Energy conservation: Passenger and container ships case studies

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The main objective of this paper is to enhance the overall performance of Marine Diesel Engine power plant onboard passenger and container ships through a proposed fresh water generator and combined heat and power system. Fresh water produced will be used for drinking, cleaning and washing purposes, contributing to the high demand consumption particularly onboard passenger ships. The main idea for the proposed fresh water generator is to use the waste heat recovered from scavenging air to provide the heat required to evaporate sea water under vacuum converting it into steam. Energy conservation system for exhaust gases in container ships has a lot of advantages which include reducing fuel consumption for ships, increasing the overall efficiency and reducing the pollutant emissions which go out into the atmosphere. Results of the suggested fresh water generator indicated that for a typical installed propulsion power of 3350 hp consuming 10 ton of fuel oil per day, 8 tons of fresh water will be produced. This amount will be sufficient for 20 persons per day. For a number of diesel engines equipped with the proposed fresh water generator the specific fresh water generation was found to be about 100 gm/hp/hr. Combined heat and power plant is one of the methods used to improve engine performances and a better environment which can reduce emissions and fuel consumption by 4.5%.

ان الهدف الرئيسى لهذه الورقة هو تحسين الاداء العام لمحركات الديزل البحرية لكل من سفن الركاب وسفن الحاويات وذلك من خلال دراسة أفضل الطرق لتوفير الطاقة حسب نوع السفينة وعدد الركاب. ولما كانت سفن الركاب تحتاج الى الماء العذب فكان يجب أن تكون الدراسة على توفير الماء العذب من حرارة العادم ولكن الحال يختلف فى سفن الحاويات حيث أن الماء الموجود يكفى أفراد الطاقم ولكن نحتاج فيها الى توفير الطاقة بتحسين أداء المحطة من خلال محطة مركبة من الديزل والبخار. بالنسبة لسفن الركاب أوضحت النتائج توفير ٨ طن/يوم مياه عذبة التى تكفى لاحتياجات ٢٠ شخص يوميا وبصفة عامة فان توفير المياه العذبة يكون بمعدل ١٠٠جم/حصان/ساعة. أما بالنسبة لسفن الحاويات فقد تم توفير حوالى ٤,٥% من استهلاك الوقود وذلك تؤدى الى انخفاض الانبعاثات الضارة بنفس النسبة.

Keywords: Fuel demand, Emissions, Thermal efficiency, Energy conservation

1. Introduction

Currently computer technology is used to electronically control large size marine diesel engines, which run on heavy fuel oil. [1]. The advantage of using electronic engines is reduced fuel consumption at part and full load conditions because the maximum pressure can be kept constant over a wider range without overloading the engine. Smoke emission at part load will also be reduced [2].

Global energy consumption in the last 50 years has increased at a very rapid rate. Renewable energy resources, such as solar energy, wind, and biomass energies are also expected to increase their share of the energy use in terms of volume. The spare capacity for oil production has decreased from 3 Million Barrels a Day (MBD) in December 2002 to just 1.7 MBD in December 2004. This is a result of the low investments in oil exploration in the 1990s which, in turn, was due to the low real prices of oil during that period [1].

Presently, the price of crude oil barrel has been changed, see fig. 1. Thus, in view of these high prices, a diesel engine with low fuel consumption will be highly appreciated.

2. Diesel engine heat balance

The energy in the exhaust gas forms the largest amount of losses (approx. 25% of the fuel input) and is considered the most attractive for recovery of the diesel engine losses. The energy loss from the engine cooling water and the charge air cooler are less than the exhaust gas loss, however, recovery process is considered economical in the light of recent change in oil prices.

