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Assessment the impact of changing ambient air temperature, humidity and air filter condition on main diesel engine performance and exhaust emissions

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ABSTRACT

As the ship running cost and environmental effects are mainly depend on engine performance and emitted exhaust emissions which are affected by engine conditions so in this study the quantitative approach is used to analysis the effect of ambient air temperature, humidity % and air filter condition on the engine performance and exhaust emission. 20 different scenarios represent ambient air temperature, humidity and air filter condition are applied on diesel engine and the result parameters related performance (Power, Compression and Maximum pressures) and emissions (NOx, CO_x and SO_x) are obtained and analysed then both the worst and the least risk scenarios are assigned..

Index Terms- Diesel Engine, Engine Performance, Exhaust Emissions, Emission Control Area

I. INTRODUCTION

AS over 95% of the world trade is transported by ships the world marine fleet reach to more than 110,000 ships and most of them are propelled by two stroke diesel engine compared to other propulsion types as table1.The ships propulsion power reached to a total of 40,000MW and 75% of that with 30,000MW from slow speed two stroke diesel engines and this show how the amount of exhaust emission released from 2 stroke diesel engine is quite high compared to that released from other engines types [1].

Diesel exhaust is a complex mixture of different material as sulphur oxides (SOx), Nitrogen oxides (NOx), Carbon monoxide and dioxide (CO, CO_2), Particulate Matter (PM), water vapour and low molecular weight of hydrocarbons and some of these gases are toxic and co_2 emission from the world shipping fleet is between 600 t0 800 million ton with around 4% of the global emission [2]. The exhaust emission is mainly depends on the fuel specifications and engine performance and it is costly to reduce the emission as 510$/ton for NOx and 930$/ton for SOx.

Also the running and maintenance costs of the main engine such as the fuel oil costs and spare parts prices are quit high compared to other ship costs and both of them are mainly depend on the engine performance so any drops in the performance will directly affect the ship costs.

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Table1 Types of Ship's Propulsion

Type of Main Propulsion	No.
2 Stroke Diesel Engine	11251
4 Stroke Diesel Engine	1699
Steam Turbine	185
Gas Turbine	28

These show that the ship economy, environment, and safety are mainly depend on the main engine performance. Two stroke diesel engines have large displacement of up to 3000 litre/cylinder and are used for propulsion of different ships types as container, bulk, Ro, Crude Oil, Product Oil, LPG and new LNG tankers. As these engines types are classified large and high power engines so the daily fuel oil consumptions are quit high and could reach to 100 ton/day and as the average price of marine fuel bunker around 500$ to 1000$/ton [3] this can give indication how the effect of fuel in ship costs so the ships owners from economy wise prefer to use the cheapest fuel types (Residual marine Fuels) which in other hand have their bad environmental effects.

II. PREVIOUS WORK

Evaluating diesel engine performance and analysis of associated exhaust emissions have been addressed in many previous studies as David V. et al [4] proposed analytic method based on condition monitoring for assessing material wear to predict diesel engine failure as they measure the wear materials such as iron and lead as a potential failure indicator, Youngjae L. and Kang Y. [5] used simulation model to analyse the combustion parameters as temperatures, pressures, NOx, COx and particulate matters (PM), Matthew F. et al [6] proposed a model to measure particulate matters (PM) emitted from diesel engine to avoid their series effects on both environment and human health, C. Felsch et al [7] proposed interactive flamelet model to predict diesel engine combustion in multiple injection events, C. Bekdemir et al [8] used Flamelet obtained show that using pure Jatropha biodiesel reduce the thermal efficiency by around 5% and increase No_x and Co_2 emissions while smoke and particulate matters decrease, Chih C. et al [10] used computational fluid dynamics (CFD) model for studying the combustion processes with various biodiesel fuels in a turbo-charged common rail diesel engine as the distributions of temperatures, pressures and pollutant formation of No_x inside the combustion chamber are obtained and analysed, Agung S. and Ahmed Y. [11] review the electrostatic precipitators methods for removing particulate matter (PM) in the diesel engine exhaust emissions, Qiuhang J. et al [12] evaluate the diesel engine performance and exhaust emissions by using integrated hybrid life cycle inventory analysis method, N. Ravikumor et al [13] study the effect of compression ratio and exhaust gas recirculation on diesel engine performance and exhaust emission, Gaurav D. et al [14] study the effect of using biodiesel from different oil sources on the performance and exhaust emissions, Majtaba S. et al [15] used Nitro Methane (NM) and Nitro Ethane (NE) as additives to diesel fuels to improve specific fuel consumption, engine performance and reduce exhaust emissions, K. Keerth et al.[16] study the effect of adding 10% of iso butanol to diesel fuel on the performance and exhaust emission of four stroke diesel engine, Eknath R. et al [17] study the effect of using blends of ethanol as fuel for single cylinder diesel engine on both performance and emissions at different values of compression ratio, Tadeusz B. et al [18] study the effect of loading condition, fouling surface deterioration of the hull and propeller and weather condition on engine performance and Dimitrios T. [19] proposed a simulation model to predict engine performance under different fault conditions.

