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Minimizing Ship Weight and an Investigation of Sustainability

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ABSTRACT

This study discusses the use of green energy and new materials for ship building. We investigate the issue of lowering ship fuel consumption through using high steel plates instead of normal steel plates, propose the use of 'green fuels' (gas fuels) as a source of inboard power and discuss the possible utilization of solar energy and wind power for support engine fuel and power usage on vessels.

Key words: Sustainability, ship optimization, green energy

INTRODUCTION

Material has always been a key element in shipbuilding. The most widely used material is steel. However, the commonly used ordinary steel plates are usually much thicker than high strength steel plates and play a significant part in the total ship weight. Reducing empty ship weight will lead to a reduction in fuel consumption. This paper evaluates the use of high strength steel plates instead of normal steel plates to reduce material thickness. Due to increasing consumption of non-renewable energy like petroleum and the urgency to improve the ecological environment, energy conservation has become an important business consideration globally. LPG/CNG/LNG are considered as "Green fuel". Compared with an ordinary fuel engine (petrol and diesel), gas fuelled engines reduce: Carbon Oxide (CO) emissions 70~90%, HC emissions 30~40%, NOX emissions 20~40%, CO_2 emissions 20% and Particulate Matter (PM) more than 95%. This technology has already been applied on car engines successfully and is widely used all around the world. Similar systems can also be installed on vessels; Dual Fuelled Diesel Engines (DFD engine) are one of the most suitable devices. In this study, DFD engines are proposed (Ehsan and Bhuiyan, 2010). Solar power and wind energy are proposed as the most attractive renewable energy sources for ships. However, low energy density and storage difficulties make it hard to use these two energy sources as the main fuel on ships but rather they are proposed as adjunct sources of power.

MATERIAL DESIGN

By using material having mechanical properties greater than those of ordinary strength hull structural steel, the minimum hull girder section modulus required can be reduced significantly therefore reducing plates' thickness in certain positions is possible to accomplish. The following contents are detail calculations for the parts of plates that need to be optimized. The minimum required hull girder section modulus, SM, at amidships is given by Eq. 1 (ABS, 2005):

$$SM = C_1C_2L_2B\ (C_b+0.7) \tag{1}$$

Where:

- C_1 = Amidships coefficient and equal to 0.0451 L+3.65 61 = L<90 m
- C_2 = Length coefficient 0.01
- L = The length of vessel, in m (ft)
- B = The breadth of vessel, in m (ft)
- C_b = The block coefficient at design draft, based on the length, L, measured on the design load waterline. C_b is not to be taken as less than 0.60

When either the top or the bottom flange of the hull girder or both, is constructed of higher-strength material, the section modulus may be reduced by the factor Q, as in Eq. 2 (ABS, 2005):

$$SM_{hts} = Q(SM) \tag{2}$$

where, SM_{hts} is minimum required hull girder section modulus with high strength material.

In this study, H47 steel is selected as high strength material so Q value corresponds to 0.62 for all situations as shown in Table 1. Three positions of the ship are optimized which include: shell plating, deck plating and bottom structure.

Bottom shell plating: The term “bottom plating” refers to the plating from the keel to the upper turn of the bilge or upper chine. The thickness of the bottom shell plating throughout is not to be less than that obtained from Eq. 3 (ABS, 2005):

$$T = (s\sqrt{h})/254+2.5 \tag{3}$$

Where:

- t = Thickness of bottom shell plating, in mm (in)
- s = Frame spacing, in mm (in)
- h = Depth, D, in m (ft), but not less than 0.1 L or 1.18 day whichever is greater

When using higher-strength material and where longitudinally framed, it is to be not less in thickness than that obtained from the following equation (ABS, 2005):

$$t_{hts} = (t_{ms} - C)\sqrt{Q} + C \tag{4}$$

Table 1: Material factor and strength (ABS, 2005)

Steel grade	Material factor (Q)	Strength reduction factor
Ordinary Strength Steel	1.00	1.000
H32	0.78	0.950
H36	0.72	0.908
H40	0.68	0.875
H47	0.62	0.824

Where:

t_{hts} = The thickness of higher-strength material, in mm (in)
t_{ms} = The thickness, in mm (in), of ordinary-strength steel, as required by preceding paragraphs of this section, or from the requirements of other sections of the rules, appropriate to the vessel type
C = The thickness coefficient equal to 4.3 mm
Q = As defined above

Side shell plating: The term "side plating" refers to the plating hold frames of dry cargo vessels and located at the side position of vessel. The side shell plating is not to be less in thickness than that obtained from:

$$t = (s\sqrt{h})/268+2.5 \tag{5}$$

where, t, s and h are defined as above.

