Real Time Monitoring of Energy Efficiency Operation Indicator on Merchant Ships

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Abstract : International Maritime Organization (IMO) proposed the Energy Efficiency Operation Indicator (EEOI) in 2005 and the Energy Efficiency Design Index (EEDI) in 2008 so as to address emission concern and regulation. Likewise, Ship Energy Efficiency Management Plan (SEEMP) and Greenhouse Gas (GHG) monitoring and management are also becoming an issue lately. This paper introduces the energy efficiency design index (operation indicator) monitoring system (EDiMS) software can continuously monitor CO_2, NO_x, SO_x, and PM values emitted from ship. The accurate inventory of ships GHG can be obtained from base of emission result during the engine shop test trial and the actual monitoring of shaft power and ship speed. In addition, the ability to store all exhaust emission and engine operation data can be applied as the useful tool of the inventory work of air pollution and ship energy management plan for the mitigation or reduction of ship emissions.

Key words : Energy efficiency operation indicator, Exhaust gas emissions, Ship energy management plan, Shipping industry

Nomenclature

c_0, c_1, c_2, c_3 : Coefficients for fuel consumption, NO_X, SO_X and PM emission

Capacity : Vessel's deadweight

C_{Fj} : Fuel mass to CO_2 mass conversion factor for fuel j

C_{FME}, CF_{AE} : Fuel conversion factors

ME : Main engine

AE : Auxiliary engine

D : Distance in nautical miles corresponding to the cargo carried or work done

FC_{ij} : Mass of consumed fuel j at voyage i

f_i, f_j, f_w : Correction factors

i : Voyage number

j : Fuel type

m_{cargo} : Cargo carried (tonnages) or work done (number of TEU or passengers or gross tonnagenes for passenger ships)

P_{eff}, P_{AEeff}, f_{eff} : Iinnovative energy efficiency technologies

P_{ME}, P_{AE}, P_{PTI} : Power for main engine, aux. engine and power take in

S_{FCME}, S_{FCAE} : Specific fuel oil consumption (main engine, auxiliary engine)

V_{ref} : Speed

x : Part load ratio for maximum continuous rating

1. Introduction

The maritime shipping industry has continuously progressed with dedicated endeavor to reduce greenhouse gas in an effort to curb global warming.

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According to the results of the 2009 Green House Gas (GHG) study team, the CO_2 emission from shipping industries slightly exceeded 1.0 billion tonnage during 2007 (one year) and it is 3.3% of total CO_2 amount exhausted from all other industries. It has been considered from study results that sea transportation as one of the most efficient transportation system but GHG emission must likewise be given utmost significance and studied for possible reduction and control [1]. Recent study has shown that reduction in carbon dioxide can be carried out by employing appropriate propulsion system plans, Waste Heat Recovery System (WHS), supplemental equipment, fuel economy mode, diesel engine rating control, speed reduction operation resulting to improved performance benefiting the maritime sector and port harbor operation [2]. Likewise, International Maritime Organization (IMO) regulations recommended modern monitoring system such as the Energy Efficiency Design Index (EEDI) and the Energy Efficiency Operation Indicator (EEOI) be present on ship propulsion system and newly constructed vessels [3].

Further, information technology (IT) has been applied and combined broadly in shipbuilding and shipping industries [4]. In this research, EEOI monitoring method using the Energy Design/Operation Monitoring System (EDiMS) and its application is introduced on merchant ship. EDiMS was developed for IMO EEDI/EEOI monitoring by Mokpo Maritime University [5].

2. EEDI / EEOI monitoring by EDiMS

EDiMS scientifically confirmed the essential benefit in the use and management of energy on ships. As shown in Figure 1, new design concept of EDiMS performs three remarkable functions. For its main purpose, a constant visual monitoring of an estimated exhaust emission volume and engine operation output data is available. All data can be transmitted periodically to head office by LAN cable and satellite.

