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Efficiency Analysis of Tanker Ship Fuel Usage by Applying Exhaust Gas Boyler and Turbo Generator Power Plant

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Abstrak

Efforts to save fuel consumption on tankers is absolutely necessary because in shipping it always faces waves and currents that inhibit the speed of the ship so that the shipping time is longer. If this happens, the fuel consumption of the ship will increase and waste will occur. This study aims to analyze fuel savings on tankers as oil supply vessels to meet domestic fuel needs. Savings are carried out by utilizing the heat energy of the exhaust gas of the propulsion main engine as a steam generator in the exhaust gas boiler (EGB). The steam production process takes place when the ship is in a sailing condition where the main engine has reached the maximum rotation. Exhaust gas boilers work with 16.5 bar pressure steam used as turbo generators to replace auxiliary engines to work as electricity generators as long as ships are on the cruise. In order to ensure the condition of the steam production system remains normal at work pressure so that the turbo generator working system remains stable for that exhaust gas boiler is equipped with automatic equipment both in the filling water supply system and ignition auxiliary boiler ignition system. Thus, as long as the ship is in shipping all the electricity needs are charged to the turbo generator, so practically with the application of this system resulting in savings in fuel consumption of MFO / MDO type vessels reaching 11.2% on each cruise.

Keywords: Tanker ship, exhaust gas boiler, turbo generator, fuel efficiency

1. Introduction

The occurrence of large currents and ocean waves results in longer shipping times for ships which means the use of ship fuel also increases. This has led to a waste of use of the ship's moving fuel including large-scale vessels (tankers).

The ship drive consists of a main engine that uses marine fuel oil (MFO) or marine diesel oil (MDO) and auxiliary engines as a generator. Usually the tanker / container drive consists of 1 main engine unit and 3 auxiliary engine units while for passenger ships 2 main engines and 3 to 5 auxiliary engines, depending on the size of the ship and the number of passengers. This study discusses the efficiency of using fuel tankers by applying boiler exhaust gas and turbo generator with a capacity of 800 kW.

This study discusses the efficiency of using fuel tankers by applying boiler exhaust gas and turbo generator with a capacity of 800 kW. Research on the efficiency of ship fuel use has been carried out, among others: efficiency in the use of fuel oil through the freshwater electrolysis process [1], installation of tools on the propeller [2], heat recovery steam generator (HRSG) on the installation of Gas and Steam Power plants [3], Bow ship modification [4], onboard DC grid system with turbo generator and generator shaft. [5], a gas turbine control modeling system in PWR type nuclear power plants (pressurized water reactor) [6]. However, these studies have not discussed the problem of the use of main engine exhaust gas heat. This research focuses on the use of main engine exhaust gas heat, by installing a gas exhaust boiler installation and 1 turbo generator unit to overcome the problem of the ship's fuel waste.

2. Backgrounds

Generally, an exhaust gas boiler (EGB) is generally called an economizer, which is an equipment consisting of the installation of pipes that are designed in such a way that the exhaust gas cylinders from the main engine of the vessel are equipped with automatic valves connected to an auxiliary boiler installation mounted on other parts in the engine room as shown in Figure 1.