Side-shell plating, where constructed of higher-strength material, is to be not less in thickness than that obtained from:

$$t_{hts} = (t_{ms} - C)[(Q + 2\sqrt{Q}/3)] + C \tag{6}$$

where, t_{hts} and t_{ms} as defined above.

All deck: In general, applications of higher strength materials are to take into consideration the side suitable extension of the higher strength material below the deck, forward and aft. Care is to be taken to avoid the adoption of reduced thickness of material such as might be subject to damage during normal operation. The thickness of the deck plating for longitudinally framed decks, where constructed of higher strength material, is to be not less than required for longitudinal strength, nor is it to be less than that obtained from Eq. 3 (ABS, 2005). With high strength material use Eq. 4.

Center girders: The vessel considered in this work is defined as Single Bottoms with Floors and Girders. Single-bottom vessels are to have center keelsons formed of continuous or intercostal center girder plates with horizontal top plates. The thickness of the keelson and the area of the horizontal top plate are to be not less than that obtained from the following equations. The girders are to extend afar forward and aft as practicable (ABS, 2005).

Center-Girder Plate Thickness Amidships is given by:

$$t = 0.063\ L+5\ mm \tag{7}$$

Where:

t = Thickness of center-girder plate, in mm (in)
L = Length of vessel, in m (ft)

With high strength material use Eq. 6.

Table 2: Empty ship weight comparison (ABS, 2005)

Empty ship weight before optimization	1678513.1 kg (1678.5 ton)
Empty ship weight after optimization	1494799.4 kg (1494.8 ton)

Side girders: Side girders are to be arranged so that they are not more than 2.13 m (7 ft) from the center girder to the inner side girder, from girder to girder and from the outer girder to the lower turn of bilge. Forward of the amidships one-half length; the spacing of girder on the flat of floor is not to exceed 915 mm (36 in.). Side girders are to be formed of continuous rider plates on top of the floors. They are to be connected to the shell plating by intercostal plates. The intercostal plates are to be attached to the floor plates. In the engine space, the intercostal plates are to be of not less thickness than the center girder plates (ABS, 2005). The scantlings of the side keelsons are to be obtained as Side Girder and Intercostal Thickness Amidships:

$$t = 0.063\ L+4\ \text{mm} \tag{8}$$

With high strength material use Eq. 6:

Floors: The minimum thickness of floors is not to be less than that obtained from the following Eq. 9 (ABS, 2005):

$$t = 0.0.1\ hf+3\ \text{mm} \tag{9}$$

where, hf is the floor depth in mm (ft).

With high strength material use Eq. 6. The model used in the approach came from Shanghai ML Marine Design Co., Ltd. which is one 86.01×21.36×5.20 m Deck Cargo Barge. This model is a non-propeller, single bottom, nobody on barge. Expect from the optimized position, all the other dimensions for the sample vessel came from original design draft; this approach keeps the original material and structure data for the rest position of the vessel for calculating total ship weight. By using the above equations, the empty ship weight prior to optimization and after optimization is shown in Table 2. Eleven percent reduction is achieved from the original design (i.e., design prior to optimization).

DUAL FUEL DIESEL ENGINE

A Dual Fuel diesel engine is usually built from an ordinary diesel engine. Builders will fit it with additional devices allowing it to utilize natural gas as a supplemental fuel. This engine type is a true diesel engine and requires some level of diesel to ignite the gas fuel. This engine type has been available to industry since the 1930's. Its use was almost exclusive to power generation where the fuel supply was a pipeline source. Its availability was almost exclusively through the Original Equipment Manufacturer (OEM) (Brett, 2008).