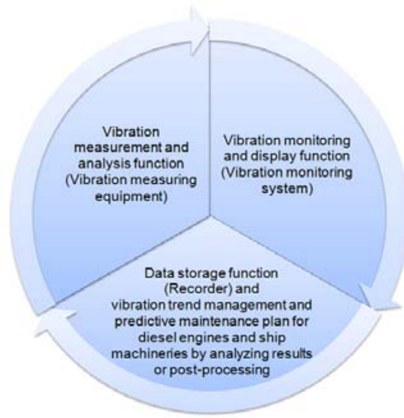

Figure 1: Design concept of EDiMS

Figure 2 illustrates EDiMS four(4) channels connection as: channel 1 for engine speed, channel 2 for ship speed indicator, channel 3 for shaft power output, channel 4 for prime mover fuel flowmeter voltage signal while channel 5~8 can be assigned for generator output power.

The AD board used for the system employs an inexpensive 8 channel A/D converter supplied by American company National Instrument NI 9215. The use of NI USB cDAQ 9172 offers convenience with regards to main power supply by simply using USB connection. However, due to engine influences such as temperatures and pressures and other vessel energy management, it may be necessary to have more than 8 channels for monitoring. This circumstance necessitates extra chassis, on which an eight (8) module upgraded to a 32-channel configuration can be assembled and extended for various functions of EEOI or EEDI.

These entire input signals in an on-line (real-time) monitoring entail a ± 10V voltage power requirement. Configuration menus in monitoring system are composed of sampling speed for necessary data storage, input/tachometer factor, the recording set-up and EDIMS set-up.

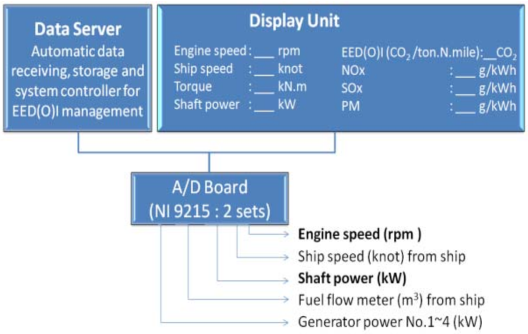

Figure 2: EDiMS system and display unit configuration

Figure 3 shows the field test instruments. On Figure 4 illustrates setup configuration of EDiMS as a separate module of the EVAMOS software. EEOI or EEDI is applied by activation or non-activation of the “auto generator power“ menu respectively. Figure 5 illustrates the EDiMS

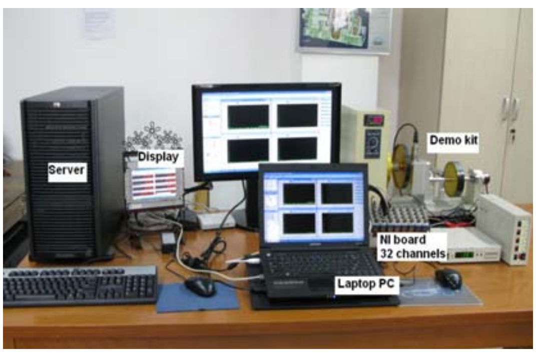

Figure 3: Field test instruments of EDiMS

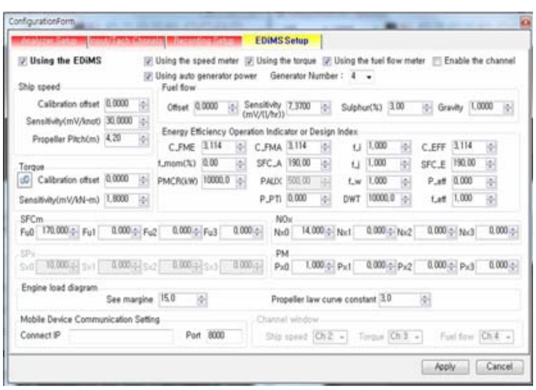

Figure 4: Setup configuration of EDiMS

computer screen display and monitoring emission values. The right hand portion of the screen display indicates the measured EED(O)I values including shaft power, ship speed, torque, CO_2, SOx, NOx and PM.