III. DIESEL EXHAUST

The ships consumed around 350 million tonnes of marine fuel oil per year and 80% of that quantity are residual marine fuels and there are different types of these residual fuel oils but the most common used is intermediate fuel oil IFO 180 and 380. [3]

the residual marine Fuel contain different contaminants such as heavy metals, sulphur, water and other contaminants contained in crude oil and even this fuel meet the specification established in the MARPOL 73/78 annex VI and ISO and also pass

Generated Manifolds (FGMs) with several pressure levels to simulate a conventional compression ignition cycle and the results obtained show that not more than 5 pressure levels are needed to simulate the diesel engine performance evaluation, Gaurav P. et al [9] study the effect of using Jatropha biodiesel with mineral diesel oil on both diesel engine performance and exhaust emission and the results

through different stages of cleaning on board the ship but still has its bad effects on both engine performance and environment.

According to IMO greenhouse study in 2014 International shipping emitted 885 million tons of co2 which represent 2.8% of the total global co2 emission for that year while in 2012 was 796 million tons which represent 2.2%. [20]

The regulations for prevention of air pollution from ships are adopted to MARPOL 73/78 in 1997 and entered into force in May 2005 to minimise the ship emission and their impact on global environment as in table 2 and in 2011 IMO adopted the energy efficiency Design Index (EEDI) and Ship energy efficiency Management Plan (SEEMP) to reduce the amount of co_2 emission per ships capacity in mile [21].

According to MARPOL 73/78 Annex VI the exhaust emission, ship speed and shaft power are continues monitored by the automatic identification System (AIS) special in Emission Control Area (ECA) which are some area in which restricted measures are adopted to minimise the air emission from ships such as Baltic sea, Caribian, north sea and north America (US and Canadian Costs) [22].

NO_x is formed in air when fuel burned at high temperature and even the NO_x are colourless and odourless they can be seen as a brown layer over urban area, while SO_x is formed from burning fuels contain sulphur, NO_x and SO_x can dissolve in water vapour found in atmosphere and form nitric and sulphuric acids which come down as acids rains also react with ammonia to form nitrates and sulphates which are the main components of PM and its bad health effect. PM are fine ($\leq$2.5 Micron) solid or liquid particles found in the air such as dust, abrasion particles, silicates, sulphates, soot and liquid droplets and their small size may cause series health problems such as decrease Lung function, weakening of the heart and premature death.

Co is a colourless and odourless gas produced in case of incomplete combustion of the fuels and it is considered high risk as it is poisonous gas. Where the co_2 is one of the greenhouse gases and released when burning fuels. There are many sets of VOC such as hydrocarbon (HC) which is emitted from the engine with incomplete combustion exhaust or when fuel evaporate directly into atmosphere. Hydrocarbons include many toxic compounds which could cause cancer and adverse health effects.

Table 2 Emission Control

	Global		ECA	
Sulphur	2004	4.5%	2005	1.5%
	2012	3.5%	2010	1.0%
	2020	0.5%	2015	0.1%
NO_z	2004		17.0 g/Kw hr.	
	2011		14.4 g/Kw hr.	
	2016		3.4 g/Kw hr.	

IV. CASE STUDY

The MAN B&W 6S60 MC-C two stroke slow speed diesel engine with Maximum Continuous Rate (MCR) 13736 Kw at 105 rpm is selected as case study for analysis the impact of changing ambient air temperature, humidity% and air filter condition in engine performance and exhaust emission. The different scenarios are applied to the engine as the ambient temperature varied from -10 c to 38 c and humidity ranged from 0.0 to 100% while air filter blockage is ranged from 0.0 to 50% and in each scenario the data related to engine performance and exhaust emission as power/cylinder, cylinder compression Pressure (pc), maximum pressure (Pz), exhaust temperatures, turbo rpm and quantity of water drained from scavenge air manifold for performance and so_x, No_x, co_2 and c for exhaust emission. The results obtained are presented in table 3 and illustrated in figure 1 and 2. And it should be mentioned here that during all scenarios the type of fuel used for the engine remain unchanged.

