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Considerations upon the performances of the main naval engine and energy efficiency evaluation

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Abstract: Nowadays, the essential source of ship propulsion is the diesel low-speed engine, and the power necessity and rate of propeller rotation especially rely upon the ship's structure and the propeller geometry. Along these lines, in order to arrive at a solution that is as ideal as could be allowed, some broad information is basic for ship diesel engine parameters that impact the propulsion ship system. The performance of any system on board ship is specifically identified with its reliability. So as to get the best out of marine motors, it is critical to screen their performances and take measures to accomplish productive combustion. The paper points the significance of estimating the performances of the propulsion motor utilizing the NHX program. NHX electronic program estimates the pressure inside engine cylinders by the usage of the beat signal from Top Dead Center (T.D.C.) of the number 1 cylinder. Additionally, analyses the after burning period at the combustion stroke of each cylinder. The E.E.O.I. (Energy Efficiency Operational Indicator) is an observing tool for ship management and fleet efficiency. The estimations of the factors have a diminishing trend amid the usage time periods, achieving at least a 30% decrease of the pollutants in the years 2025 contrasted with the values before the implementation of this index. E.E.D.I. index has been considered as the biggest and most dominant sections of the sea business.

1. Introduction

The impact of the main motor operational parameters on fuel consumption is critical. Aside from the sea trial of the structure part of the ship, the essential machinery of the motor room, for example, boilers, auxiliary motors and the main engine are additionally tested. This information relating to sea trials/ machinery trials, shop trials/test bed trials and the obtained performance curves empowers the Chief Engineer to run the ship securely and economically.

An engine room logbook is a track record of all ship machinery parameters, performance, maintenance, and malfunctions. The recorded values and information are used as a reference, to compare and record data to assess the ongoing performance of different engine room machinery.

In order to facilitate the successful implementation on board ships from the operational point of view of the EEDI reduction requirements and implicitly of the current levels of NOx, was developed the concept of SEEMP - Ship Energy Efficiency Management Plan. This management plan establishes a mechanism for ship owners and their teams to improve the efficiency of systems onboard ships.

SEEMP allows the development of an energy efficiency monitoring system on board ships over time using indices such as EEOI (Energy Efficiency Operational Index). The implementation of this

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instrument forces both ship owners and their operators to consider operational procedures and refurbishment of vessels at any stage of their operating cycle.

2. The main propulsion diesel engine of VLCC tanker ship

The ship propulsion is provided by a MITSUBISHI 7UEC85LSII type engine like in figure 1, two-stroke, slow and reversible, with a constant overcharging pressure that develops a rated output of 27000 kW at a speed of 78 rpm, as shown in table 1, the ship working with a maximum speed of 15.50 Nd, [1].

Figure 1. Main propulsion engine.

Table 1. Main propulsion engine parameters.

Characteristics	Values
Bore	850 [mm]
Stoke	3150 [mm]
Cylinders	7
M.C.R. power	27020 [kW]
N.C.R. power	22965 [kW]
Speed	76 [rpm]

3. Propulsion engine performance diagram to reach economical fuel consumption

3.1. Propulsion engine fuel consumption

After the working of the ship is done and before offering it to the owners, S.A.T. (sea acceptance tests) are done to test that the ship can pass on the legitimately guaranteed speed. The principal job of the S.A.T. is to select the speed of the tanker shipaccording to the RPM and propulsion engine power.

Beside the S.A.T. the fundamental systems of the engine room, for instance, boilers, diesel generators and also the propulsion engine are in like manner tested. All systems have a test record isolated from the S.A.T. data, which is done in the gathering plant and is called as F.A.T. (factory accetance tests) or test bad. It is common to have main engines, generators, assistant systems etc, having these demonstrating test bed information. This data identifying with S.A.T. and F.A.T. enables the Chief Engineer to run the ship safely and financially, [2].