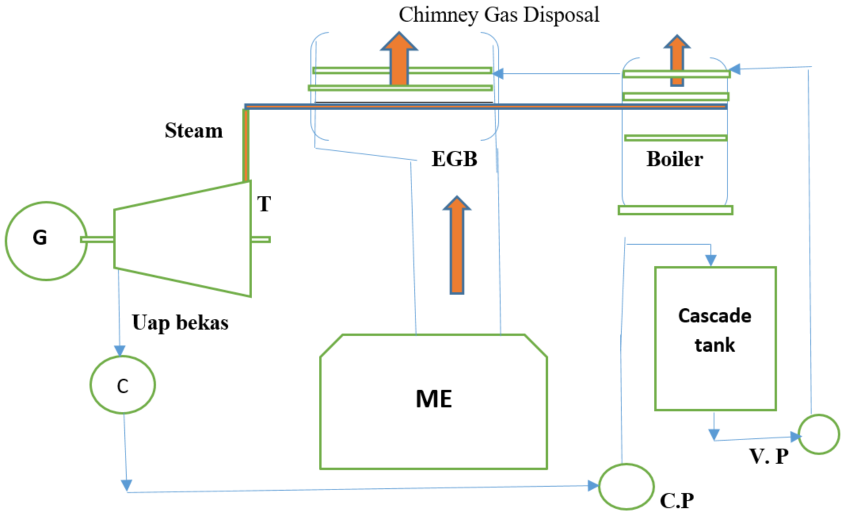

Figure 1. Installation of the exhaust gas boiler and its equipment

Figure 1 shows that the exhaust gas boiler is operated when the ship is shipping in the free sea, where the shipbuilding telegraph system (maneuver) has been completed, the main engine (ME) at maximum speed (full speed). Through a thermometer installed on each ME cylinder head showing a temperature of 325 0 C, this indicates that the steam production system at EGB has worked, the steam pressure on the steam drum (steam drum) reaches 16.5 kg / cm2, then the installation system setup The turbo generator is immediately carried out then the panel shows a 380 volt voltage, and a frequency of 60 Hz by parallelizing the generator first and then releasing the current from the auxiliary engine (AE) so that the sailing vessel already uses a turbo generator by applying EGB, the fuel savings will the difference can be seen when compared with ships that do not implement a steam generator heat recovery system (HRSG). If in the voyage there are currents and waves coming from behind the ship, then the ship gets a fairly large thrust, this has an impact on the main engine to occur over speed, the rotation will rise, and cause considerable vibration, then for the safety of the main engine round must be lowered in half-style position thus resulting in a decrease in exhaust gas temperature as heat energy from EGB this results in decreased steam production, pressure below 14.5 kg / cm2, then the burner of the Auxiliary boiler at the position of burning fuel occurs to produce steam so that the turbine's work remains stable. If the current and wave change direction from the front, the load of the vessel becomes large again, then the engine rotation must be raised again at the maximum speed/full speed position by increasing the injection pump regulator (injection pump) the exhaust temperature of the main engine rises to normal temperature, the gas boiler exhaust produces steam under normal conditions, the pressure reaches 16.5 kg / cm^2 automatically burner from the auxiliary boiler stop (cut in & cut out controller settings) as shown in Figure 1.

In conditions like this the use of fuel in the main engine occurs with a savings that is of great value, while in the auxiliary boiler there is the use of extra fuel which has a smaller value than the savings on the main engine. calculation by formula.

The use of fuel in condition 1 compared to the use of fuel in conditions2 is equal to the number of turns in condition 1 of power 3 compared to the number of turns in condition 2 of power 3 is equal to engine power at condition 1 compared to power in condition 2, or in equation written:

$$\frac{B1}{B2} = \frac{n1^3}{n2^3} = \frac{N1}{N2} = \frac{V1^3}{V2^3}. \quad (1)$$

The equation will be used in the calculation of efficiency in the discussion of the proposed system.

The Rankine cycle or steam power cycle is the simplest theoretical cycle that uses steam as a working medium as used in a steam power center. Steam power center consisting of supporting components in which the work system of the component works and contributes according to its function, namely: Boiler, steam heater (super heater), Steam Turbine, Condenser, boiler water pump and generator electricity. Boilers (1) where the burner burns the fuel absorbed by the boiler water in the pipes occurs the steam production process, comes out of the steam drum into the steam heat (super heater) (2) pressure and temperature (enthalpy) is increased then enter the steam turbine rotating an electric generator (3), a low pressure steam former enters the condenser (4) there is a process of condensing used steam into condensate water by a boiler water filling pump (feed pump), the water re-enters the boiler, the process as shown in Figure 2.

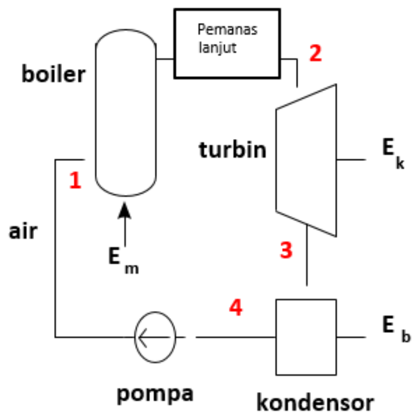

Figure 2. Installing a turbo generator.