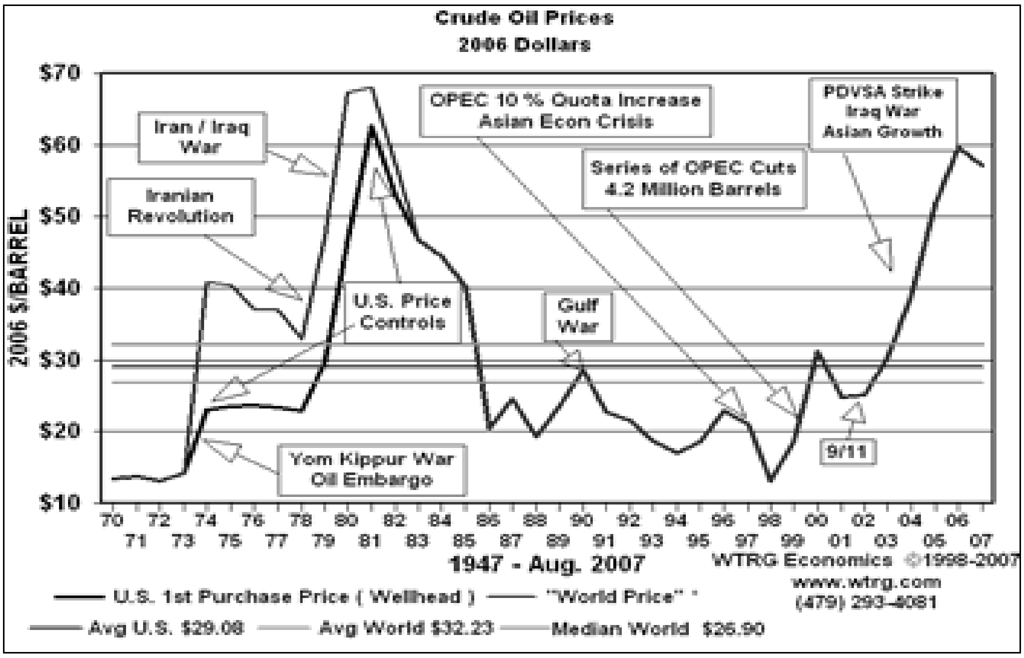

Fig. 1. Prices of crude oil barrel from1970 to Aug. 2007.

3. Parameters of Waste Heat Recovery (WHR)

There are three sources for waste heat; they are exhaust gas (220 °C - 265 °C), air coolers (air temperature 130 °C – 170 °C at MCR), and fresh water jacket cooling (65 °C - 80 °C). Relative percentages are shown in fig. 2 for a typical diesel engine.

The proposed fresh water generator, using waste heat from scavenging air, in addition to conventional fresh water generator, using waste heat from cooling water, will be sufficient for the required amount of water in passenger ships. Introducing a fresh water generator in the scavenge air system is expected to raise the overall thermal efficiency of the marine diesel engine. Waste Heat Recovery (WHR) systems include fresh water generation, combined heat and power, shaft generator, and turbocharger.

3.1. Air mass flow rate calculation

In modern two-stroke turbocharged engines, a charge air cooler is necessary. Compression will raise the air temperature and a charge air cooler is fitted to reduce the temperature of the air between the turbocharger and the engine inlet manifold, causing increased air density at lower induction temperature. The engine is maintained at safe working temperatures and the lower compression temperature reduces stress on piston rings, piston and liner. The mass flow rate of air passing through the proposed fresh water generator can be calculated from:

$$m^{\cdot}_{air} = m^{\cdot}_{f} \frac{A}{F} \lambda \,. \qquad (1)$$

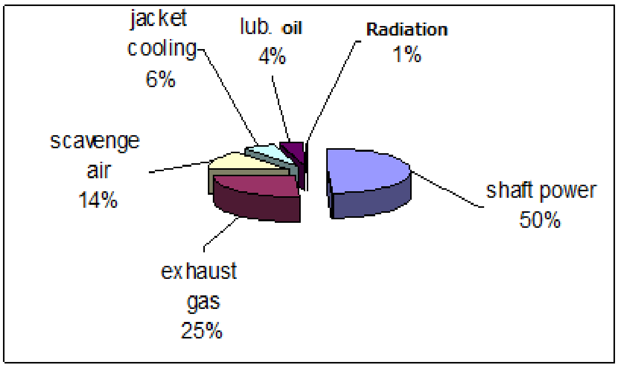

Fig. 2. Heat balance of a Sulzer 12RTA96C engine [3].