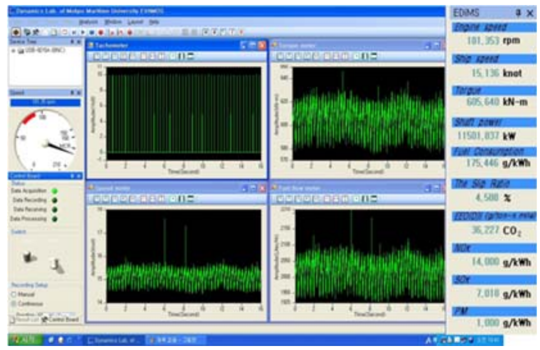

Figure 5: EDiMS raw signal and emission values display

EDiMS software uses directly the transmitted speed signal converted to voltage from ship instead of a tachometer. In this case, propeller slip ratio is calculated considering sea routine, weather fluctuations and other factors. Hence, f_w, a function of EEDI formula and still being deliberated in IMO, can be obtained by experimental method through sea routine. In the absence of speed signal from ships, ship speed can be estimated using the rpm and propeller pitch data assuming there is no slip. If fundamental values, fuel consumption rate and operation margin value are assumed with ‘zero input’, according to sequence required by IMO, EEDI is obtained. Then, EEOI is achieved by inputting the average increase in fuel consumption of generator and operation margin value during voyage. This study has been based on particular system alone but for two or more complex systems, the EDiMS program configuration can be modified.

The EEDI / EEOI formulas are given in Equations (1) and (2) respectively. Meanwhile, Equation (3) is the average EEOI formula.

$$EEDI=\frac{(\prod_{j=1}^{M} f_j)(\sum_{i=1}^{nME} P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)})+(P_{AE} \cdot C_{FAE} \cdot SFC_{AE})}{f_i \cdot \text{Capacity} \cdot V_{ref} \cdot f_w}$$
$$+\frac{\left\{(\prod_{j=1}^{M} f_j \cdot \sum_{i=1}^{nPTI} P_{PTI(i)}-\sum_{i=1}^{Peff} f_{eff(i)} \cdot P_{AEeff(i)}) \cdot C_{FAE} \cdot SFC_{AE}\right\}}{f_i \cdot \text{Capacity} \cdot V_{ref} \cdot f_w}$$
$$-\frac{(\sum_{i=1}^{\neq ff} f_{eff(i)} \cdot P_{eff(i)} \cdot C_{FME} \cdot SFC_{ME})}{f_i \cdot \text{Capacity} \cdot V_{ref} \cdot f_w} \quad (1)$$

$$EEOI=\frac{\sum_j FC_j \times C_{Fj}}{m_{cargo} \times D} \quad (2)$$

$$Average\ EEOI=\frac{\sum_i \sum_j (FC_{ij} \times C_{Fj})}{\sum_i (m_{cargo} \times D_i)} \quad (3)$$

Fuel consumption and NO_x and PM emission values measured from shop test results can be used by the curve fitting method of the Equation (4). Also, the fuel consumption of prime mover can be applied alternatively by the converting voltage signal of flowmeter. SO_X is applied as sulphur content and fuel consumption quantity.

$$y=c_0+c_1 \cdot x+c_2 \cdot x^2+c_3 \cdot x^3 \quad (4)$$

Figure 6 shows the load diagram from EDiMS. The right hand portion of the screen display

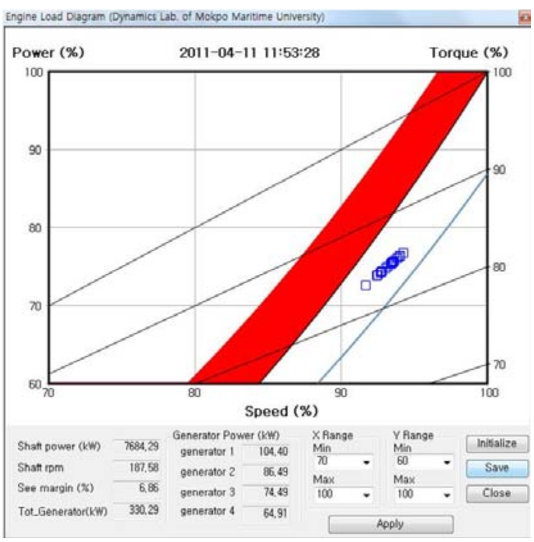

Figure 6: Power consumption display for EEOI or EEDI real time monitoring

indicates the measured values for shaft power, generator power, ship speed and fuel consumption for EEOI or EEDI monitoring. Supplemental monitoring of SO_X, NO_x, and PM emissions is also available and is displayed on the local unit indicating the measured values. File management of this data can be maintained on a PC storage unit or either be transmitted to shipping company headquarters through e-mails.