The dual fuel engine type has a number of quality attributes. A primary benefit is that of fuel flexibility, operating with cleaner cheaper natural gas when available and on diesel alone when necessary. Many hundreds of these engines were employed in the US during the rural electrification period (Reddy *et al.*, 2008). After grid power became economical, many of these engines were discarded. With uncertainties in power availability, emissions and the current price of diesel, dual fuel engines are gaining a new popularity (Einang, 1996).

A single cylinder diesel engine (Model S1100DONGFENG, China) widely used in Bangladesh was chosen for this study. The engine was designed to operate in a narrow speed range (about

Table 3: Property of the sample engine (Ehsan and Bhuiyan, 2010)

Brand	Dongfeng
Model	S1100D
No. of cylinders	One, Horizontal
Type	4-Stroke, DI-17°BTDC
Displacement	903 cc
Bore x stroke	100×115 mm
Compression ratio	20
Rated power (12 h)	11 kW (15 PS)
Rated speed	2200 rpm
Cooling	Water, Radiator
Lubrication	Forced, SAE30
Fuel tank	16 liters
Starting	Manual

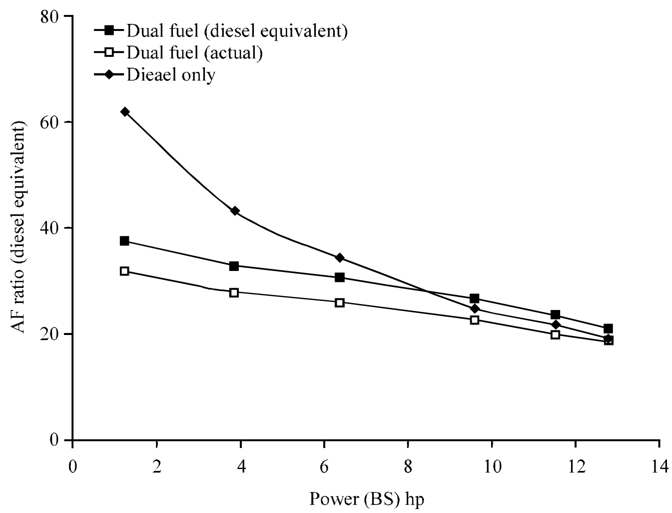

Fig. 1: Air-fuel ratio (AFR) in dual operation (Bhuiyan *et al.*, 2010)

1800-2200 rpm), with a rated speed of 2200 rev/min. The engine was tested at constant rated speed throughout its power range with diesel-only and dual fuel operations using a standard hydraulic (water-brake) dynamometer (TFL-109, Germany) and the test results were de-rated to standard conditions according to BS5514 (Ehsan and Bhuiyan, 2010).

In Table 3, the attached specification of the engine shows a maximum rated power of 15 metric horsepower (PS) at 2200 rpm, in real testing however, the maximum power was found to be limited to about 13 hp when running on diesel. Later the engine was tested at 10, 30, 50, 75, 90 and 100% of the actual rated load, at a constant rated speed of 2200 rpm in dual fuel mode. For each setting, diesel was used as the pilot fuel for starting auto ignition while natural gas from line supply was used as the main fuel. For each power level the proportion of natural gas replacing diesel was gradually increased by manually opening a control valve to determine the maximum possible diesel replacement using natural gas with satisfactory engine performance. The overall accuracy of Brake Power and Brake Specific Fuel Consumption rates are expected to be within ±2% error band (Ehsan and Bhuiyan, 2010).