3.2. Main engine system optimisation

Amid the factory tests or shop preliminary trial, the performance bends of the diesel engine are plotted. The performance bends are the charts of various parameters on x-axis plotted against diesel engine power or load on the y-axis. These distinctive plotted bends are as per the following:

- Engine speed in rpm versus engine load: This bend helps in learning whether the main engine is overloaded or not. A higher power produced at a lower speed demonstrates an over loaded diesel engine;
- Mean effective pressure versus engine load: These parameters are utilized to calculate engine power, so these two parameters should be correlated. If the correlation does not happen, there may be read calculation errors;
- Maximum cycle pressure versus engine load: This bend helps in knowing the state of fuel injection gear, injection timing and the pressure in the chamber and so on;
- Compression pressure versus engine load: This bend demonstrates the state of the parts keeping up compressions like the pistons, piston rings and valves;
- Scavenge pressure versus engine load: It shows the state of the turbo charger and related auxiliary parts;
- Exhaust gas temperature in collector versus engine load: It demonstrates the enthalpy of the exhaust gas before passage in the turbocharger. Before and after turbo charger values gives the temperature drop over the turbo charger and is a pointer of turbo charger effectiveness;
- Exhaust gas temperature after exhaustvalve versus engine load: This bend reveals insight into the ignition, fuel injection, timing and compression pressure and so on. A higher temperature might be caused due to subsequent to consuming;
- Exhaust gas temperature after turbocharger versus engine load: This bend is helpful as it demonstrates the enthalpy caught from the gas by the turbo chargerand subsequently its condition. On the off chance that the collector temperature is inside range yet the outlet temperature is higher it might show fouling of the turbo chargerand consequently the related lower air pressure and high gas temperature, [3].

3.3. Economical fuel consumption

The propulsion engine will work with low consumption if it is great kept up in maintenance condition and is continue running at the low rating where the Specific Fuel Oil Consumption is the most economical.

Apropulsion engine has good performanceif it performs well and safety at rated speed and load. For instance, if a propulsion engine is having a continuous rating of 20000 kW at 105rpm speed and can't achieve the evaluated rpm and is creating 20000 kW rashly at 97rpm speed, there is lost ship's speed.

It additionally tells that there is an issue, the ship can't give speed, it is over expending fuel and that the motor is over loaded. It focuses on either ship body fouling, harmed propeller or a flawed prime mover and so forth. In such cases, the cautious investigation of the SAT (sea acceptance tests), motor factory information and the execution bends will decide the reason for the issue.

For investigating, first, the fundamental motor performance must be taken on a decent climate day when the motor burden is enduring. The primary motor must be rushed to its appraised power, [4].

From figure 2 diagram the following points are inferred:

- At 75% MCR load the rpm speed attained is lower than the sea trial tests;
- The maximum cylinder pressure $P_{maximum}$ is lower than the SAT (sea acceptance tests);
- The compression pressure $P_{compres}$ is almost same as sea trial confirming that the running gear like the piston, piston rings and exhaust valves are working good;
- The scavenge pressure is almost normal suggesting that the turbo charger is in satisfactory condition and the enthalpy of the exhaust gas is higher than normal for this rpm speed;
- Exhaust temperatures are all increased suggesting abnormal combustion, after burning or change of timing. It may also indicate faulty fuel injection equipment.