3.2. Design of proposed fresh water generator evaporator

In the sea water evaporator, sea water passes in the tubes and hot air passes outside the tubes. Considering the double-pipe heat exchanger, the fluids may flow in counter flow, and the temperature profiles for this case are indicated in fig. 3.

The theoretical heat transferred from scavenging air to sea water in the evaporator can be determined from the following equation:

$$Q = \dot{m}_{sw}\, Cp_{sw}\, \Delta t_{sw} = \dot{m}_{air}\, Cp_{air}\, \Delta t_{air} \, . \tag{2}$$

The heat transfer from hot air to sea water can take the following form:

$$Q = U_e \; A_t \, \Delta T_m \, , \tag{3}$$

where,

$$\Delta T_m = \frac{(T_{h1} - T_{c1}) - (T_{h2} - T_{c2})}{\ln\left((T_{h1} - T_{c1})/(T_{h2} - T_{c2})\right)} \, . \tag{4}$$

3.3. Case study

The following case study is used to illustrate the procedure explained in the previous sections. Consider a ship propelled by a 2-stroke 4 cylinders diesel engine, (MAN B and W S46MC), having an output power/ cylinder = 1310 kw, specific fuel consumption, at max continuing rating, of 174 g/kw.h and having a speed of 129 r.p.m. Other particulars pertaining to operating conditions are given in table 1.

The engine particulars and the associated operating conditions yielded the following results concerning the amount of water generated as well as evaporator and condenser dimensions

3.4. Cost of fresh water generator

Having designed the fresh water generator, it would be necessary to examine the facility of installing it on the propulsion system. The cost of different elements of the proposed fresh water generator (evaporator, condenser, pumps,…etc) was estimated based on the local market price in the year 2008. It was found out that the total cost of the proposed fresh water generator reached about 2600 US$. This generator will produce about 12 ton/day of fresh water. Based on a 20 US$/ton of water, the generated water produced annually (270 days) will save about 65,000 US$, which is almost 2.6 times the initial cost of the fresh water generator.

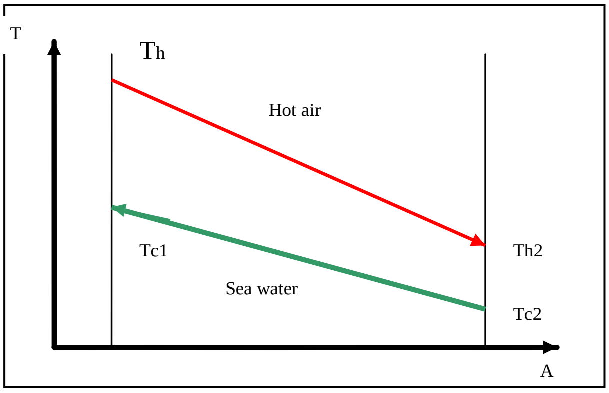

Fig. 3. (T-A) Chart for temperature profiles counter flow in double-pipe heat exchanger (in evaporator) [6].

Table 1
Operating conditions for the selected case study

Air fuel ratio A/F	18.3
Air inlet temperature to the evaporator T_{h1}	133 °C
Air outlet temperature from the evaporator T_{h2}	45 °C
Sea water temperature before entering condenser t_2	30 °C
The quantity of sea water passing through evaporator ton/day	1.781kg/s
Air flow rate	4.63 kg/s
Tube diameter d	0.0245 m

Table 2
Design parameters for MAN B&W S46MC evaporator and condenser

Air flow rate	400.4 ton/day
Quantity of sea water passing through evaporator.	1.781 kg/s
Quantity of fresh water generated	0.1386 kg/s
The quantity of sea water passing through condenser $\dot{m}_{c\,sw}$.	1.254 kg/s

3.5. Effect of installed proposed fresh water generator on overall efficiency

Consider a SULZER 12 RT FLEX 96C engine, having output power of 68640 KW, at MCR, the engine specific fuel consumption 172g/kw.h using heavy fuel oil with calorific value = 42720.8 kj/kg. A typical energy distribution in the diesel engine with waste heat recovery is illustrated in fig. 4.