Analysis of the results obtained shows that:

The ambient air temperature has a direct effect in engine performance as increasing the temperature reduce the compression and maximum pressures and consequently reduce the power and turbo rpm and in the same time the exhaust temperature increase and the reasons behind that is when increasing ambient temperature the density of air in the manifold reduced and so the weight of air entered to the cylinder reduced which cause reduction in compression pressure and consequently the maximum pressure, power and turbo rpm reduced as the cylinder power reduced by 7.5% when ambient temperature change from -10 c (north sea) to 38 c (Arabian gulf) and this reduction in power lead to increase in specific fuel consumption (SFC) and consequently ship running costs. In the time the exhaust temperature increased according to that by 49.6%.

And regarding the effect of ambient temperature on the exhaust emission the results show that increasing ambient temperature increased the co_2, c and so_x by 38.2%, 10.7 and 38.5% respectively and it should mentioned herein that these levels of emission are accepted if the ship is sailing in open sea but in ECA area these levels of emission are not allowed specially so_2 levels and in this case the ship could be in legal problems and the only alternative for the ship is to change the fuel used to low sulphur fuel.

Regarding the effect of humidity% the results show that:

The worst risk in the engine performance in case of increasing humidity% is the increasing the quantity of condensate water drained from air manifold by 16% at the same ambient temperature (30 c) and by 31% when changing humidity% from 0.0 to 100 and ambient temperature from 30c to 38c as if these water are not full drained out from the air manifold and part of them enter the engine cylinder the probability and consequences of the risk of cold corrosion become quite high and this can be explained as follows.

As shown in table there is sox in engine exhaust and the present of condensate water inside the cylinder will form sulphuric acid which is high corrosive substance for cylinder liner as increasing the wear rate and consequently running and maintenance costs and engine safety. The humidity% affect the other parameters of engine performance but not so series as condensate water drained from air manifold as increasing humidity% cause reduction in compression, maximum pressures, turbo rpm and power by 9.7%, 6.3%, 5.0% and 4.0% respectively.

Regarding the effect in the exhaust emission the results show that there are no any effect as all exhaust emissions keep their levels unchangeable.

Regarding the effect of air filter condition the results in tables and figures show that:

For the engine performance increasing the air filter blockage from 0.0% to 25% reduce the compression, maximum pressures, turbo rpm and power by 18.9%, 13.4%, 9.3% and 10.6 respectively and these show how the engine performance is affected by the condition of air filter but the worst risk is that increasing the exhaust gas temperature as it is increased by 31.5% and when the blockage% increase to 50% the engine is slowed down as the high exhaust temperature safety device is automatically initiated to avoid more worst consequences.

Regarding the exhaust emission the air filter condition is directly affected the emission as increasing filter blockage from 0.0 to 25% increase the emissions of co, sox and co2 by 25%, 20% and 20% but the worst effect is the increasing of c levels as it is increased by 49.5% and this cause high probability of burning this carbon in the pass of exhaust causing fire in exhaust gas boiler, the reason behind that increasing the filter blockage% directly reduced the quantity of air flow to the engine and lead to incomplete combustion so unburned fuels with carbon contents released with exhaust.

Comparing and analysis of the results obtained from three scenarios as in table 4 show that:

Regarding engine performance the highest risk are power reduction from air filter blockage and the next is the increasing the quantity of condensate water drained from air manifold. While fore exhaust emission increasing the carbon (c) from air filter

Blockage came as the highest risk and increasing the so_x from ambient temperature came second while increasing co_2 from ambient temperature came third.

Table 3 Effects of the Ambient Temperature

Ambient Temp. C	Kw/ Cyl.	Emission					Engine Performance.					
		NO_x ppm	CO ppm	SO_x ppm	CO_2 %	C mg/ m^3	$P_{Max.}$ Bar	$P_{Comp.}$ Bar	P_{Ind} Bar	T/C rpm	Average Exh. Temp.	Water Drain L/h
-10	1400	1012	65	26	3.4	56	170	148	19.9	16301	244	0.0
-5	1399	1003	64	26	3.4	56	168	146	19.9	16099	247	0.0
0.0	1395	983	62	27	3.5	56	165	142	19.9	15794	253	0.0
5	1390	969	61	27	3.6	57	161	137	19.9	15520	261	0.0
10	1370	954	59	28	3.7	57	157	132	19.8	15180	271	0.0
22	1370	919	56	30	4.0	59	148	122	19.8	14458	298	0.0
30	1340	895	53	33	4.4	61	141	112	19.4	13750	330	0,04
38	1295	873	50	36	4.7	62	132	101	18.9	13096	365	0.13

Table 4 the highest risks

The highest Risk Consequence	Scenario	Rank
Engine Performance		
Power reduction	Air filter blockage	1
Increasing quantity of condensate water drained from air manifold	Humidity %	2
Exhaust Emission		
Increasing C%	Air filter blockage	1
Increasing SO_x%	Ambient Air Temperature	2
Increasing CO_2%	Ambient Air Temperature	3
Increasing CO%	Air filter blockage	4