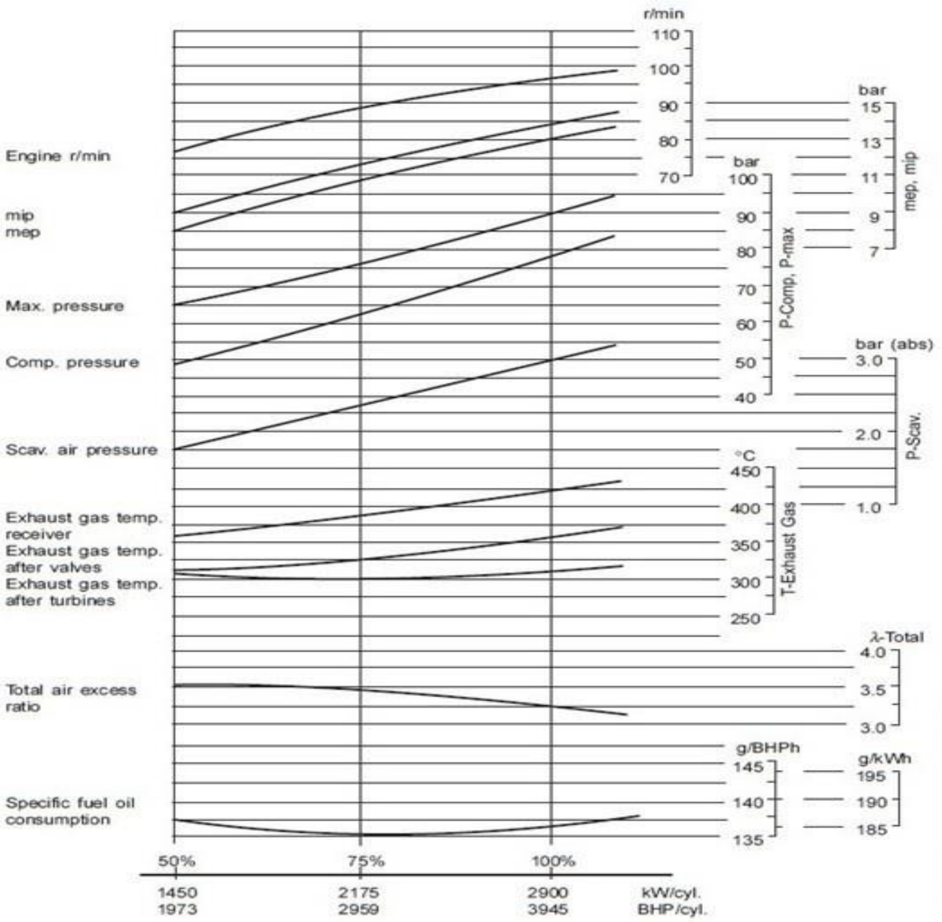

Figure 2. Performances chart of the propulsion engine.

The above figure will comprehend the utilization of performance bends for a chief engineer. After the propulsion motor performance has been taken and plotted on the first execution bends from the SAT data, the issue can be discovered and SFOC re-established to nominal quantity. Along these lines at any phase amid the lifetime of the ship, we can comprehend why she isn't performing dependent on plotting her parameters on the performance bends, [5].

3.4. Best practices for ship optimization systems

Optimisation of the propulsion system using additional means to improve engine efficiency may include:

- Use of fuel additives;
- Adjustment of cylinder lubrication oil consumption;
- Valve improvements;
- Torque analysis;
- Automated engine monitoring systems.

Ship to guarantee performance check of the main engine to ensure an adjusted yield from all cylinders.

The check might happen according to "SHIPNet", which interval ought not to be under 10 moving days (or once per each Ballast and Laden voyages).

Ship to ensure optimizing Alpha/S.I.P./Pulse Jet Lubrication system by adjusting the feed rate according to the fuel quality.

The optimisation shall also be conducted as per manufacture's reduction plan under the supervision of the Shipmanager considering condition of the cylinders.

One of the best practices for ship optimisation systems is a management plan that includes:

- Main engine exhaust valves and F.O. valves maintenance carried out as per ShipNet planned maintenance system & makers recommendations;
- Main engine turbocharger air filters are maintained clean by replacing the filter elements every week;
- A regular dry wash of Main engine turbochargers to maintain maximum efficiency;
- The ship carries out main engine, performance test at every ballast and loaded voyage to asses in due time its condition;
- Main engine cylinder E.C.L. system cylinder oil feed rate maintained as per the guidance from the ship Manager. The effectiveness of the optimized feed rate is checked by inspecting the piston and liner at regular intervals;
- Cooling water test carried out every week and chemicals (liquid D.E.W.T.) dosed as per requirements to avoid any scale, corrosion in the system;
- The condensate water salinity of C.O.P.T. and T.G. condensers is monitored continuously and recorded;
- E.G.E. soot blowing carried out 3 times a day while at sea. Auxiliary Boiler soot blowing carried out every time after departure and before arrival to the ports. Auxiliary boiler burner maintenance and test carried out before entering the ports;
- Fuel consumption of the main engine, boiler and diesel generator are measured and recorded daily in the engine logbook and 'ABLOG'. The percentage of power and thermal load are daily computed by 'MOL-B' method. Extra slow steaming speed mode of the main engine is implemented and used at charterer demands, [6].

4. Monitoring Performance of the main diesel engine

The marine engine on ships is used for 2 main purposes: for propelling the ship and for generating electricity, which assists in powering the ship's propulsion plant. Ensuring this will not only reduce the generation of pollution from engines but also the over all operating cost of the ship.

Following are ways to monitor and measure the performance of the engine:

- Measure the Peak Pressure by Mechanical Peak Pressure Gauge

This strategy is typically applied to 4 stroke engine where a pinnacle weight gage is utilized for singular cylinder and pressure produced amid burning is noted. With a similar gage, the pressure of the cylinder is additionally measured when the unit isn't firing.

