the change of the fuel price affects the system life cycle cost. If the fuel price is relatively low (200 USD/Tonnes to 300 USD/Tonnes), the conventional steam propulsion system is able to provide a better return rate to the ship owner because the initial cost of the system caused a larger effect to the life cycle cost. As a result, the cheaper conventional steam propulsion LNG Carrier can perform better. In the current situation, the fuel price is fluctuating at higher range which is around 400 USD/Tonnes to 700 USD/Tonnes. The operating cost gives a larger effect to the life cycle cost in this situation. Therefore, the high performance steam propulsion LNG Carrier can make better return rates to ship owner.

With the current fuel price, the high performance steam propulsion LNG Carrier is able to provide better economic performance, even though the initial cost for the proposed system is 160% higher than conventional steam plants. Therefore, the high performance steam propulsion system is the better choice for shipping companies.

6.0 CONCLUSION

The analysis was carried out to compare the performance between both systems. From the technical performance analysis, the high performance steam propulsion LNG Carrier is able to work with higher efficiency and lower fuel consumption. The specific fuel consumption of the proposed system is 34 g/kW.h lesser compared to conventional steam propulsion systems.

In addition, economic performance has been carried out in this project. Compared to conventional steam plants, high performance steam plant is more economical to work in the current economic condition. The higher fuel price caused the operating cost of LNG Carrier to increase. The designed system which is able to operate with lower fuel consumption increased the economic performance for the steam propulsion system. Therefore, the proposed system is more competitive compared to the previous systems.

7.0 FUTURE WORK AND RECOMMENDATION

Further studies of the high performance steam plant are required to improve the system design approach and the accuracy of the system analysis. Below are the suggestions for future research.

i. Increase the system working temperature and pressure to a higher level if suitable materials are available.
ii. Detailed evaluation of the safety and reliability of the new system compared to the previous systems.
iii. Study the system in detail by selecting a suitable piping grade and control system.
iv. Research for the possibilities for the system to run with cheaper fuel such as solid fuel like coal.
v. Obtain the actual construction and operating cost from the ship owner to increase the accuracy of economic performance analysis.

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REFERENCE

1. T. Yuki. 2007. Reheat Boiler for Marine Reheat Cycle Plant: *JIME*, 42.
2. Y. A. Cengaland M.A.B. 2007.*Thermodynamics An Engineering Approach*. (6th ed.). New York, Americas: McGraw-Hill.
3. M. Ito. and K.H.a.e. 2007. Development of High Efficiency Marine Propulsion Plant (Ultra Steam Plant): *Mitsubishi Heavy Industries, Ltd. Technical Review*, 44.
4. *Reheat Plant for New Generation LNGC Propulsion*. Available from: http://www.mhi.co.jp/en/products/pdf/ust.pdf.
5. O. M. M. a. A. M. Diaz, 2003. Izar BOG Reliquefaction Systems for Marine Applications.*World Maritime Conference. 2003.* 17-20 Oct. San Francisco USA.
6. A. Konstantinos. 2006. Techno-economic Evaluation of Various Energy Systems for LNG Carriers.*Diploma Thesis.National Technical University of Athens Athens*.
7. Y.Kumakura.and H. Sasajima. 2001. A Consideration of Life Cycle Cost of a Ship, in Practical Design of Ships and Other Floating Structures: *Elsevier Science Ltd*, 29-35, Oxford.
8. J. H. C.Meijers. 1980. Some Economical Aspects of the Routeing of Ships. Ship Routeing for Optimum Performance: *Transactions IME*, 2.
9. (2003) Revenue Maximisation in the Transportation of LNG at sea by using Alternative Ship Propulsion Systems. *SIGTTO PANEL MEETINGMarine Service GMBH*. Sept. Hamburg, Germany.
10. Mitsubishi Heavy Industrie.*Main Boilers (for Steam Propulsion Vessels).* Available from: http://www.mhi.co.jp/en/products/detail/marine_propulsion_boilers.html.
11. R. R. P. a.o.Viswanathan. 2008. U.S. Program on Materials Technology for Ultrasupercritical Coal-Fired Boilers, in Advances in Materials Technology for Fossil Power Plants: *Proceedings of the 5th International Conference*. *ASM International*.United State.
12. M. Boss, T.G., S. Feeny and M. Montgomery, *Recent Advances in Ultra Super Critical Steam Turbine Technology*.