As showed in Fig. 1 and 2 natural gas has a different Air-fuel Ratio (AFR) in dual operation. AF ratio decreases sharply with increased load, as the fuel flow (diesel-only or dual) increases while

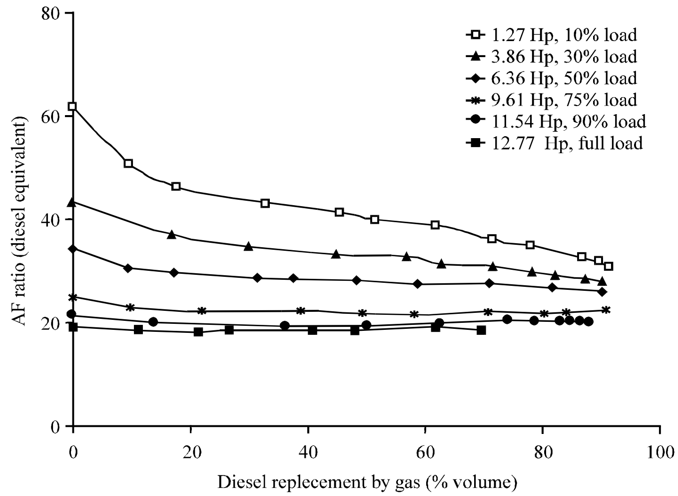

Fig. 2: Air-fuel ratio (AFR) in dual operation (Ehsan and Bhuiyan, 2010)

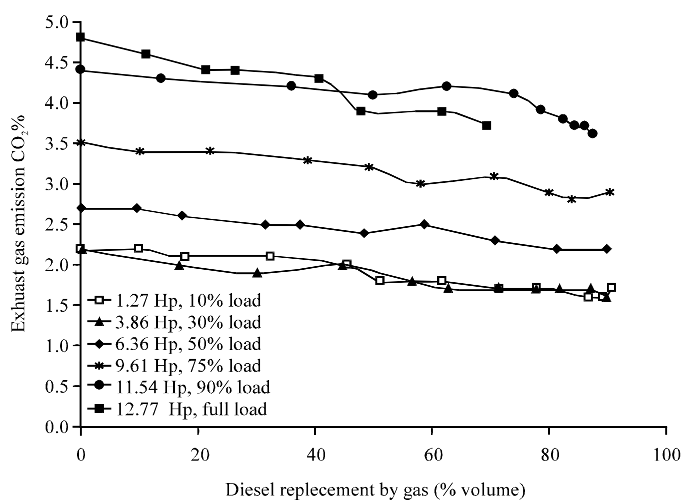

Fig. 3: CO_2 Emission of the sample (Ehsan and Bhuiyan, 2010)

the air flow decreases slightly. On the other hand, natural gas has a higher requirement of air for stoichiometric combustion (17.2 by mass) compared to diesel (14.6 by mass). As a result of a high rate of diesel replacement with natural gas the engine is restricted in terms of maximum power produced. For loadings of 10, 30, 50 and 75% of the actual rated load the engine could produce the required power with up to 90% diesel replacement. At 90% load up to 88% replacement was possible but at full load this was restricted to 69% diesel replacement only (Ehsan and Bhuiyan, 2010).

Figure 3 and 4 show the variation of CO_2 and CO emission from the engine with increased diesel replacement of natural gas at different power levels. Exhaust analyzer measurements showed that generally, the volume of CO (less than 0.1%) formed and the proportion of CO_2 (2-5%) in the exhaust gas was very low which is typical of a diesel engine. With higher diesel replacement the level of CO_2 generation decreased and CO emission was found to increase (Brett, 2008). The late burning of the mixture with higher diesel replacement levels of natural gas had caused more fuel

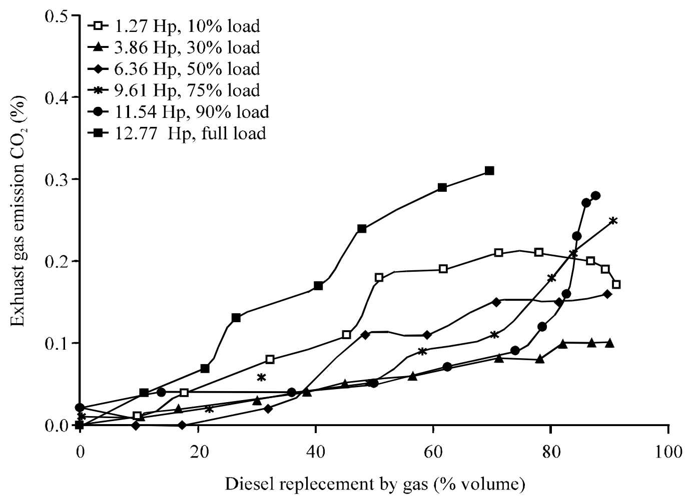

Fig. 4: CO Emission of the sample (Ehsan and Bhuiyan, 2010)