The variety in the peak pressures produced is then considered for drawing out defective units, changing fuel racks and upgrading burning chamber parts with a specific end goal to accomplish effective ignition.

- Indicator Card Measurement

This is another mechanical technique to gauge the performance of engine cylinders by applying marker drum and plotting diagram on cards. Two sorts of cards are utilized for this reason control card and draw card. With the assistance of these two outlines, we can decide the compression pressure, peak pressure and engine power.

- Digital Pressure Monitoring

DPI (digital pressure indicator) is an electronic mode to screen the power and performance of the motor. With the assistance of digital pressure indicator, the variety in the chamber performance can be plotted and deciphered in graphical structure and remedial move can be made.

- Intelligent Combustion Monitoring (I.C.M.)

The new age motors are persistently checked by Intelligent Combustion Monitoring, which estimates the real-time cylinder inside pressure. This bundle offers an expansive scope of information preparing devices for assessing performance and for deciding engine glitches (extensive blow-by, exhaust valve working, fuel injection etc.).

- Monitoring of Engine Control Parameters

The motor control parameters like fuel injection timing, exhaust valve timing, variable turbocharger vane opening points, lambda control and so on are checked and any variety is set to accomplish the most ideal proficient burning.

- Engine Parameters

The motor realsparameters, in figure 13 and table 2, are the best hotspot for discovering any blame or variety in the motor working. Variety in temperature, pressure and power created by each cylinder must be as often as possible checked and alteration must be done in like manner to accomplish proficient combustion, [7].

5. Main engine performance using NHX programed

5.1. Programme monitoring

Following charts are shown by analyzing soft on PC:

- P- θchart, in figure 3;
- P-V chart, in figure 4;
- LogP-LogV chart, in figure 5;
- Heat Release chart, in figure 6;
- P_{comp} chart, in figure 7;
- Measured Data Report, in figure 8;
- Overlay of P- θrelease chart;
- Main engine pressure, in figure 9 and 10;
- another 3D diagrams, in figure 11 and 12.

5.2. Engine monitoring onboard

In order to monitor the engine performance, it needs to measure the power output and fuel consumption of the engine. For monitoring main engine performance, the peak pressure of each unit is taken at several engine loads as shown in figures 3, 4 and 5 with simple diagrams and figure 6 with 3D diagram.

All the engine parameters,shown in figures 9 and 10, such as exhaust temperatures, fuel rack readings, fuel oil, lube oil and cooling water pressure, temperatures, scavenge air pressure, turbocharger speed, etc. are taken.

Compare the readings with previous and test bed reports, compare the peak pressures of all units to ensure even loading of all cylinders, as shown in figure 7 for cylinder number 1. Various readings are taken from running engine, such as pressures and temperatures, as shown in table 3 and figure 8. These are easily obtained, and can be used to indicate changes in operating conditions when compared to previous stable readings. To ease the operator's work and be easily read, the NHX program offers 3D charts as shown in figures 11 and 12.

The readings need to be taken over an extended period of time to avoid rouge readings producing the incorrect analysis. For Engine builders software programs are available that can analysesuch data to indicate the condition of the engine [8, 9].

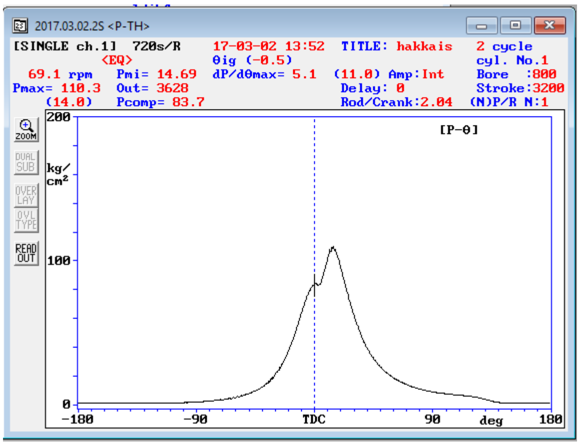

Figure 3. Main engine cylinder 1, P-Th.

