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FUEL SAVING ANALYSIS AND STABILITY ASSESSMENTS OF MALAYSIAN OFFSHORE FISHING VESSELS FITTED WITH DUAL FUEL DIESEL AND COMPRESSED NATURAL GAS

I. Zainol[1], A. F. Ahmad Fuad[2], M. Zaifulrizal Z.[1], Nuraihan I.[3], S. A. M. Adam[1] and M. R. Zoolfakar[1]
[1]Marine Engineering Technology Section, Universiti Kuala Lumpur, Malaysian Institute of Marine Engineering Technology, Lumut, Perak, Malaysia
[2]Programme of Nautical Science and Maritime Transportation, Universiti Malaysia Terengganu, Kuala Nerus, Terengganu, Malaysia
[3]Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, Skudai, Malaysia
E-Mail: ismailz@unikl.edu.my

ABSTRACT

Malaysia fishing industries are heavily dependent on the fossil fuels to satisfy its energy demand. Fuel cost of fishing vessels normally accounts for more than 50% of the annual operating expenses. With the increasing of global fuel prices, the future of this industry has exposed fishermen to uncertain future. Nowadays, clean burning alternative fuel such natural gas has become a great interest for fuel saving. A duel fuel diesel engine is a diesel engine that has been fitted to use compressed natural gas (CNG). Dual fuel engines provide numerous potential advantages such as cost saving, fuel flexibility, lower emissions, better efficiency and easy conversion of existing diesel engines without major modifications. This paper describes a study to reduce fuel consumption by introducing a dual fuel diesel and CNG for Malaysian offshore fishing vessel. An analysis of fuel consumption reduction is presented, together with stability assessments. The results reveals that dual fuel diesel can provide noticeable lower fuel consumption compared to existing diesel engines and stability assessment signify that the conversion to dual fuel engine has no adverse effects to vessel stability.

Keywords: dual fuel, compressed natural gas, offshore fishing vessel, stability.

INTRODUCTION

Fishing industry is one of the main sources of economy in our country. The production value of the national fisheries sector is worth 12.77 billion ringgit in 2014, and offshore fishing constitutes about 10.4% of the total value [1]. Offshore fishing vessels in Malaysia operate using diesel engine as a prime mover. However, the uptrend of fuel prices changes has affecting the profitability of fisheries, as fuel costs for the industry have risen substantially over the last forty years [2]. The fuel costs play important role in fishing in all nations, and although the actual proportion varies between fisheries it can reach up to 50%, for example in the motorized canoe fleet in Senegal [3].

Increasing fuel prices has urged governments to provide fuel-subsidies to support the viability of fishing operations [2][4][5]. Malaysian government has been spending millions of money to reduce diesel cost through subsidy. Every year, oil price keeps rising thus increasing the amount of money that the government has to spend on oil subsidy. The effects of Malaysian government policy on subsidy rationalization to offshore fishing vessel starts in 2011 when Malaysian government decided to drawback subsidy incentive to offshore fishing vessel which resulting to the factors that drive local fishing industry to run at a loss and uncompetitive [6][7].

Impending possible fuel crisis in local fishing industries in future has caused researchers to investigate the possibility of utilization of alternative cheaper fuel such as Compressed Natural Gas (CNG). CNG is Natural Gas stored under pressure of up to 250 bars. Malaysia has a gas reserve which the size is three times more than petroleum oil. This is a reason why industry player should start turning to gas as the alternative fuel. The use of CNG as an alternative fuel for marine engines has been increasing rapidly over the past few years. The first classed ship approved to run on CNG is bulk carrier 'Accolade II' built in Australia in 1982.It recorded 50% savings from fuel and engine maintenance cost in 3 years. In 1985, two sister ferries 'Klawata' and 'Kullet' are modified to run on dual fuel mixture of approximately 90% CNG and 10% diesel fuel. It had gained significant cost savings and 5 years pay back of investments [8].