V. Conclusion and Recommendation

The results obtained from 20 scenarios show that:

- The worst risks in case changing ambient temperature is the power reduction and increasing so_x emission level.
- The worst risk in case changing humidity% is that increasing the quantity of condensate water drained from air manifold and consequently the increasing of cylinder liner wear rate.
- the worst risk related air filter blockage% is increasing exhaust temperature which could lead to slow down the engine and the risk of power

reduction can come next that for engine performance while for emission the effect are more worst as all emissions levels increased but increasing c came as the worst one

And it can be recommended that:

- Continuous monitor for the ambient air temperature and humidity%
- Effective system for monitoring piston ring condition to avoid the blowing pass
- Continuous check for the auto drain system in air manifold to avoid entering the condensate water into cylinder
- Continuous monitor for exhaust emissions especially in ECA area
- Further study for analysis the effect of other engine faults on both performance and exhaust emission.

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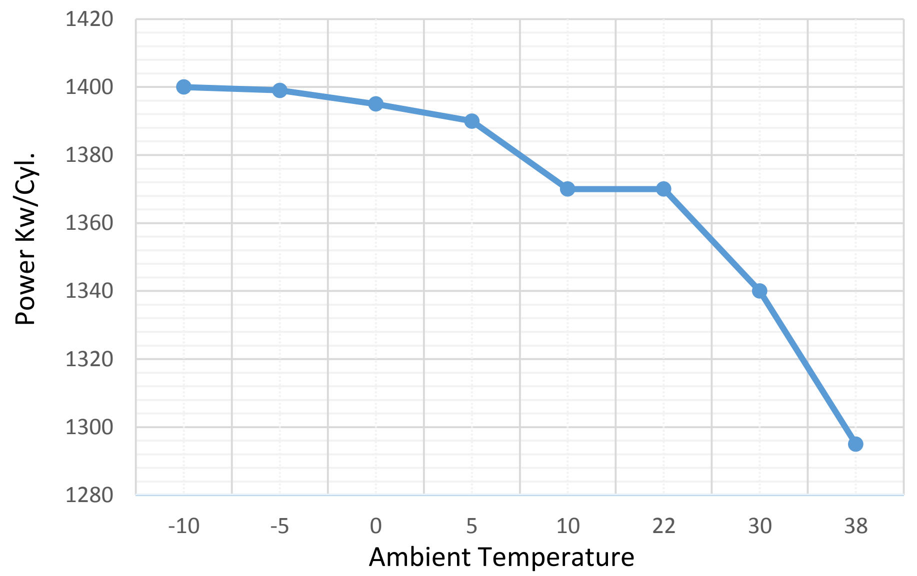

Figure 1 The impact of Ambient Temperatur on Engine Power

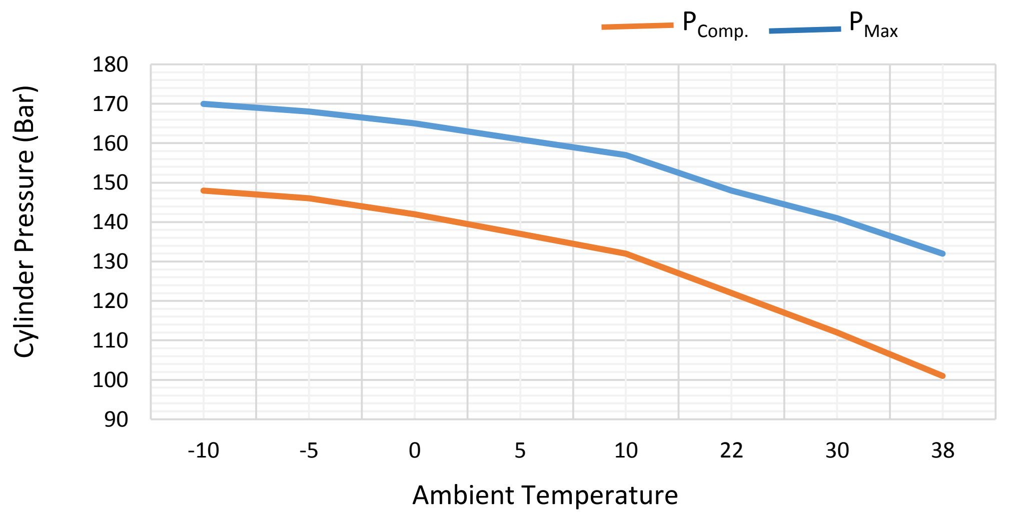

Figure 2 The Impact of Ambient Temperature on Engine Performance