If the above engine is equipped with fresh water generator in the scavenge air system, the quantity of fresh water generated will be 327.201 ton/day. The addition of the proposed fresh water generator to the scavenge air system will result in the overall efficiency increase by about 1%. This is illustrated in fig. 5.

In addition to the case study, a number of diesel engines producing power ranging from 722 to 5490 kw/cylinder is examined and the amount of fresh water generated with the proposed generator is calculated and plotted in fig. 6. A new parameter is introduced denoted as specific fresh water generated in analogy to specific fuel consumption. For the range of power tested, an average value of 108 gm/kw.hr was obtained.

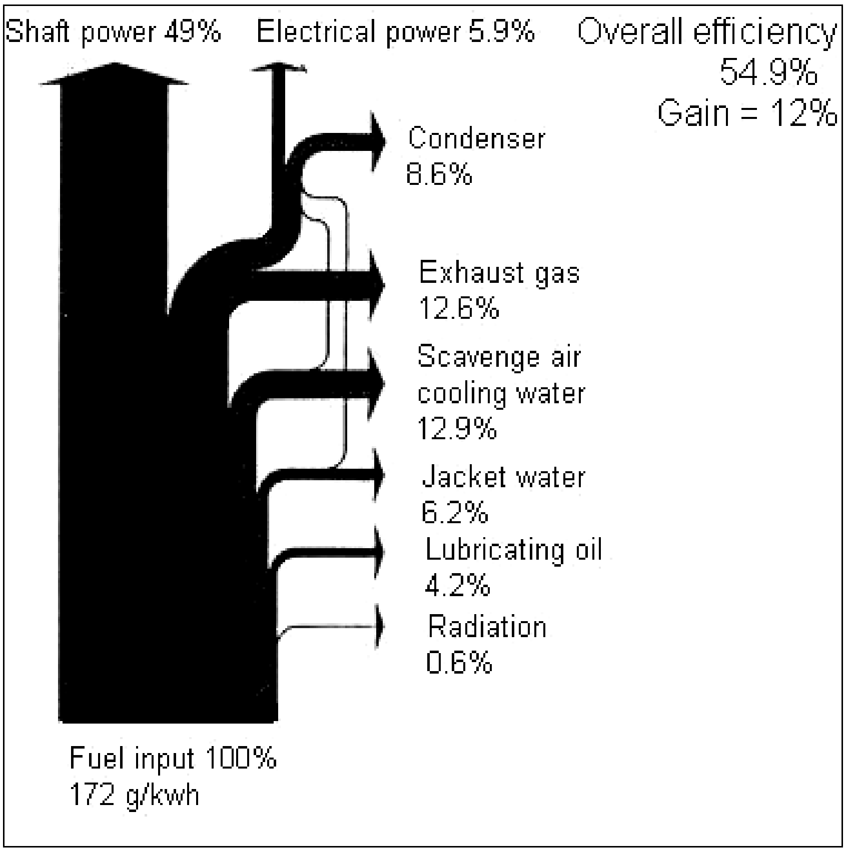

Fig. 4. Total heat recovery for 12RT FLEX 96C engine showing the 12% gain in overall efficiency for the total heat recovery plant. [3].