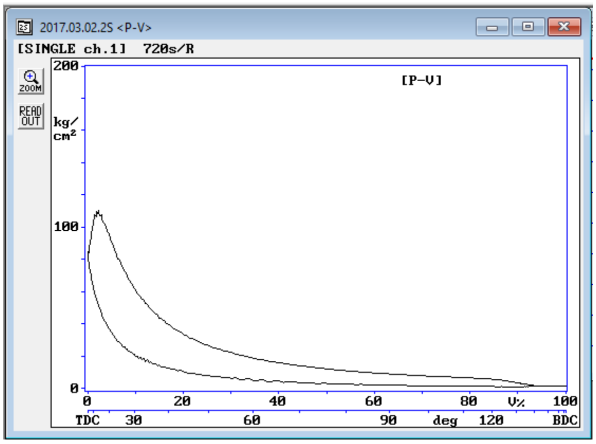

Figure 4. Main engine cylinder 1 P-V NHX diagrams.

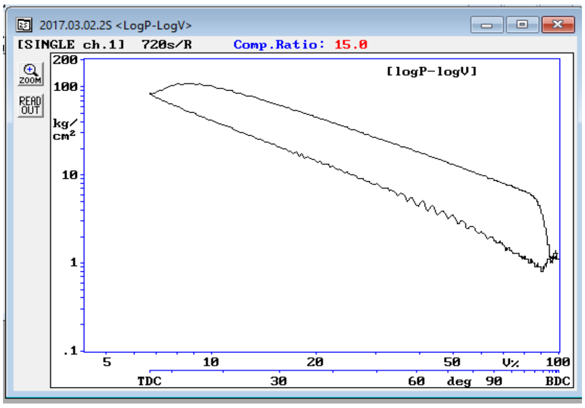

Figure 5. Main engine cylinder 1, LogP-LogV.

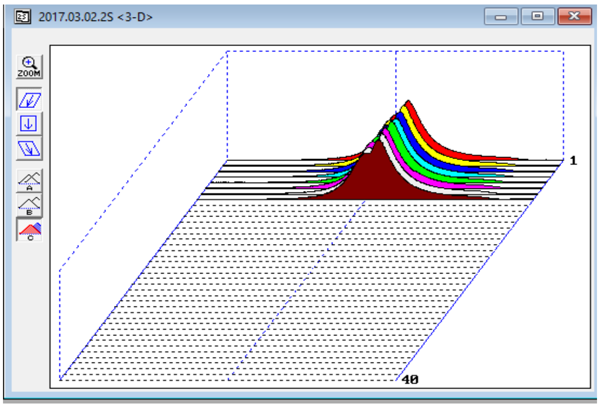

Figure 6. Main engine cylinder 1 3D NHX.

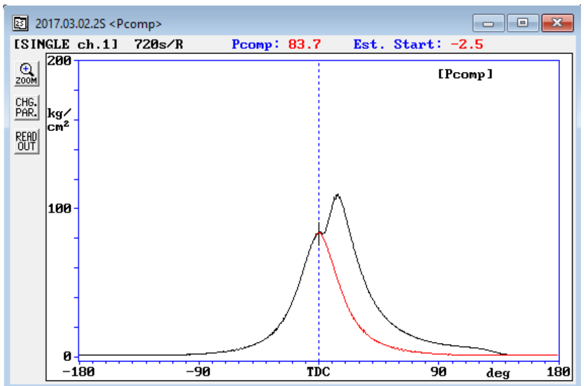

Figure 7. Main engine cylinder 1, Pcomp.

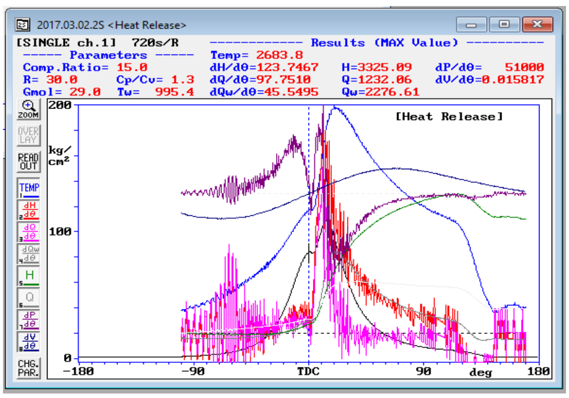

Figure 8. Main engine cylinder 1 Heat release NHX diagrams.