3. Ship monitoring

Table 1 lists the specification of the ship. The test has been carried-out during a two-month round trip (Pusan - Kaohsiung - Panama Canal - Pusan) voyage of the ship.

Table 1: Experiment vessel specification

Ship	Ship Type	4,600 TEU Container vessel
	Dead Weight	63,253 tonnage
	Ship Length	284.23 m
	Breadth	32.20 m
	Draft	13.518 m
Main Engine	Engine Type	8RT-flex96CB
	Power output	45,778 kW at 102 rpm
	Fuel Consumption at Shop	175 g/kWh
Aux. Engine	Engine Type	6L28/32H (4sets)
	Power output	1,750 kW at 720 rpm
	Fuel Consumption at Shop	190 g/kWh

Figure 7 shows the fuel consumption quantity calculated by curve fitting method of the measured results at engine builder's shop test.

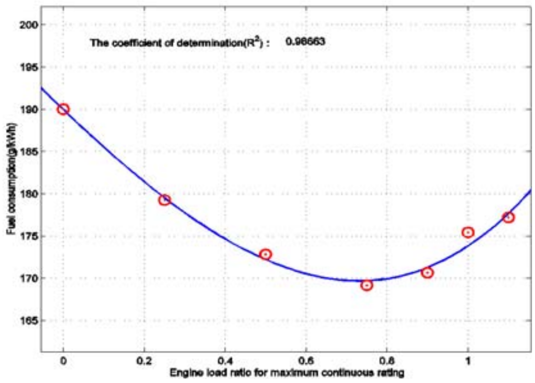

Figure 7: Fuel consumption of 8RT-flex96CB engine according to engine builder ship test

Table 2: Exhaust emission factors for 2007 inventory

Emission		Emissions factor(kg emitted/tonnage fuel)	Guideline Reference
CO		7.4	CORINAIR
NMVOC		2.4	CORINAIR
CH_4		0.3	IPPC 2006/ CORINAIR
N_2O		0.08	IPPC 2006/ CORINAIR
CO_2	HFO	3130	IPPC 2006
	MGO	3190	
SO_2	Residual (2.7 %S)	54	CORINAIR
	MGO (0.5%S)	10	
NO_X	Slow Speed	90/78 (85)	-------------
	Medium Speed	60/51 (56)	
	Boilers	7	
PM10	Residual	6.7	CORINAIR
	MGO	1.1	

NOx and PM can be calculated by using also the curve fitting method. This function enables an accurate automatic calculation and estimation of actual quantity the ship exhaust gases such as CO_2,NO_x, SO_X, PM in real-time condition and provides a data base of exhaust gas emissions for one year period. Even though exhaust gas monitoring instrument has been installed in practice, NOx measurement has some durability problem, complex measurement process, and difficulty in continuous monitoring. Hence, estimated measurement based on shop trial measurement, fuel sulphur content, correction calculation and operation margin experience will provide accurate GHG inventory. Likewise, estimated measurement of the ship SEEMP automatic data acquisition describes service load reduction and benefits management of shipping company.

Figure 8: Actual test ship (Hyundai Voyager)

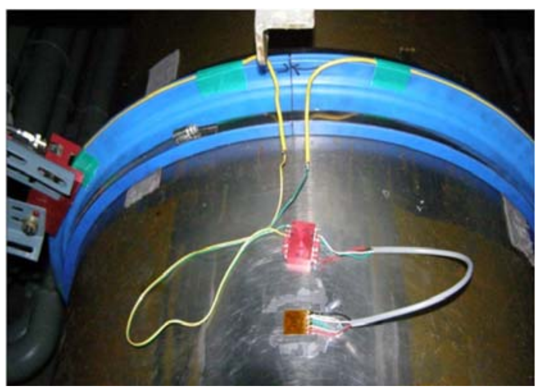

Figure 9: Telemetry system for EEOI monitoring test

Figure 8 shows the actual test ship HD

VOYAGER of Hyundai Merchant Marine Company, a 4600 TEU container vessel with a 45778 kW power output at 102 rpm of engine speed. Figure 9 is the telemetry system application for power measurement. Furthermore, to accomplish the experiment and using torque meter or similar instrument in to that Figure 9, it must conform to ISO guidelines [6~8] and IMO regulation [9]. Thus, it is encouraged that new buildings should be equipped with EDiMS during the early stage. For the speed signal, the Doppler Effect ship speed indicator was utilized. Fuel consumption for main engine was measured through the fuel flow meter whereas fuel consumption for auxiliary engine (power consumption 1,394.45 kW) and cargo capacity (i.e. 65% of deadweight) was applied practically to IMO EEDI formula.

