ENERGY AND ECONOMIC ANALYSIS USING BOIL-OFF GAS ONBOARD LIQUEFIED NATURAL GAS TANKER VESSEL

MUHAMAD SHAFRILNIZAM BIN ROSLI

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Universiti Teknologi Malaysia

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To my beloved wife Nur'Ain and my lovely daughters Syafiqa and Hannah

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ABSTRACT

Liquefied natural gas (LNG) tanker vessel is operated to carry natural gas at cargo temperature of around -163°C. The containment system is designed to allow heat to escape into the cargo area. Around 0.15% of boil-off gas (BOG) is typically present in the cargo volume per day. Thus, the cargoes from the loading terminal are not fully delivered to the client due to the BOG phenomenon. This thesis looks into the utilization of BOG in the boiler. Modern marine boilers installed onboard the LNG carriers are capable of burning 100% BOG or heavy fuel oil (HFO). It can also use both BOG and HFO in a dual fuel burning operation. A Malaysia International Shipping Corporation (MISC) Berhad vessel which has operated for five voyages and has the same shared route of loading and discharge port was identified as a sample. The data main source was from the vessel's engine log book. The investigation is conducted by profiling the steam system onboard. On further analysis, the estimated fuel costs and operating characteristics of the facility were determined, focusing on evaluating the fuel to steam conversion efficiency of the boiler. It was found that during the laden voyage, more energy saving of BOG was obtained as compared to HFO in the range of 72.9% to 97.6% whilst in the ballast voyage, less BOG was obtained in the range of 7% to 75.9%. The percentage energy saved varies whereby the percentage is high when vessel encountered shorter routes or purposely more BOG been utilized through forced boil-off method. The plant efficiency is about the same regardless of the type of fuel burnt in the boiler, whether it is burning combined BOG and HFO, 100% BOG or 100% HFO. The only difference is the amount of fuel burnt in the boiler. Hence, it is the owner best interest to decide which fuel to use that provides lesser fuel consumption and less cost.

ABSTRAK

Kapal tangki gas asli cecair (LNG) berfungsi membawa gas asli pada suhu sekitar -163°C. Sistem penebat tangki direka untuk membolehkan haba menyerap ke dalam ruang kargo. Adalah dianggarkan 0.15% *boil-off gas* (BOG) wujud di dalam ruang kargo setiap hari. Oleh itu tidak semua kargo dari terminal pengisian dapat diterima oleh pelanggan disebabkan oleh fenomena BOG ini. Tesis ini melihat penggunaan BOG di dalam dandang. Dandang marin moden dipasang di atas kapal tangki LNG berkebolehan untuk membakar 100% BOG atau minyak bahan api berat (HFO). Ia juga berkebolehan untuk membakar kedua-dua BOG dan HFO pada masa yang sama dalam pembakaran dwi operasi. Sebuah kapal milik Malaysia International Shipping Corporation (MISC) Berhad telah dipilih sebagai bahan kajian yang mana didapati lima pelayaran adalah menuju ke pelabuhan yang sama. Sumber data utama adalah daripada buku log enjin. Penyiasatan yang dilakukan adalah dengan memprofilkan sistem wap yang terdapat di atas kapal. Apabila analisis lanjutan dibuat, anggaran kos bahan api dan karakter operasi fasiliti dapat ditentukan dengan fokus tertumpu kepada menilai penukaran bahan api kepada kecekapan wap dandang. Didapati sewaktu kapal belayar dengan muatan kargo penuh, lebih penjimatan tenaga oleh BOG diperolehi berbanding HFO dalam lingkungan 72.9% ke 97.6% manakala dalam pelayaran ballas, kurang BOG diperolehi dalam lingkungan 7% ke 75.9%. Peratusan penjimatan tenaga adalah berbeza di mana peratusan adalah tinggi apabila kapal menempuh jarak pelayaran yang dekat atau lebih banyak BOG digunakan melalui cara paksaan BOG. Kecekapan janakuasa kapal agak sama walaupun menggunakan sumber bahan api yang berbeza, samada pembakaran bersama BOG dan HFO, 100% BOG atau 100% HFO. Perbezaannya cuma jumlah bahan api yang dibakar di dalam dandang. Oleh itu, terpulang kepada pihak pemilik kapal untuk menilai bahan api yang terbaik dan sesuai digunakan yang akan memberi pengurangan bahan api yang digunakan dan pengurangan kos.

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BOG	-	boil-off gas
BTU	-	British Thermal Unit
CPP	-	controllable-pitch propeller
FPP	-	fixed-pitch propeller
GTT	-	Gaz Transport and Technigaz
HFO	-	heavy fuel oil
LNG	-	liquefied natural gas
LNGC	-	liquefied natural gas carrier
m^3	-	cubic meters
MDO	-	marine diesel oil
mtpa	-	million tonnes per annum
$\dot{m}_{steam}$	-	mass flow rate of steam
h_{steam}	-	enthalpies of steam
$h_{feedwater}$	-	enthalpies of feedwater
$\dot{m}_{fuel}$	-	mass flow rate of fuel
HHV	-	fuel higher heating value
η_{boiler}	-	boiler efficiency

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CHAPTER 1

INTRODUCTION

1.1 Background

LNG Carrier

Since 1960s, all LNG ships have used steam boilers to generate power for both propulsion and ship services with a high degree of reliability. The steam drives the main engine, generators, powers auxiliary equipment like pumps, and provides the heat source for fuel tanks, etc. The steam turbine plant is highly reliable and widely adopted. The ability to use both boil-off gas (BOG) and heavy fuel oil (HFO) ensures clean combustion. However, these plants suffer from inferior fuel efficiency and high fuel costs. Maximum overall efficiency and economy of a steam power cycle are the principal design criteria for plant selection and design. Modern marine boilers installed onboard the LNG Carrier are all top fired and each is provided with three dual-fuel burners.