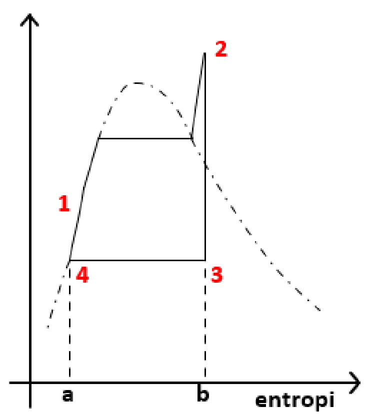

Figure 3. Steam entropy process scheme.

The amount of energy coming in from the results of combustion of fuel through the boiler is Em, while the effective energy available on the turbine shaft is the working energy Ek which is used as a turbo generator, while the energy wasted through the condenser is Eb. Assuming that the loss that occurs is very small then Eb is the total energy lost, expressed in equations (2) to (4) as follows:

$$Em = Ek + Eb \quad (2)$$

$$Ek = Em - Eb \quad (3)$$

$$\text{Efficiency } (\eta) = \frac{out\ put}{Input} = \frac{Ek}{Em} = \frac{Em-Eb}{Em} \times 100\ \% \quad (4)$$

with: E_m is the amount of heat from combustion which is 100%, E_k is the amount of heat from the steam which is useful to drive the turbine and generator, E_b is the amount of heat that is wasted and in the form of used steam which then enters the condenser to be used as kettle filler water back through kettle filler pump.

Figure 3, is a constellation entropy temperature diagram, which explains that the area of 1-2-3 and 4 is the amount of output energy E_k, while the area of a-b-3-4 is the energy wasted E_b, the area of a-b-2-1 represents the amount of energy input from burning fuel E_m. To increase the effectiveness of the cycle is done by reducing the condenser pressure. Ideally the lowest condenser pressure is the saturation pressure according to the lowest temperature of the cooling water or the air used as the receiver. In the temperature-entropy diagram this means lowering the temperature line 4-3. This process is carried out using cooling water in the condenser which has a lower temperature (sea water).

3. Heat balance in the boiler

Boiler performance parameters such as efficiency and evaporation ratio, heat energy used and wasted are detected in the Boiler Energy Balance (BEB) diagram. BEB is a balance of the total energy entering the boiler to heat energy which leaves the boiler in a different form. The values written on the Sankey diagram, namely the heat balance, are values that have been accurately generated from research, including by the US Department of Energy, by Exergy Design Joint Research Lab at Osaka University Japan, published by the Australian Government, Department of Energy Resources and Tourism in 2010. [4].

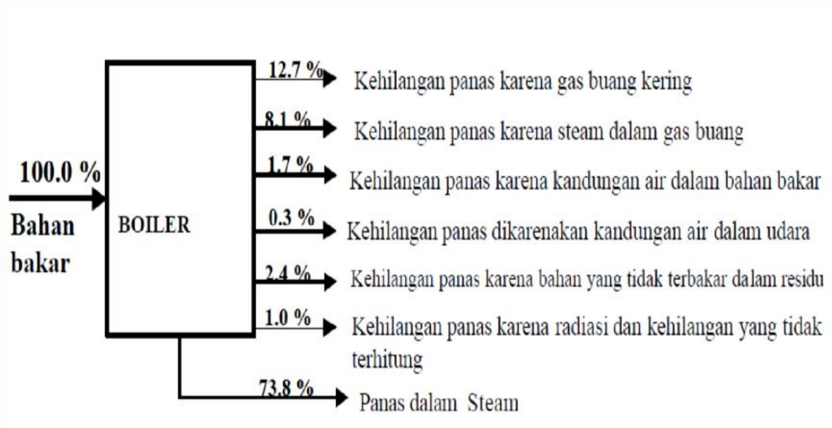

Figure 4. Energy flow diagram of the heat balance

Figure 4 shows that the combustion of fuel in the boiler, heat energy lost, including heat lost due to exhaust gas, heat is lost in the water content of the fuel, heat is lost due to unburned fuel, and heat loss due to radiation all amounted to 26.2%, so useful heat (boiler efficiency) is usually written ηk = 73.8% is as steam-forming heat, this means that every 1 kg of fuel (100%) with the value of combustion (NP) kJ / kg, then the heat energy that is useful as a steam forming energy (Q)