CNG as an alternative fuel in an engine could be divided into three main types namely Dual fuel, Bi-fuel, and Dedicated fuel. The aim of this paper is to focuses on dual fuel diesel. Dual fuel diesel engine (traditionally) is a diesel engine that has been fitted with additional devices allowing it to utilize natural gas as a supplemental fuel. A basic difference between the dual fuel engine and the conventional oil fuel diesel is that the dual fuel engines compress a mixture of gas and air while diesel engine only compresses air. The dual fuel engine type has a number of quality attributes. According to [9] a primary benefit is better control over the air/fuel ratio resulting in better performance, fuel economy, and lower emissions than engine operating on dedicated (100%) gaseous fuel. Dual fuel engine maintains the same power output of a standard diesel engine while simultaneously running mainly on natural gas [10]. Many researchers have demonstrated that the performance of dual fuel not only comparable but exceeding limitations particularly in emission control as study by [11][12].

There are several types of engine conversion of dual fuel systems e.g. conventional diesel pilot, using spark ignition or direct pressure. In this paper, the High

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Pressure Direct Injection (HPDI), as shown in Figure-1 has been selected due to its performance.

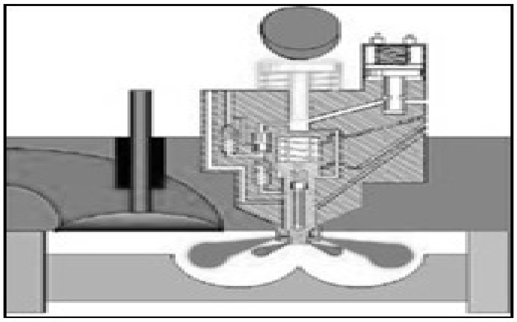

Figure-1. Schematic diagram of HPDI injector [13].

This HPDI will inject both diesel and gas simultaneously into the combusting chamber. This system requires less modification and proved to be more efficient compared to pilot injection [13]. This paper intends to analyse fuel saving dual fuel engines for Malaysian offshore fishing vessel and assess its stability condition.

Conversion to dual fuel engines

This section started with collecting the technical data of existing fishing vessel on vessel operation, engine system and general arrangement. For this study, a basis vessel was selected to simulate the fuel saving that can be made using the dual fuel engines. Hence, Perintis Purse Seiner was chosen as the basis ship.

The conversion includes the modification required and components of the CNG kit. The calculation of fuel consumption analysis was carried out to determine the potential saving can be gained. Finally, general arrangement plan of the proposed system was constructed to indicate the final layout and location of CNG tank.

Vessel profile

The vessel profile selected for this study is from Perintis Purse Seiner which is classed as C2 offshore fishing vessel operated at Kuala Terengganu, Terengganu. Both technical data and general arrangement of this vessel are presented in Table-1 and Figure-1.

Table-1. Perintis technical details.

Length Overall, LOA (m)	25.97
Length Between Perpendicular, BP (m)	23.38
Length Water Line, LWL (m)	21.25
Breadth (m)	6.25
Draught Amidships, T (m)	1.48
Displacement Volume (m3)	84.48
Engine Horsepower (kW)	235
Specific fuel consumption (g/kW) At 1800 rpm	214

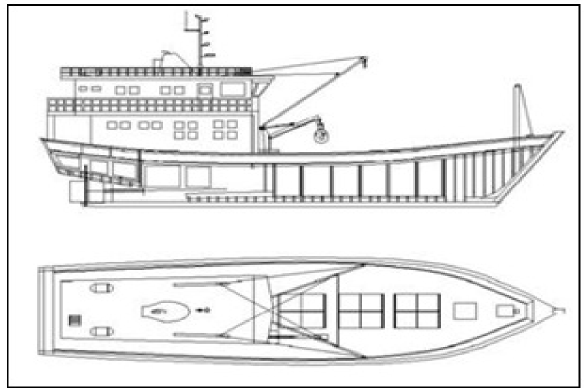

Figure-2. General arrangement of Perintis.

Engine conversion

The process of engine conversion from diesel engine to dual fuel engine includes retrofitted existing diesel engine with addition of HDPI and gas control unit, installation of CNG tank and piping system.