to remain partially unburned increasing the formation of carbon monoxide and decreasing the proportion of Carbon-dioxide. This would contribute to the reduction of efficiency at light loads (Ehsan and Bhuiyan, 2010).

SOLAR AND WIND ENERGY

Photovoltaic (PV) system as a support power supply system for lighting on vessels: Recently, solar powered cars and aircrafts are generating more research and development. Compared with cars and planes, ships have a much larger dimension, thus they have more surface area from which to generate solar power. The low travelling speed of ships make it convenient to have solar power devices on board, also these devices would have little effect on the total ship weight and stability. Other factors (like deck and upper hatch cover insulation) can be considered at the same time (Yasin *et al.*, 2011). Ferries usually have flat and wide tops and comparatively small hull structures. According to recent solar power technology, ferries should be considered first as a trial (Thwaites, 2006). Other types of vessels (tugboat, container ship, bulk cargo vessel, etc.) have less deck space. The only space that can be used to install solar panels is at the top of the deckhouse and on different balusters (which have limited space). However, these kinds of ships have few passengers on board (mainly sailors), so installing solar panels for bath or heating during winter time is a rewarding choice to reduce fuel consumption (Yasin *et al.*, 2011).

As shown in Table 4, for both reliability and quality factors, using PV system on vessel is similar as using diesel fuelled generator. And at the diesel price of 7 Yuan kg^{-1}, both plans will cost same amount of money in 20 years operation. However, the price of diesel is more than 10 Yuan kg^{-1} recently, therefore, using PV system may cost less (Al-Hadidi and Ibrahim, 2008).

Sail usage on vessels: According to sails character, the vessels for sail installation should have high stability and plenty of deck space. Usually, bulk cargo carrier and crude oil tankers are the most suitable types. Bulk cargo carriers, with flat and wide decks, make it easy to arrange the location of sails. Depending on modern sail-making technology and the ships travelling condition, cyclometer sails with rigidity frame is most suitable for this type of vessel (Marchaj, 2003). For

Table 4: System power supply versus diesel fuelled generator supply (Tong, 2008)

Compare item	PV system power supply	Diesel fuelled generator supply
Power Supply Reliability	Basically Satisfactory	Satisfactory
Power Supply Quality	Satisfactory	Satisfactory
Total Cost for operating 20 years	366300 Yuan	336940 Yuan

vessel at certain velocity, when it is influenced by certain direction and velocity wind, energy ΔPS gain from the wind can be expresses in Eq. 10:

$$\Delta = \frac{V_s}{75\eta}(X_{WF} + X_R + 13\beta^2 X_H) \tag{10}$$

Where:
V_s = The velocity wind apply on sail
X_{WF} = The force apply on sail
X_H = The resistance of water
X_R = The resistance caused by rudder operation
η = it the push efficiency

Force on sail X_{WF} use Eq. 11 and 12:

$$X_{WF} = \frac{1}{2} C_{xmax} \rho V_S^2 S \tag{11}$$

$$C_{xmax} = C_{Lsin}\theta\text{-}C_{Dcos\theta} \tag{12}$$

Where:
C_{xmax} = The maximum push coefficient
θ = Angle between ship stem center line and wind direction
S = The area of sail
C_L = The lift coefficient
C_D = The drag coefficient

Velocity of wind Vs is obtained from Eq. 13 and 14:

$$V_A^2 = V_S^2 + V_C^2 - 2V_S V_C \cos(180° - \theta - \beta) \tag{13}$$

Because usually **β** is very small, Eq. 13 can be simplified as:

$$V_A^2 = V_S^2 + V_C^2 + 2V_S V_C \cos\theta \tag{14}$$

Drag force caused by rudder operation X_R is expressed in Eq. 15:

$$X_R = 52.3A_R\, V_S^2 (1-\omega)^2 \frac{6.13A_C}{A_C + 2.25}(1 + 3.6S_{1.5})\sin^2\delta \tag{15}$$