$$Q = ῃk \times NP \quad (5),$$

another formula are

$$Q = S \times (Ê_{IK} + Ê_{IR}) \text{ kj / hour} \quad (6),$$

$$Ev = S / Be \ (\text{kg.uap / kg.bb}) \quad (7)$$

and

$$ῃ_k = \frac{Ev\,(h1-h2)}{LHV} \ x\, 100\,\%\ (\%) \quad (8)$$

where Q is the amount of heat needed to form steam (kJ/kg) of fuel, NP is the value of combustion, namely the amount of heat produced from each kg of fuel in complete combustion (kJ/kg), S is the amount of steam produced (kg /hour), ÊIK is steam enthalpy coming out of the boiler - enthalpy of water enters the economy unit kj; ÊIR is the enthalpy of steam coming out of reheater - enthalpy enters the reheater unit of kj / kg, Ev is the evaporation factor. B_e is the use of fuel per hour of units of kg / hour ῃ k is the percentage of boiler boiler efficiency (%).

4. Heating Value

To calculate the value of combustion from fuel in the type of fuel used in boilers or diesel engines, the step is to know the content of the elements of the fuel. In general, the type of HFO / MFO consists of elements of Carbon (C), Hydrogen (H), Oxygen (O) Sulfur (S), Ash (A), Water (W) and the percentage of the elements listed on the type of product from used fuel as shown in Table 1.

Table 1. The content of elements in HFO types. (ASTM Standard D-396) [4]

Elements	Percentages
Carbon (C)	86,10 %
Hydrocarbons (H_2)	11,90 %
Oxygen (O)	0,28 %
Nitrogen (N)	0,20 %
Sulfur / belerang (S)	1,3 %
Ash (A)	0,02 %
Water (W)	0,2 %

The formula for calculating the value of combustion (NP) and Q, there are 2 types, namely:

a. The highest combustion value (HHV) = gross caloric value (GCV) is the combustion value of the total heat energy of all components of the fuel that is oxidized with O_2.
b. Lower Heating Value, LHV = net caloric value (NCV) is the value of combustion or the amount of heat energy after being reduced by the heat used to evaporate the liquid in the fuel, whether the liquid is mixed in the fuel or liquid formed by the oxidation process.

The formula for calculating HHV and LHV as follows:

$$Q_{High} = 33915.C + 144033\,(H - O/8) + 10468.\,S \text{ kj/kg } \textit{of fuel} \quad (9)$$

$$Q_{Low} = 33915.C + 121423\,(H - O/8) + 10468.\,S - 2512\,(W + 9 \times O/8) \text{ k j / kg } \textit{of fuel.} \quad (10)$$

Calculating the values of HHV and LHV based on the types of fuel with the contents of the elements as listed in table 1, are as follows:

Q_{Hight} (HHV) = 33915. 0,8610 + 144033. (0,119 – 0,0028 /8) +10468. 0,013 = 46.426,41 kj/kg *of fuel*.

Then Q_{Hignt} = 46.426,41 kJ / kg *of fuel*.

Q_{Low} (LHV) = 33915 .0,861 + 121423 (0,119 – 0,0028/8) + 10468.0,013 – 2512(0,002 + 9.0,0028/8) = 43.730,80 kj/kg *of fuel*.

Therefore Q_{Low} = 43.730,80 kJ / kg *of fuel*.

In the steam engine to calculate the usability of the turbine, the amount of steam produced by the boiler, and the amount of fuel used every hour, a diagram called the Muller diagram is needed or is often called an enthalpy diagram, but it requires precision and accuracy, so to facilitate the use of tools the easy and fast steam table, as shown in the table below,

Table 2. Steam table.

Steam Pressure (kg/cm^2) P	**Boiling Water Temperature (^{0}C) Td**	**Type of Steam Volume (m^3/kg) Vu**	**Enthalpy of boiling water (kJ/kg) Wd**	**Evaporation heat (kJ/kg) r**	**Fully Entalpy steam (kJ/kg) i"**	**Type of water volume (dm^3/kg) Vw**
0,1	45,8	14,7	192	2.392	2.584	-
0,2	60,1	7,7	251	2.358	2.609	-
0,3	69,1	5,2	289	2.335	2.624	-
0,4	75,9	4,0	317	2.318	2.65	-
0,5	81,4	3,2	340	2.305	2.645	-
1	99,6	1,69	417	2.257	2.674	1,044
2	120,2	0,89	505	2.200	2.705	1,061
15	198,2	0,13	844	1.948	2.792	1,154
20	212,4	0,099	908	1.893	2.801	1,177
25	223,9	0,080	961	1.843	2.804	1,197

Calculate heat needed in the steam production process in boilers and fuel consumption. Based on Table 2 and the data recorded on the measuring instruments are as follows:

In the Sankey diagram obtained boiler efficiency = 73.8% it can be calculated heat to forming the steam (Q) = ῄk x NP (LHV) = 0.738 x 43.730.8 kj / kg = 32,273.33 kJ / kg bw.