Figure-2 shows dual fuel flow diagram. It starts with gas flow from CNG cylinder to gas regulator. The pressure will drop and diesel fuel is pumped at same pressure to fuel rail. The control unit functions to control the ratio of gas and diesel trough injection into combustion chamber.

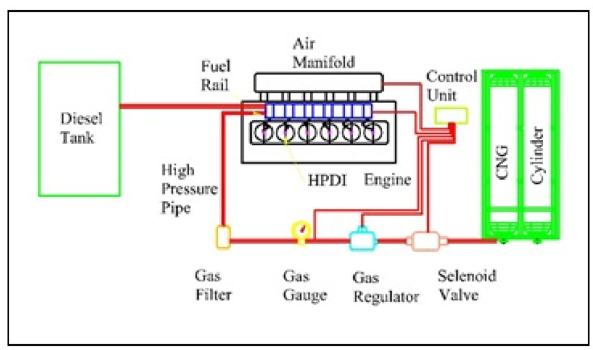

Figure-3. Dual fuel system flow diagram.

FUEL SAVING ANALYSIS

Fuel consumption

The fuel saving analysis was carried out to compare the fuel rate of dual fuel to conventional diesel engines. This to confirms that the fuel saving can be gained as mentioned previously.

To calculate the engine fuel consumption, some experiments had to be done on the engine to accurately determine the various factors such as torque, brake power and volume flow rate of dual fuel. In this study, following assumptions were made to simplify the fuel consumption analysis as follows:

a) Torque for diesel and dual fuel are equal
b) Input powers are equal for both diesel and dual fuel for at constant speed and load conditions.

c) Fuel substitution ratio (SR) is set as 0.3 for Diesel and 0.7 for CNG

Specific fuel consumption is defined as the measurement of fuel flow rate per unit power output. It is inversely proportional to efficiency of the engine as lower values of specific fuel consumption are favourable for higher performance. In this study, power output measured is brake power. Brake specific fuel consumption is defined as:

$$bsfc = \frac{\dot{m}_f}{BP} \times 3.6 \times 10^6 \quad (1)$$

bsfc = specific fuel consumption (g/kW.hr)
m· = mass flow rate of fuel (kg/s)
BP = brake power (kW)

Using the formula, brake specific fuel consumption for diesel and gas at maximum operating conditions were calculated. For dual fuel operation, fuel substitution ratio (SR) is set as 0.3 for Diesel and 0.7 for CNG. These ratios of fuel consumption are set for safety purpose. If any problem occurs, such as leakage, diesel can be used to generate auxiliary system such as water pump. Local fishing vessel is made from wood, which is not 100% watertight. Therefore, it is important to ensure that the water pump is ready to be operating in any conditions .The input power is taken to be the same for both diesel fuel and dual fuel since the engine is operating under the equal speed and load conditions. Input power (IP) was calculated using Equation 2. Figure-3 shows variation of the equivalent of brake specific fuel consumption for various engine speeds for both diesel and dual fuel operation. As shown in the figure, BSFC for dual fuel operation is noticeably lower compared to original diesel operation. Brake specific fuel consumption of dual fuel system at maximum load was estimated as 205.31g/kW.hr. It is about 4% lower compared to diesel engines. The data revealed good value of fuel saving can be gained by using dual fuel operation.

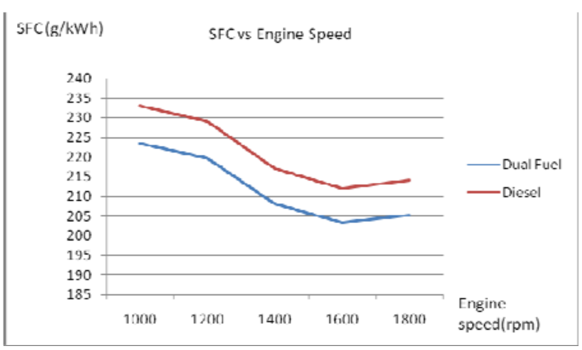

Figure-4. Specific fuel consumption comparison.