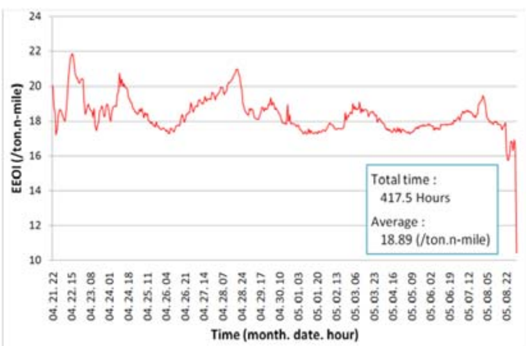

Figure 10: The monitored EEOI value from Kaohsiung port to Panama Canal

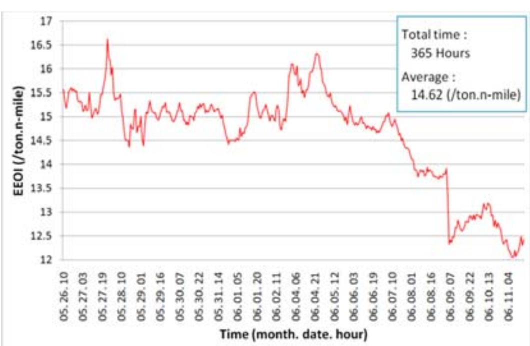

Figure 11: EEOI value from Panama Canal to Pusan port

Figure 10 and 11 shows the EEOI on-line measuring results for from Kaohsiung Port to Panama Canal and from Panama Canal to Pusan Port voyages, respectively. Average value of EEOI for Kaohsiung – Panama Canal voyage is 18.89 whereas that of Panama Canal – Pusan Port voyage is 14.62. In this study, the focal point will be the Kaohsiung Port – Panama Canal voyage. Figure 12 graphs the average daily fuel consumption for the Kaohsiung Port – Panama Canal voyage with 177.60 g/kWh whereas Figure 13 indicates the average power developed on the same trip with 28441kW. Figures 14 ~ 16 show the exhaust emission values. NO_X, SO_X and PM average emission values are given as 16.72 g/kWh, 8.35 g/kWh, and 1.17 g/kWh, respectively.

Furthermore, the data measured in this test using the EDiMS program confirms the correlations between ship's fuel consumption, power and exhaust gas emissions. Comparison of the relationship between EEOI in Figure 11 and NO_x in Figure 15 indicates the EEOI (CO_2)peak value can easily be matched to the NO_x lowest value, thereby confirming its inverse proportionality to one another.

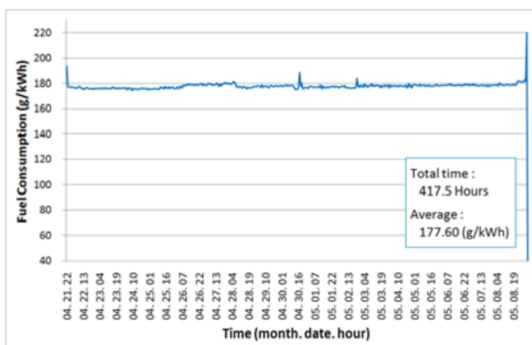

Figure 12: Fuel consumption from Kaohsiung port to Panama Canal

Also, comparison of the relationship between the fuel consumption in Figure 13 and SO_X in Figure 16 indicates that an increase in fuel oil consumption results in an increase in SO_X emissions as peak values in figures.