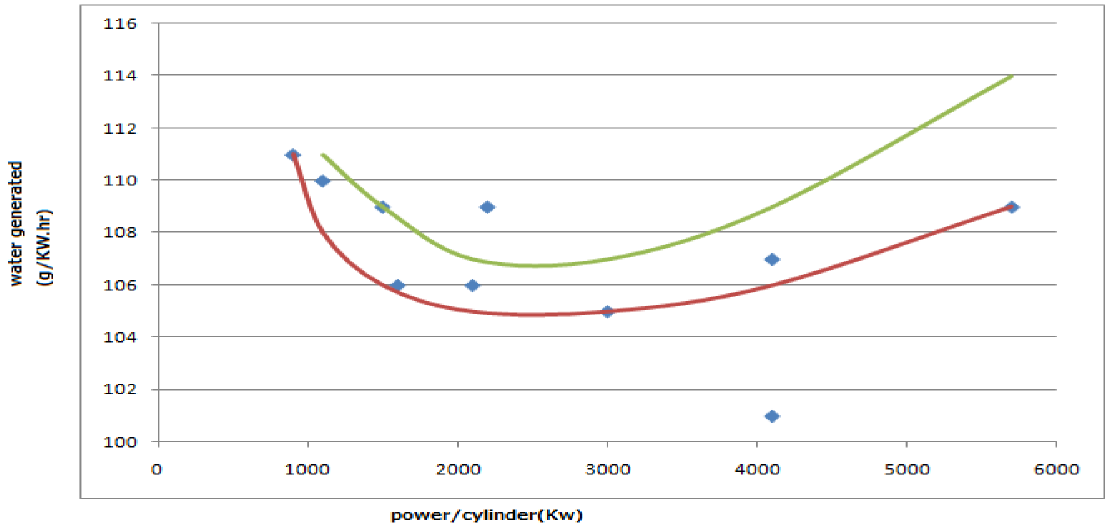

Fig. 5. Relationship between power per cylinder and quantity of fresh water generated.

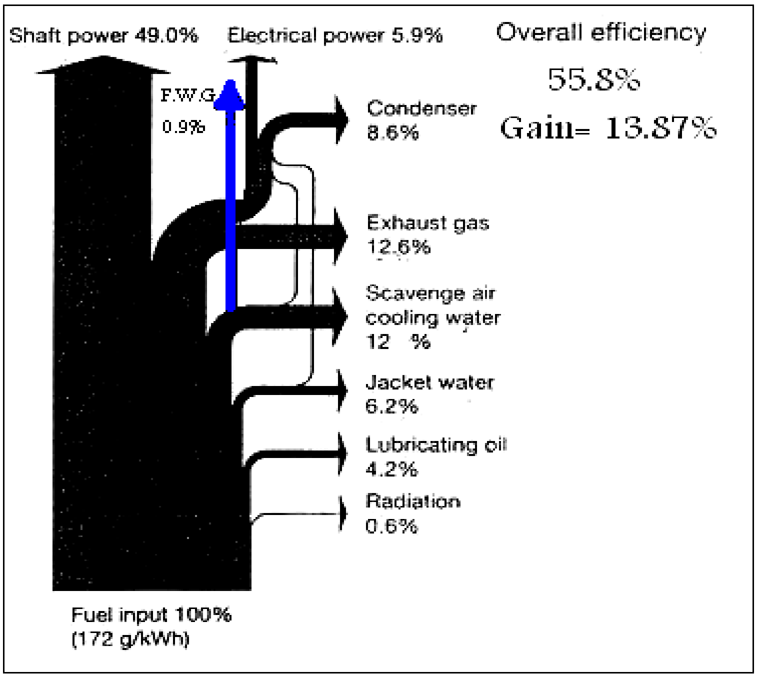

Fig. 6. SULZER12 RT- flex 96C engine after fresh water generator installation.