Steam Boiler Efficiency (ῄ$_k$) = $\frac{Ev\,(h1-h2)}{LHV}\ x\ 100\ \%$ $(\text{ῄk standart} = 73{,}8\ \%)$

Water entering the boiler has a temperature 62 ^{0} c on table 2,

Intalphi (h_2) = 266 kj /kg

Water temperature in the boiler 99,5 ^{0} c become full steam on table 2

Intalphi (h_1) = 417 kj/kg

$$ῄ = \frac{Ev\,(417-266)}{43.730{,}8}$$

therefore : $Ev = \frac{0{,}738\ x\ 43.730{,}8}{151} = \frac{32.273{,}33}{151} = 213$

G steam (S) = Ev x Gbb (Be)

therefore $S = \frac{Guap}{Ev} = \frac{50.000}{213} = 234{,}7$ kg/hour

So the use of auxiliary boiler fuel every hour is = 234,7 kg.

Calculate heat as steam forming (Q) in the EGB, and S as needed, for the steam production process in the exhaust gas boiler from the main engine, based on the Sankey diagram as shown in Figure 5.

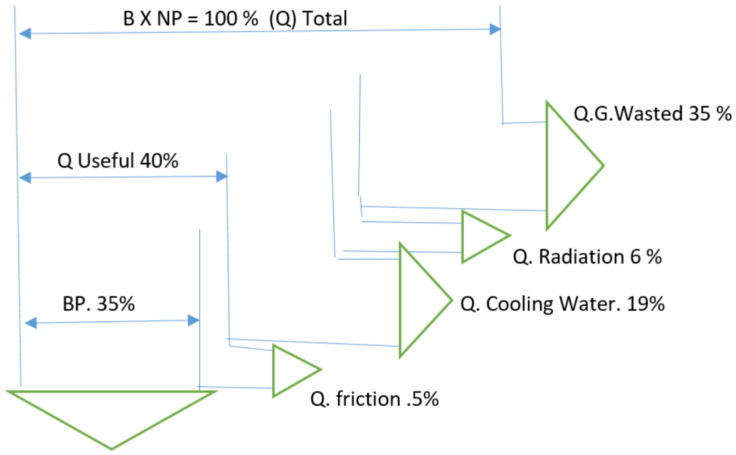

Figure 5. Sankey diagram (heat balance) on a diesel engine.

Fuel every spraying (Binj) $= \frac{bi\ x\ Pi}{z\ x\ n}$ kg/minutes (11)

Binj $= \frac{0{,}173 \text{ x } 10.830}{6 \text{ x } 85} = \frac{1.873{,}59}{510} = 2{,}97 \frac{\text{kg}}{\text{menit}} = 2{,}97\ x\ 60 = 178{,}2\ kg/hour$

In the Sankey diagram the heat is wasted on the exhaust gas = 25 % (Averaged Value)

Therefore Q wasted gas = 0,25 x 2,97 x 46.426,41 kj = 34.471,61 kj (steam forming heat)

34.471,61 is vapor evaporation *x* (h1-h2) or 34.471,61 = Ev (h1-h2)

ῃk $= \frac{Ev\ (h1-h2\ )}{Qhigh} = \frac{34.471{,}61}{46.426{,}41}\ x\ 100\% = 74{,}5\ \%$ is the efficiency of the exhaust gas boiler (EGB)

Calculate the amount of steam (S) produced by the exhaust gas boiler (EGB) :

ῃ $= \frac{Ev\ (h1-h2\ )}{Qhigh}\quad therefore\ Ev = \frac{ῃ\ x\ Q\ high}{(h1-h2\ )} = \frac{0{,}745\ x\ 46.426{,}41}{417-266}$

Ev $= \frac{34.587{,}68}{151} = 229{,}1$ therefore : S (G steam) = Ev x Be = 229,1 x 178,2 = 40.818 kg/hour

Through the calculation of formulas and equations and data from control devices installed on ME, AE and EGB and Turbo generators, obtained directly during the trial, the ship on the shipping turns out that the exhaust gas boiler every hour produces steam of 40,818 kg with a pressure of 16, 5 bars are able to drive turbo generators to meet all electricity requirements during ships on the cruise.