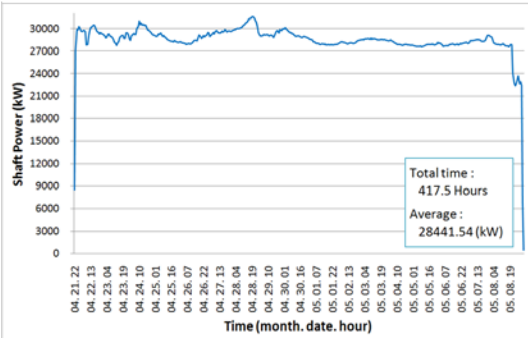

Figure 13: Shaft power from Kaohsiung port to Panama Canal

Figure 13 and Figures 14 and 16, on the other hand, illustrate the power developed and the NO_x and PM exhaust emissions during the voyage. Considering the peak values of power, it can be assumed that an increase in power would result in lower NO_x and PM exhaust emissions.

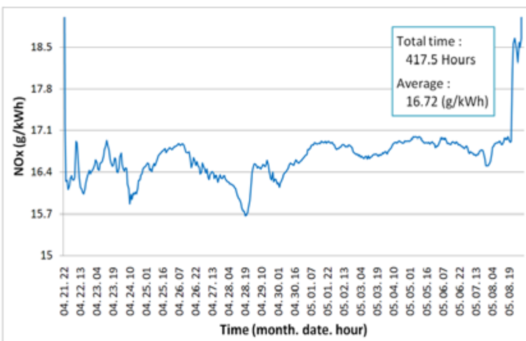

Figure 14: NO_x emission from Kaohsiung port to Panama Canal

Figure 17 graphs the ship slip ratio for the Kaohsiung Port – Panama Canal voyage. For this voyage, average ship slip ratio of a 5.89 % was recorded. Particularly, the ship slip ratio is important for f_w correction factor of EEDI. These measured values can be stored in the PC unit or be transmitted to shipping company by E-mails via satellite. Lastly, comparison of the relationship between the EEOI in Figure 10 and the ship slip ratio in Figure 17 noted that the peak values occurred at the nearly same time frame. Hence, it can be presumed that an increase in ship slip ratio will result to an increased CO_2 emission values.

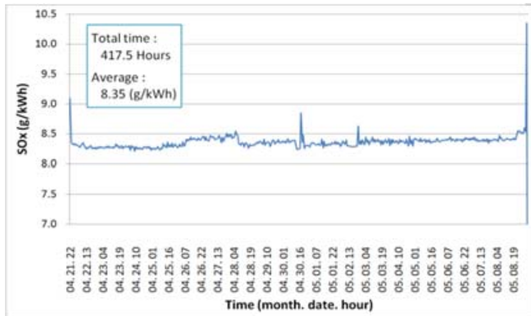

Figure 15: SO_X value from Kaohsiung port to Panama Canal

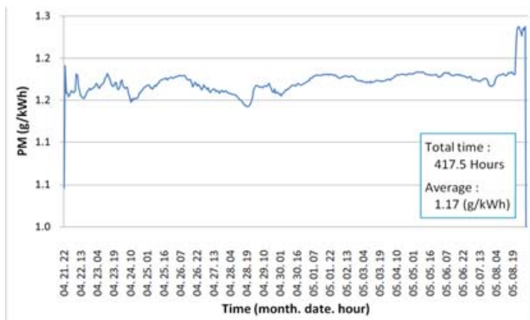

Figure 16: PM value from Kaohsiung port to Panama Canal

Figure 17: Ship slip ratio from Kaohsiung port to Panama Canal

4. Conclusion

This study describes the development of the EDiMS program in relation to the present continuous monitoring of EEOI or EEDI shipping certification according to the IMO rules and regulations. The results of are summarized as follows:

1) EEOI real time measurement could be confirmed. It is believed that the verification of the EEDI inspection practice will be carried out through the measurement required by ISO.

2) A data base can be created for EEOI to measure ship engine parameter, power and to control air pollution source such as CO_2, NO_x, SO_X and PM. Therefore, it is believed that necessary judgment to appropriate set up of the software will conveniently contribute to the ship application and risks, building inventory and ship energy management plan.

3) The software capability will be improved in shortest possible time due to the expectations and participations from the ship owners and shipping companies with accurate advices from specialists.

Acknowledgement

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