4. Fresh water generated

The relation between the amount of water generated (using the proposed fresh water generator) and the engine power (or amount of fuel consumed) is given in fig. 7. Depending on the power installed one can use such a chart to determine the expected amount of water generated. Alternatively, for a certain required fresh water on board (particularly for passenger ships), one can examine the needed power to generate such amount. Typically, for a 20 board, about 8 ton of fresh water per day will be needed based on 400 lit/person/day. An engine power of 3350 hp equipped with fresh water generator will be required for this case.

5. Energy conservation in container ships

The container ship (Melbourne) is taken as a case study. Melbourne is a modern gearless Panama container vessel which was built by South Koreas Samho Shipyard in 1998. It joined schiffahrts fleet in April 2002.The main parameters and specifications of the selected container ship are shown in table 3.

6. Heat recovery system" combined diesel and steam turbine CODAS"

Much has been published about reducing exhaust gas emissions from marine diesel engines with attention being on either controlling the generation of the emissions inside engine cylinders, removing the emissions by after treatment of the exhaust gases, or in the case of SOx emissions restricting the fuel specification. There is very little margin left in the large marine diesel engine for reducing CO_2 emissions through improving engine thermal efficiency. After the 1973 oil crisis, considerable investment was put into reducing engine fuel consumption with the result that for some years the largest-bore engines have had an overall thermal efficiency of almost 65%.

Combined Cycle power is commonly used to run intermediate load plants, operating more hours than a peaking plant. Combined power plants also produce less NOx and CO_2 emissions than a gas turbine plant. Fig. 8 shows a Combined Cycle Plant. There is a considerable amount of energy available in the exhaust gases of a gas turbine engine that can be used as the energy source for another system. An example of combined system is combined Diesel and steam turbine (CODAS) as shown in fig. 8.

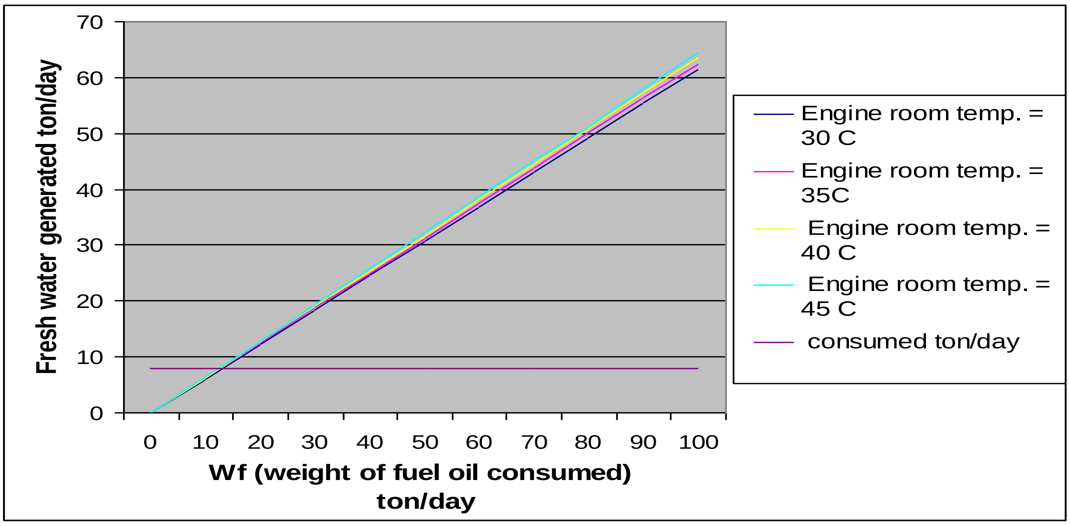

Fig. 7. Relation between fresh water generated and weight of fuel consumed.