Fuel amount

The total of fuel amount the fishing vessel in dual fuel mode was calculated based on fuel consumption rate after conversion to dual fuel system. Table-2 summarize the fuel rates and operation profiles of Perintis. The average distance is about 70 nautical miles per day with average speed of 12 knots.

Table-2. Fuel amount.

Distance	70 nautical miles @ 129.64 km
Average speed	12 knots @ 6.17 m/s
Specific fuel consumption for diesel	214 g/kWh
Specific fuel consumption for CNG	186.05 g/kWh
Specific fuel consumption for dual fuel	205.31 g/kWh
Fuel density (diesel)	0.84g/litre
Power at 85% of MCR	235 kW
Fuel consumption for a day = specific fuel consumption x 85% MCR power x duration	205.31 g/kWh x 235 kW x 6 = 289.5 kg
Fuel consumption for a trip (7 days)	289.5kgx7=2026.5 kg
Total fuel consume in liter	2026.5 /840g.litre^{-1} = 2412.5

It was estimated that the fishing vessel operates its engine at average speed for 6 hour per day. For 7 days per trip, it consumes about 2412.5 liters. This amount is combination of diesel and CNG. For CNG itself, the calculation was based on fuel substitution ratio of CNG to diesel as 70:30. At 200 bar filling pressure, the weight of CNG is estimated as 1 kg equal to 1 kg of diesel in liter. Thus, it is estimated that total amount of CNG is about 1689 liters. Therefore the amount of diesel consumed is 30% of total fuel consumption which is 723.8 in liters. The total amount of diesel including 10 % margin is about 965 liter. It is noted that it's only 4% fuel savings as mentioned previously. However, the actual savings can be more in term of monetary savings as CNG is noticeable has lower price compared to diesel.

As mentioned previously, Malaysia government has cut of subsidy for offshore fishing boats where the 2015 market fuel price for diesel has increased to RM 2.00 per liters from subsidized prices of RM1.25 per liters meanwhile CNG is RM 1.05 per liters. Total fuel cost of fishing vessel operating on conventional diesel engine is RM5029 meanwhile total fuel cost of fishing vessel operating on dual fuel system is RM3704. It's about 26 % fuel cost savings can be achieved through of using CNG as alternatives fuel.

The dual-fuel using diesel and CNG for offshore fishing vessel are proven to offer lower fuel consumption as well as practical and environmental advantages. However, poorly executed conversion works can lead to higher fuel consumption, lower power efficiency and high maintenance costs. Thus, it is suggested that the engine modifications to assure low fuel consumption with acceptable engine performance by optimizing fuel mixture ratio, compression ratio and engine cooling. Hence, in another words, the savings was mainly contributed by lower price

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of CNG. As long as CNG price remain cheap and well subsidize by government, the using of dual fuel system onboard the Malaysia fishing vessel will be noteworthy.

TRIM AND STABILITY ANALYSIS

General arrangement

The general arrangement was developed to show a detail layout of dual fuel system. As shown in Figure-4, the plan specifies the location of engine and CNG cylinder. Structural modifications to upper deck were made including attaching a support structure to hold the CNG cylinders.

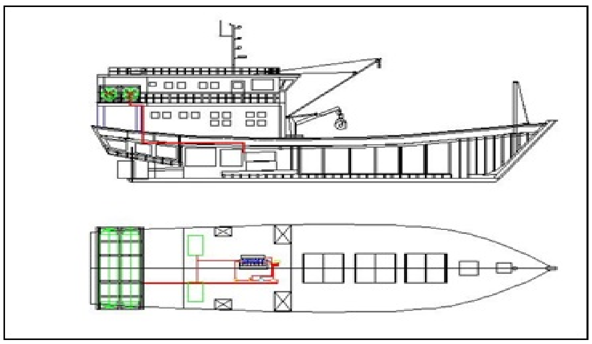

Figure-5. Proposed location of CNG cylinder.