5. Research Model

The research model in ship fuel efficiency analysis is the exhaust gas boiler from the main engine, the auxiliary boiler and auxiliary engine (AE) are carried out with a trial system as long as the ship is in the cruise at different conditions respectively at a 24-hour time estimator. The results of research from the ship were applied with software on the Engine Room Management (ERM) simulator. Figure 6. below.

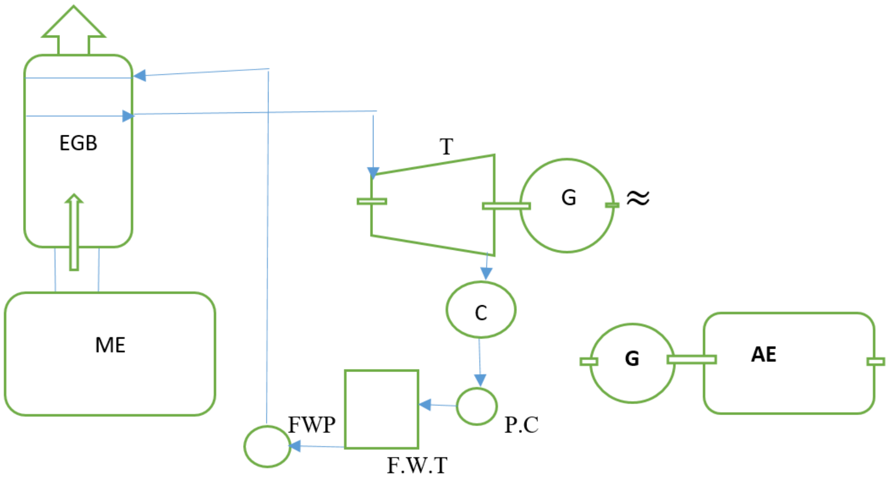

Figure 6. Installation of exhaust gas boiler, turbine, generator, and auxiliary engine.

Figure 6. shows the boiler gas exhaust (EGB) is a boiler to produce steam which is the heat source from the exhaust gas temperature of the main engine, ME (main engine) is the main engine to drive the main motor of the ship, EGB is a exhaust gas boiler that functions to produce steam , T is a steam generator driving a generator, G is a generator of electricity generation, C is a condenser which functions to condense used steam from the turbine into fresh water, the PC is a condenser pump which functions to transfer condensate water to the reservoir tank, FWT (fresh water tank) is a tank fresh water supply kettle filler, feed water pump (FWP) is a boiler water filling pump, the auxiliary engine (AE) is a diesel engine driving a power plant generator.

The method used in this study has a flowchart as follows:

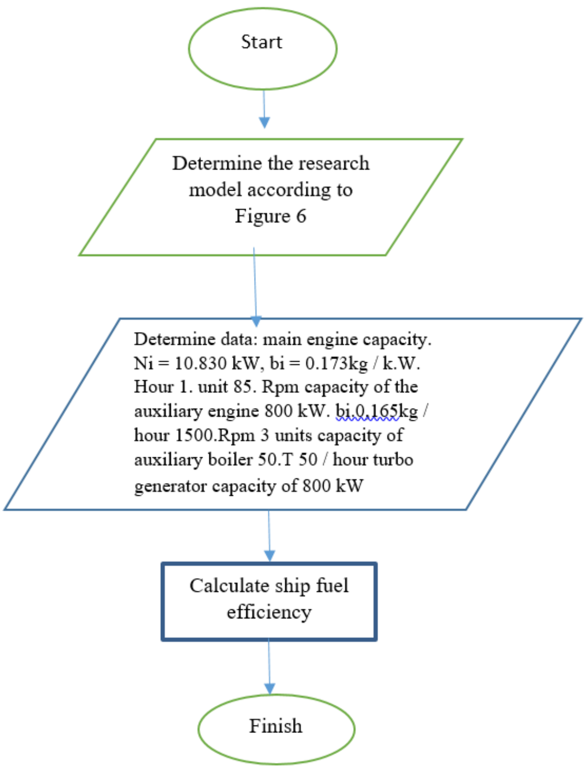

Figure 7. Research Flowchart Model

6. Results and Discussion

In the calculation based on data (ship particular) in the estimated time of 1-day cruise (24) hours with the main engine condition at maximum rotation (85 Rpm).