Table 3
Technical specifications of Melbourne container ship

Length over all	231.5 m
Breadth	32.2 m
Draft	12.2m
Speed	23 kn
Dead weight	45400 ton
Gross tonnage	36600 ton
Main engines types	Hyundai B&W 8k80 MC-C
Brake power of main engines	28880 kw
Fuel consumption	107 ton/day

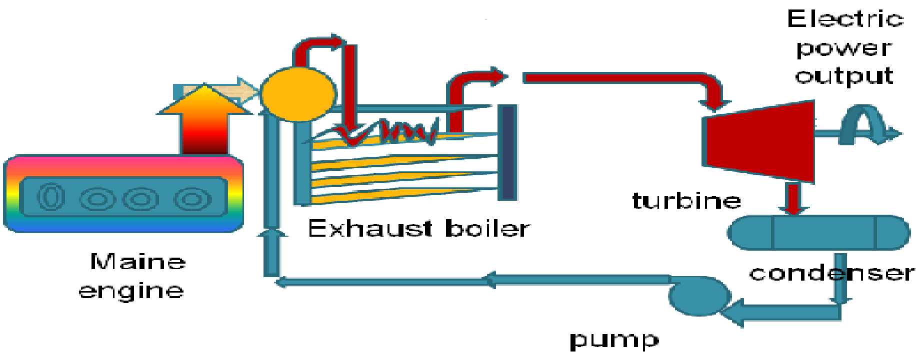

Fig. 8. CODAS system.

Engine heat balance and performance analysis for the container ship (Melbourne) can be expressed in the following equation.

$$Q_a = BHP + Q_{cw} + Q_{rad} + Q_{exh}. \quad (5)$$

The added heat can be calculated from,

$$Q_a = m_f * Cv . \quad (6)$$

The radiation heat can be assumed to be 3% of added heat. The cooling heat can be calculated from,

$$Q_{cw} = m_{cw} * BHP * Cp_{cw} * \Delta cw. \quad (7)$$

Exhaust gases can be calculated from,

$$m_{exh} = Q_{exh} / (Cp_{exh} * (T_{exh} - T_{amb})). \quad (8)$$

The amount of exhaust heat affect on the steam turbine output power, also the steam turbine efficiency affected the recovered energy as shown in the following fig. 9.

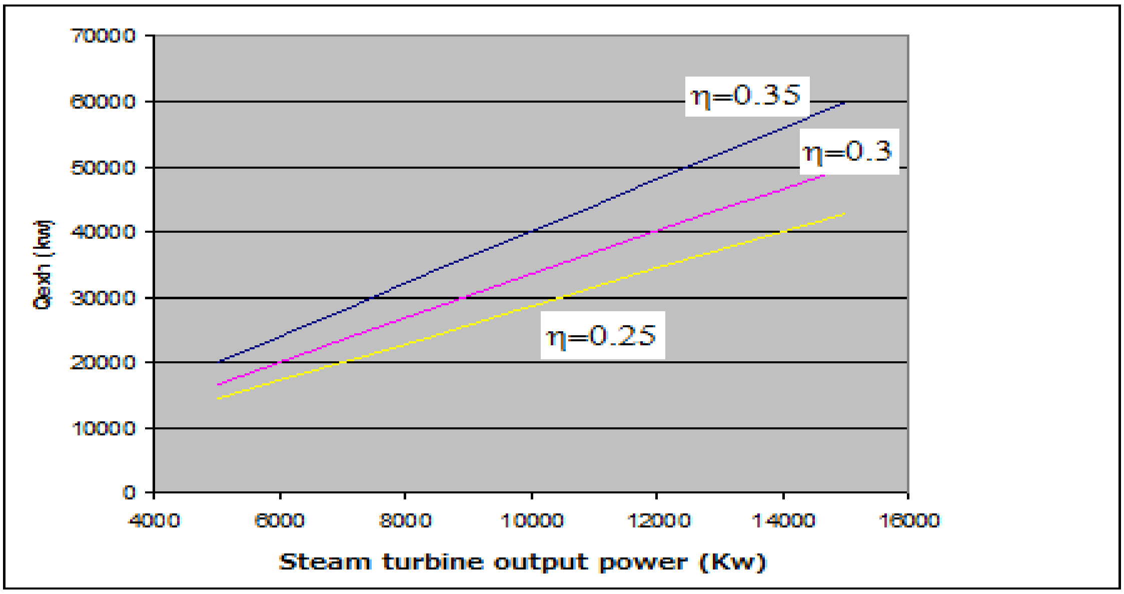

Fig. 9. Steam turbine output power and engine exhaust gases output relation at different efficiencies.