Stability analysis

Stability analysis was carried out to determine the stability of the boat after conversion to dual fuel. This is important as it become a major requirement in ensuring the safety of boat. Initial stability of boats can be evaluated in terms of form parameters and vertical centre of gravity. However, in Malaysia, there are no requirements for the stability of wooden fishing vessels which means there is no stability requirement or stability guidelines are available. Current practice is by applying standard IMO criteria to all fishing vessels or to the larger vessels since there is no stability regulation of small craft. Several researches have been conducted to provide better guidelines for stability and safety of fishing vessels as discussed in [14,15]. For this stability analysis, the vessel stability is assessed using stability criteria provided by [ ] as shown in Table-3.

Table-3. Stability criteria [16].

Criteria	Value	Units
a) Area 0 to 30	0.055	m.deg
b) Area 0 to 40	0.090	m.deg
c) Area 30 to 40	0.03	m.deg
d) Max GZ at 30 or greater	0.200	m
e) Angle of maximum GZ	25.0	deg
f) Initial GMt	0.350	m

Transverse stability was determined by plotting the GZ curve. GZ curve is the curve of statical stability that shows the variation of GZ at various angles of heels. By using GZ curve, stability of vessel can be assessed using selected stability criteria as discussed previously.

The centre of gravity, VCG of the vessel is calculated as 2.09m. Previous VCG is found as 2.06m, this signify some reduction in GM due to rise in VCG. The calculations of the initial metacentric height GM and righting lever GZ were made and illustrated in Figure-5. The waveform profile was set to be flat with assumed wavelength of 6.054m and wave height of 0.459m.

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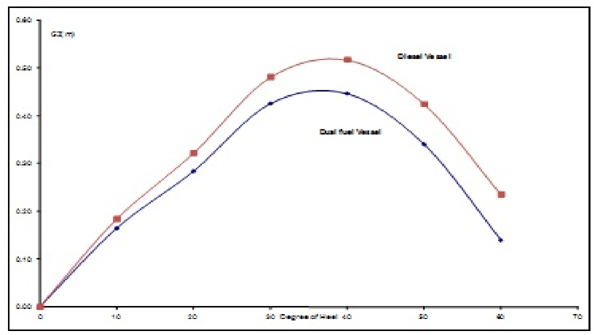

Figure-6. GZ curves.

As can been seen from the graph, area from 0° to 30° is 0.11m.rad. Meanwhile, the area from 0° to 40° is 0.20m.rad. Maximum GZ at 30° was found to be 0.45m with 37° angle of maximum GZ. Initial GM is 0.75m. All the parameters were drawn and compared to stability criteria as presented in Table-4.

Table-4. Results of transverse stability assessment.

Criteria	Actual	Required	Evaluation
a) Area 0 to 30	0.11m.rad	≥0.055m.rad	Pass
b) Area 0 to 40	0.20m.rad	≥0.09m.rad	Pass
c) Area 30 to 40	0.09m.rad	≥0.03m.rad	Pass
d) Max GZ at 30 or greater	0.45m	≥0.02m	Pass
e) Angle of maximum GZ	37°	≥30°	Pass
f) Initial GM	0.75m	>0.35m	Pass

The stability criteria results of fishing vessel after conversion to run on dual fuel suggest that the vessel is yet to be considered safe and stable as the results have proved it has passed all the stability criteria with high positive margins.

Trim analysis

Longitudinal stability considers the vessel stability through two important parameters which are trim and the final draughts at the perpendiculars of the boat. As expected, the trim obtained was increased from 1.366m to 1.516m by stern and only lead to 0.03m changes in draft at FP and AP. The results of stability assessment signify that the boat is practically unaffected by the changes and thus has no adverse effects to boat safety.

CONCLUDING REMARKS

This paper study on the possibility of gaining fuel savings by using dual fuel engines in offshore fishing vessel and analyse its stability condition. The results revealed that significant savings can be gained with no adverse effects on its stability condition. Hence, it is concluded that dual fuel system using diesel and CNG could be an environmental friendly system for Malaysian offshore fishing vessel as the effort of reducing an operation cost and increase the turnover fish landing together providing promising better environment for future.

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