Where:

A_R = The rudder area
ω = The flow rate
A_c = The rudder length versus width rate
S = The Surge rate
δ = The rudder angle

From the computation, $\Delta PS = 5.77\times10^5$ kWh was obtained; while the main engine's fuel consumption rate is around 178 g/kWh+5%, the vessel average velocity is 12 knot. By using the estimating software we can easily get total fuel saving of 102.7 ton; the sail produces 0.229 kWh energy per square meter. During the voyage, 3.4 ton fuel can be saved every day due to the use of sails. According to the annual wind frequency, the annual fuel saving can reach 1060.8 ton. With higher vessel velocity more wind energy will be applied by sail, by using different coefficient for the different types of vessel, the sail area needed can be obtained.

RESULTS

For the minimizing of empty ship weight case, 11% reduction of empty ship weight was achieved from the original design. DFD engine's exhaust analyzer measurements showed that generally, the volume of CO (less than 0.1%) formed and the proportion of CO_2 (2-5%) in the exhaust gas was very low. By using sailor on vessels 3.4 ton fuel can be saved every day, the annual fuel saving can reach 1060.8 ton.

DISCUSSION

CO_2 emissions from global shipping amounts to 10% of total transport CO_2 emissions worldwide.(Nwaichi and Uzazobona, 2011) This result alerts the shipping industry of the urgency of building environmentally friendly ships. In the process to minimizing the ship weight presented in this paper, we reduced the total ship weight by 11% and the CO and CO_2 emissions of DFD engines are considerably lower than diesel engine. Finally, the usage of solar and wind energy will contribute to saving significant amounts of fuel every year. Future areas of research include risk analysis, safety factors and refueling issues.

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REFERENCES

ABS, 2005. Rules for Building and Classing Steel Vessels Under 90 Meters (295 Feet) in Length, 2006. American Bureau of Shipping, Houston, TX., USA., pp: 17-81.

Al-Hadidi, M.M. and Y.K. Ibrahim, 2008. Renewable energy resources, study case for Jordan. Trends Applied Sci. Res., 3: 165-173.

Brett, B.C., 2008. Potential market for LNG-fuelled Marine vessels in the United States. Ph.D. Thesis, Department of Mechanical Engineering, Massachusetts Institute of Technology, Massachusetts, USA.

Ehsan, M. and S. Bhuiyan, 2010. Dual fuel performance of a small diesel engine for applications with less frequent load variations. Int. J. Mech. Mechatron. Eng., 9: 30-39.

Einang, P.M., 1996. Natural gas as a ferry fuel. http://www.sintef.no/upload/MARINTEK/PDF-filer/Publications/The%20Norwegian%20LNG%20Ferry_PME.pdf

Marchaj, C.A., 2003. Sail Performance: Techniques to Maximise Sail Power. 2nd Edn., Adlard Coles Nautical, USA., ISBN-13: 9780713664072, pp: 23-67.

Nwaichi, E.O. and M.A. Uzazobona, 2011. Estimation of the CO_2 level due to gas flaring in the Niger Delta. Res. J. Environ. Sci., 5: 565-572.

Reddy, K.T., P.R. Reddy and P.V.R. Murthy, 2008. Experimental investigations on the duel fueled diesel engine. Asian J. Scientific Res., 1: 429-436.

Thwaites, T., 2006. Hello solar. New Scientist Reed Business Information Ltd., pp: 52-55.

Tong, X., 2008. Aplication of PV system on fresh water vessels (Chinese). Zhe Jiang Insititute of Technology, pp: 1-17.

Yasin, A., G. Napoli, M. Ferraro and V. Antonucci, 2011. Modelling and control of a residential Wind/PV/Battery hybrid power system with performance analysis. J. Appl. Sci., 22: 3663-3676.