IOP Conf. Series: Materials Science and Engineering **591** (2019) 012108 doi:10.1088/1757-899X/591/1/012108

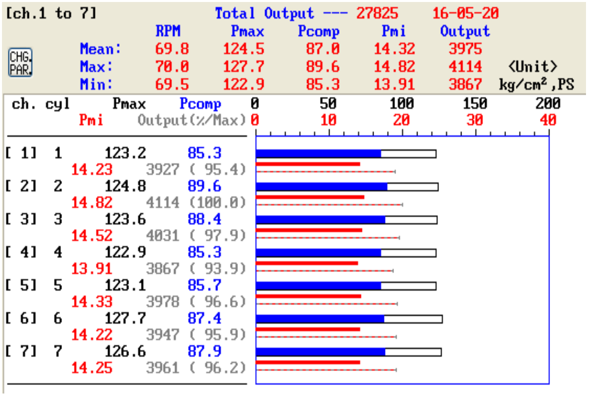

Figure 9. Main engine pressure, load 1.

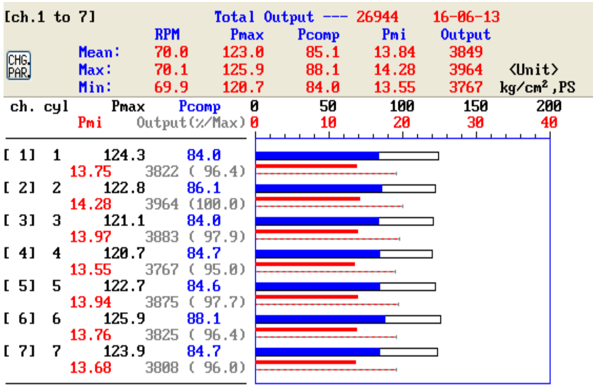

Figure 10. Main engine pressure, load 2.

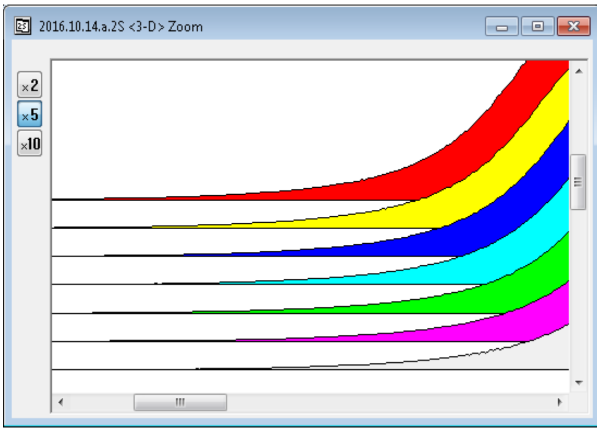

Figure 11. Main engine cylinders 3D NHX diagrams.

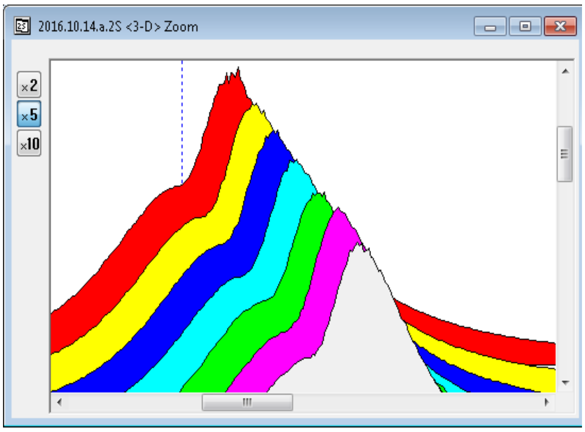

Figure 12. Main engine cylinders 3D NHX diagrams 2.

Table 2. Mitsubishi engine real parameters.