Also from the environmental point of view the carbon quantity, sulfur, and hydrogen have been decreased. For Carbone quantity, it has been decreased from1.077 kg of exhaust /s to 1.029 kg/s. For hydrogen quantity, it has been decreased from 0.123 kg/s to 0.118 kg /s. For sulfur content, it has been decreased from 0.012 kg/s to 0.0118 kg/s.

7. Conclusions

Because of the increasing demand for fossil fuel and the increase in its prices in the last period in addition to the decrease of the international reserves of fossil fuel and the researches done proved that the international oil reservoirs will vanish in 2050, scientists try making the best use of the energy in fuel through use of the exhaust energy called energy conservation.

There are a lot of losses from engines every day in addition to pollutant gases which spread in the atmosphere. So, this lost energy needs to be conserved. Energy conservation system has a lot of advantages which include:

i) Reducing fuel consumption for ships
ii) Increasing the overall efficiency
iii) Reducing the pollutant emissions into the atmosphere
iv) Saving lost money

Based on the first case study (passenger ship) outlined in this paper a number of remarks are observed:

1. The inclusion of fresh water generator utilizing scavenging air in a marine diesel engine power plant will contribute to the overall thermal efficiency.
2. An outlined method is developed for estimating the amount of fresh water generated for a typical installed diesel engine power plant.
3. A new parameter to indicate the specific fresh water generated is introduced and values for a range of power were estimated.
4. A chart relating the amount of fresh water generated and the amount of fuel consumed was developed.

From the container ship case study (2) the fuel consumption will be reduced by 4.5 %, and the exhaust gases will be reduced.

Finally, more work is required to enhance the performance of marine diesel engines through examining the different parameters affectingtheir operation.

Nomenclature

A	Surface area in m^2,
A/F	Air fuel ratio
BHP	Break horse power (hp),
Cp	Specific heat for air at constant pressure = 1.005 kj / kg,
Cp_{exh}	Exhaust gases specific heat in kcal/(kg*k),
Cp_{cw}	Cooling water specific heat in kcal/(kg*k),
$\dot{m}_{air}$	Air flow rate in kg/s,
$\dot{m}_{f}$	Mass of fuel consumed ton/day,
$\dot{m}_{sw}$	The quantity of sea water passes, through evaporator ton/day,
m_{cw}	Cooling water circulation in kg/s,
m_{st}	Steam mass flow rate in kg/s,
Q	Theoretical heat transfer from scavenging air to sea water in W,
Q_{rad}	Radiation heat losses in kw,
Q_{cw}	Cooling water heat in kw,
Q_{exh}	Exhaust heat in kw,
T_1	Engine room temperature in °K,
T_2	Temperature after turbo charger in °K,
T_{c1}	Sea water outlet temperature from the evaporator in °C,
T_{c2}	Sea water inlet temperature to the evaporator in °C,
$Tcc1$	Sea water outlet temperature from condenser in °C equals $T_{sw\ out}$,
$Tcc2$	Sea water inlet temperature to condenser in °C equals $T_{sw\ in}$,
Th_1	Air inlet temperature to the evaporator in °C,
Th_2	Air outlet temperature from the evaporator in °C,
ΔT_m	Log Mean Temperature Difference (LMTD) in °C,
ΔTmc	Log mean temperature difference in °C,
$Thc1$	Steam inlet temperature in °C,
$Thc2$	Fresh water outlet temperature in °C,
t_2	Sea water temperature before entering condenser,
Uc	Overall heat transfer coefficient, for steam condenser,
u	Sea water velocity in m/s, and
X	Dryness fraction.

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