The boilers are capable of burning 100% boil-off gas (BOG) or 100% heavy fuel oil (HFO) explained by Gaughan [1]. With the improved insulation systems provided on modern LNG carriers, the natural boil-off gas can provides more than half the fuel needed for full power while the vessel is under way at design speed. The balance of the fuel demand is met by either burning HFO or forced boil-off (FBO).

Forced boil-off is generated when LNG is pumped from a cargo tank to a shell-and-tube heat exchanger, where it is vaporized and sent to the engine room. The choice whether to supplement the natural boil-off with HFO or with FBO depends on the relative cost of the bunker fuel versus delivered cargo and can change from trip to trip. Since HFO must be heated before it can be pumped to the boilers in order to meet the requirement for quick changeover to liquid fuel, should the master gas valve close, the liquid fuel system is provided with a hot fuel oil boost-up system.

On steam ships, the means provided to consume boil-off unneeded for propulsion or electrical power is handled in what is called a "steam dump system." The boil-off is consumed in the boilers and any excess steam is dumped to the main condenser. In most cases on modern ships an auxiliary condenser is provided as a backup.

Calculations, estimates, and predictions of steam plant performance will allow for all normal and expected losses and loads and should, therefore, reflect predictions of monthly or annual net operating heat rates and costs. A steam plant with a good performance will have optimized cycle heat balance (made during the conceptual or preliminary design phase of the project). The heat balance depicts, on a simplified flow diagram of the cycle, all significant fluid mass flow rates, fluid pressures and temperatures, fluid enthalpies, electric power output, and calculated cycle heat rates based on these factors. A heat balance is usually developed for various increments of plant load (i.e., 25%, 50%, 75%, 100%, etc.) [2].

1.2 Problem statement

As a ship owner, MISC Berhad currently operates a total of 23 steam turbine driven LNG tankers. This includes the Tenaga Class (1 vessel), Puteri Class (5 vessels), Aman Class (3 vessels), Puteri Satu Class (6 vessels), Seri A Class (5 vessels) and Seri B Class (3 vessels). Steam turbines can run for years and years without scheduled maintenance. Stimulating the original choice of steam turbines for LNG tankers were:-

(i) The need for high-power output,

(ii) Proven reliability

(iii) Ability of the associated boiler plant to burn low-grade fuel

(iv) Ability of the associated boiler plant to burn cargo BOG

(v) Turbine maintenance was also relatively modest in cost.

In a LNG carrier cargo tanks, certain percentage (i.e. 0.15% of volume) of boil-off gas escapes to the atmosphere and can be utilize effectively so as to combust in the operated water tube boilers. The raised problem statement in the theses is by utilizing the Boil-Off Gas (BOG) in the boiler, how much is the energy savings that we can achieved in boiler operation. It had never been analyzed technically by the vessels operator since:-

(i) boil-off gas is obtained for free

(ii) heavy fuel oil is been provided by the charterer

1.3 Objective of study

The objective of this study is to :-

i. To calculate the amount of energy saved (heavy fuel oil saved in tonnes and monetary value) through burning boil off gas (BOG) in boiler while on laden and ballast voyage.

ii. Economic saving comparison through BOG burning against HFO burning in boiler

iii. To compare the thermal efficiency produced through BOG burning against HFO burning in boiler

1.4 Scope of study

Current design on the cargo containment system allow for heat leak into cargo with estimation of 0.15% boil-off gas (BOG) from cargo volume per day. This means that not 100% cargo from loading terminal could be delivered to the client due to the BOG phenomenon. In addition to the loss during the voyage from an export to an import terminal, called the laden voyage, the return voyage of the tanker, called the ballast voyage, also incurs additional boil-off loss. During the ballast voyage, a small amount of cargo, called heel, is retained inside the cargo tanks to maintain them at their normal carrying temperature of -163°C [3].

The scope of study will focus on the investigation of the boiler operation. Various characteristic within the varied fuel mode with data and result analysis will be collected / calculated from the identified LNG vessel. This include the:-

i. heavy fuel oil (HFO) burning in boiler
ii. dual burning (HFO + BOG)
iii. 100% boil-off gas (BOG) burning availability

The analysis of the collected data will covers the energy saving made through the heavy fuel oil saved in tonnes and monetary value through burning boil-off gas (BOG) in boiler while on laden and ballast voyage. The thermal efficiency produced through BOG burning against HFO burning in boiler will be calculated and compared. Economic study will be made through BOG burning against HFO burning in boiler as comparison. By using the data acquired from vessel, the analysis would focus on evaluating the fuel-to steam conversion efficiency of the steam plant. The identified variables for BOG burning are mainly composed of the composition of gas, sea condition and the boil-off rate.

1.5 Significance of study

The energy and economic analysis using boil-off gas onboard liquefied natural gas tanker vessel result findings will evidently help in considering of maintaining steam turbine as LNG Carrier propulsion alongside with the new age type of propulsion (e.g. slow speed diesel engine, dual fuel diesel engine, gas turbine, etc.).

1.6 Research Outline

This thesis is organized as follows: Chapter 1 gives the background of the research including the brief history, objective, problem description, significance and contributions of the research, scope of research and lastly research outline. Chapter 2 is dedicated for the review of literature. The research methodology employed in this research is fully discussed in Chapter 3. In Chapter 4, research result is presented statistically with discussion and conclusion from the presented work is drawn in Chapter 5.

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