Cylinder No. / parameter	Average	1	2	3	4	5	6	7
Pmax kg/cm²	124.3	125.9	123.1	125.60	124.2	122	125.2	123.9
Pcomp kg/cm²	86.2	87.50	86.50	92.30	84.60	83.90	83.80	84.80
Pmax/Pcomp	1.4	1.44	1.42	1.36	1.47	1.45	1.49	1.46
Indicate Mean EFF Press kg/cmf	14.3	14.19	14.61	14.40	14.15	14.18	14.02	14.38
Indicate Horse Power (x10) PS	3965.7	3939	4056	4003	3936	3936	3892	3998
Cyl Out Exh Gas Temp (°C)	348.3	337	344	343	363	344	346	362
Fuel Pump Mark (Load Index)	73.3	74	74	74	73	73	73	72
Jacket Cool FW Out Temp (°C)	84.6	85	85	85	84	85	84	84
Piston Cool Oil or W Out (°C)	58.9	59	59	60	59	59	59	57

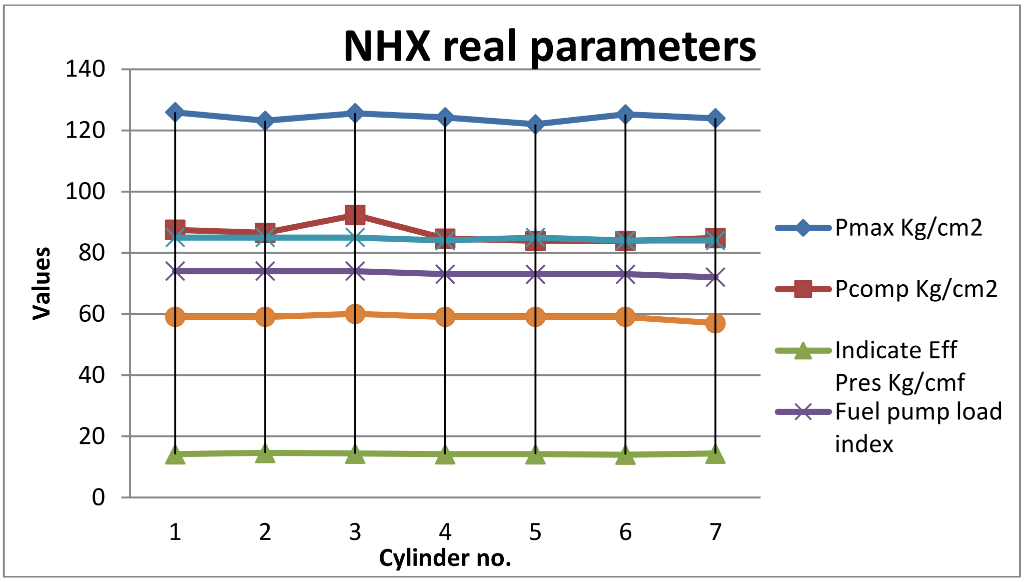

Figure 13. Mitsubishi 7UEC85LSII NHX real parameters.

Table 3. Mitsubishi engine output parameters, [10].

Item	Main Engine Output (PS)	(%)	Fuel oil consumption rate (g/PS.H)	Cyl oil consumption rate (g/PS.H)
By Fuel Oil Consumption (MOL- B method)	29636	80.7	126.5	13.78
By HWX Analysis/SEC/MIP Indicator	27760	75.6	135.0	14.71
By Shaft Power Meter	26965	73.4	139.0	15.15

6. Energy efficiency indicators calculation for VLCC tanker ship

6.1. Calculation of Energy Efficiency Design Index(E.E.D.I.) is made by using the next equation, equation (1):

$$EEDI = \frac{f_i x P_{ME} x C_{FME} x SFC_{FME} + P_{AE} x C_{FAE} x SFC_{FAE}}{f_i x f_w x v_{ref} x capacity} \tag{1}$$

$$EEDI = \frac{0.945x20265x3.1144x163.6+925.5x3.20x190}{1.025x1x15.38x305301} \tag{2}$$

$$EEDI = \frac{9757444.88+562704}{5225989.86} = 2.14\ g/t * knots \tag{3}$$

where:

- conversion factor for heavy fuel oil: $C_{FME} = 3.1144$
- main engine power, equation (4):

$$P_{ME} = 0.75 \times (MCR_{MEi} - P_{PTOi}) = 20265\ kW \tag{4}$$

- specific fuel consumption: $SFC_{FME} = 163.6\ \frac{g}{kWH}$

- necessary power for auxiliary engines, equation (5):

$$P_{AE(MCRME>10000\,kW)} = (0.025 \times \sum_{i=1}^{nME} MCR_{MEi}) + 250 = 925.5\,kW \quad (5)$$

- conversion factor for marine diesel oil: $C_{FAE} = 3.20$
- specific fuel consumption: $SFC_{FAE} = 190\ \frac{g}{kWH}$
- correction factor: $f_j = \frac{0.516 L_{PP}^{1.87}}{\sum_{i=1}^{nME} P_{iME}} == 0.945$
- capacity factor: $f_i = \frac{0.00115 L_{PP}^{3.36}}{capacity} = 1.025$
- ship speed: $v_{ref} = 15.38$
- ship deadweight: $capacity = 305301\ tdw$ [11, 12]

Table 4. EEDI reduction factor for tanker ships.