The calculation of the efficiency of the use of fuel is divided into 3 conditions, such as follows:

1. The first condition of a ship sailing using Auxiliary Boilers:
   a. Then the fuel consumption (B) on the main engine per day = bi x Ni x 24
      B = 0,173 x 10,830 x 24 = 44,966.16 kg.
   b. b. Calculation of fuel consumption (B) on the Auxiliary boiler (steam boiler):
      = 234.7 kg x 24 = 5,632.8 kg

   The number of a + b (B1) = 44,966.16 kg + 5,632.8 kg = 50,598.96 kg
2. The second condition is that ships are sailing with main engines and auxiliary engines:
   a. Main engine usage = 44,966.16 kg.
   b. Use of auxiliary machines (Generator Drives):
      B = bi x Ni x 24 = 0,165 kg / kw hour x 800 k x 24 hours = 3,168 kg
      Amount of a and b = Fuel usage of main engine + auxiliary engine:
      (B_2) = 44,966.16 kg + 3,168 kg = 48,134.16 kg
3. Fuel usage in third condition: Sailing vessel, applying exhaust gas boiler (EGB) with turbo generator:
   Fuel usage is only the main engine (B_3) = 44,966.16 kg.

   Efficiency in the first condition is compared to the second condition:

   η = (B1-B2) / B1 x 100% = (50,598,96-48,134,16) /50,598.96 x 100%
   η = 2,464.8 / 50,598.96 = 0.0487 x 100% becomes Efficiency = 4.87%

   Efficiency in the second condition compared to the third condition:

   η = (B2-B3) / B2 x 100% = (48,134-44,966,16) /48,134 x 100%
   η = 3,167.84 / 48.134 x 100% η = 0.658 x 100% = 6.58%%

   First condition efficiency compared to third condition:
   η = (B1-B 3) / B1 = (50,598,96-44,966,16) /50,598.96
   η = 5,632.8 / 50,598.96 = 0.112 x 100% = 11.2%

Table 3. results of calculations for all three conditions every 24 hours of shipping:

Conditions	Main Engine fuel consumption	Auxiliary engine fuel consumption	Boiler fuel consumption	Total fuel consumption	Efficiency
1st conditions	44.966,16 kg	=======	5.632,8 kg	50.598,96 kg	4,87 %
2nd conditions	44.966,16 kg	3.168 kg	=======	48.134 kg	6,58 %
3rd conditions	44.966,16 kg	======	=======	44.966,16 kg	11,2 %

From the data in Table 3, it is stated that in the first condition, the ship sailing with the main engine and boiler spent 50,598.96 kg of fuel for 24 hours, while the ship sailed on average for 20 days each month so that the use of fuel ships = 20 x 50,598.96 kg = 1,011,979.2 kg this is a waste. Whereas in the second condition, the ship sailed with a main engine and auxiliary engine with fuel consumption of 48,134 kg for 24 hours, when sailing for 20 days the amount of fuel consumption = 20 x 48,134 kg = 962,680 kg when compared to the first condition, there was a saving (efficiency) = 6.58%., in the third condition, the ship sails with the main engine and applies

EGB due to working only the main engine, the use of fuel for 20 days sailing = 20 x 44,966.16 kg = 899,323.2 kg if compared to the first condition, there was a saving (efficiency) which reached 11.2%, whereas if the third condition was compared with the second condition, the savings (efficiency) were 4.87%.

7. Conclusion

By applying the exhaust gas boiler (EGB), ship fuel consumption can be saved up to 11.2%. So that the monthly operational costs of the ship can be reduced, the impact of heat absorption by EGB, the temperature of the exhaust gas coming out of the chimney, down to around 165 0c means it does not cause air pollution and global warming, by applying EGB and turbo generators, the temperature in the engine room it becomes cooler, noise and vibration from AE does not exist, this means the condition in the engine room becomes more comfortable, does not adversely affect the health of the engine operator, another advantage is by applying a turbo generator, as long as the AE is in a stop condition, thus the usage age of AE (Life time) becomes longer and the cost of maintaining machine maintenance becomes more efficient.

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