Ship Type	Size	Period 0 January 2013-December 2014	Period I January 2015 – December 2019	Period II January 2020 – December 2024	Period III January 2025 and onwards
Tanker	20000 dwt and above	0	10 %	20 %	30 %

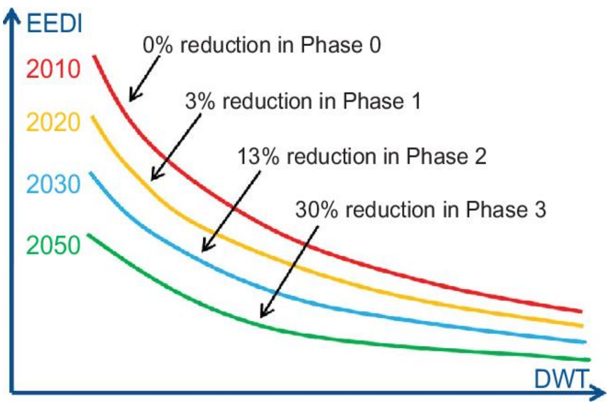

Figure 14. EEDI reduction factor [4].

6.2. Calculation of Energy Efficiency Operational Indicator (E.E.O.I.) is made by using the next equation, equation (6)

$$EEOI = \frac{977.2x3.114 + 52.3x3.114 + 143.2x3.20}{250000x6506} = 2.25\ 10^{-6}\ tCO2/t\ x\ miles \quad (6)$$

where:

- fuel consumed (tones):

$$Fuel_{consumedME} = 977.20\ tones\ HFO$$

$$Fuel_{consumedBoiler} = 52.30\ tones\ HFO$$

$$Fuel_{consumedDG} = 143.2\ tones\ MDO$$

- carbon factor for each type of fuel:

$$C_{Carbon} = 3.1144\ forHFO$$

$$C_{Carbon} = 3.20\ forMDO$$

- crude oil transported:

$$Cargo_{transported} = 250000\ tones$$

- distance during ship voyage (miles):

$$Distance = 6506\ miles$$[13, 14]

7. Conclusions

The marker outline is critical to know the ignition in the cylinder and furthermore to adjust the engine. The chart is taken intermittently from the indicatorvalve equipped on the chamberheadand the burning condition is to be confirmed. The compression pressure andmaximum pressure in the chambercan be assumed from the indicatordiagram. An engine indicator is the gadget used to take the indicator outline, which can be considered as a 'stethoscope' for diesel engines. Indicatordiagrams give the efficiency of combustion in the cylinder, condition of the running gear, irregularities in fuel pumping and injection and a lot of things.

The E.E.D.I.from equation (1) and E.E.O.I.from equation (6) calculation is depended on the year of the ship built. From the beginning of phase I from the 2015 year to the 2020 year, the required E.E.D.I. value will be supervised strictly following the new changes of I.M.O, as shown in figure 14 and table 4. Regulations for M.E.P.C. (Marine Environment Protection Committee)[15, 16].

In the decrease of CO_2 gas emanations, additionally, EEDI is an incredible issue that requirements to tackle from ships. As of late, the marine business is gradually developed both the quantity and quality by applying current science and innovation into the field of ship constructing and working. MEPC - Marine Environment Protection Committee is additionally given the correction about Regulations with a craving of the atmosphere changes decrease [17, 18].

Using alternative ship fuel will reduce sulfur oxide (SOx) emissions by 90% to 95%. This reduction level will also be mandated within the so-called Emission Control Areas (ECAs) by 2015. A similar reduction is expected to be enforced for worldwide shipping by 2020. Global natural limited resources dominate our times, and the maritime industry faces the same challenges as the rest of the world in terms of energy consumption. Ship owners and port authorities want to reduce fuel consumption and improve efficiency. This will please both, the investors and legislators, because, ultimately, lower energy consumption means lower costs, [19].

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