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Experimental investigation for reducing emissions in the maritime industry

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Abstract

Shipping transportation is the foremost imperative mode of transportation in universal coordination. At display, more than 2/3 of the full worldwide exchange volume accounts for shipping transportation. Ships are utilized as an implies of marine transportation, introducing large-power diesel motors with exhaust containing nitrogen oxide NOx, sulfur oxide SOx, carbo di-oxide CO_2, particular matter PM10, hydrocarbon HC, and carbon mono-oxide CO which are the most dangerous contaminants found in exhaust gas from ships. Ships radiating large amounts of exhaust gases have become a significant cause of pollution in the air in coastal areas, harbors and oceans. therefore, IMO (the International Maritime Organization) has established rules to reduce this emission. This experiment shows the measurement of the exhaust gases emitted from the Aida IV ship main engine using marine diesel oil fuel (MDO). The measurement is taken by the Sensonic2000 device on 85% load which is the main sailing load. Moreover, the paper study different emission reduction technologies as alternative fuel which as liquefied natural gas (LNG) which is applied to the system, and reduction technology which is represented as selective catalytic reduction technology added to the marine diesel oil system (MDO+SCR). The experiment calculated the amount of nitrogen oxide NOx, sulfur oxide SOx, carbo di-oxide CO_2, particular matter PM10, hydrocarbon HC and carbon mono-oxide CO because they are having the most effect on the environment. The reduction technologies are applied on the same ship engine with the same load. Finally, the study found that MDO+SCR is the more efficient technology for Aida IV ship as a training and supply ship due to low consumption and no need to modify the engine just adding the SCR system to the exhaust line which is easy and cheapest. Moreover, the differences between them in the emission are not so big.

Keywords: *Emission reduction; ships; Selective Catalytic; Heavy fuel oil, LNG*

Introduction

Ships are very important method for transportation in this time and take the biggest part in international trade, but due to their huge volumes which can take large amount of merchandise they are using very powerful engines which consume a large amount of fuels[1].For more profits ship owners seeking for the cheapest type of fuel which is HFO (Heavy Fuel Oil), the produced exhaust has Nitrogen oxides (NO_x), Di-oxide (CO_2), Sulfur oxides (SO_X), Mono-oxide (CO), Hydrocarbons (HC) and Particulates Matter (PM) which seriously affect our current circumstance and greatly affects human wellbeing, these emanations expanded because of the huge number of boats which cause high level of air contamination [2].

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It is accounted for that air contamination discharged from ships are assessed to cause 50,000 unexpected losses each year in Europe, at a cultural expense of more than €58 billion every year[3]. Different associations worried about air contamination as of late directed. As more broad investigation that featured the wellbeing and government assistance ramifications of consuming fuel oils and determined the monetary advantages of dispensing with these emanations [4]. To diminish transport discharges (IMO) the International Maritime Organization has set up close cutoff points on SO_x and NO_x emanations, just as (ECAS) the four worldwide Emission Control Areas the United States Caribbean Sea, the Baltic Sea region, the North Sea region and North America region [5]. Besides, (MEPC) the Marine Environment Protection Committee put out an objective to diminish NO_x outflows to their least level by 2016 during its 57th meeting. As a proportion of lessening transport discharges, IMO guidelines have constrained boats to utilize essentially costlier fuel and will be needed to be worldwide by 2020. Without a doubt this will adversely affect transport financial aspects because of expanded running expenses, which will inspire every one of those with an interest in the marine field to look for and give different answers for this issue. Accordingly, various endeavors are made to discover an answer for the issue [6]. In addition, it is hard to gather exact exhaust discharges from ships because of the spreading and portability of boats, making checking and management of boat exhaust emanations hazardous [7]. This paper talks about this issue according to the perspective of guidelines, cost measurements, and the sort of fills for accomplishing decrease of outflows.

Fig 1 Global ship emissions

In order to safeguard the environment, marine diesel engines must be constructed in a variety method to saving energy and hence emissions reduction. Liu Ying has examined the save of energy and methods for reducing emissions from marine engines based on cost-cutting and reducing emissions of diesel fuel, and some recommends application for saving energy and emissions-reduction technology, as well as some recommendations theoretical underpinnings for future maritime endeavors[8]. Furthermore, Nujhat Choudhurya has discovered the interaction of nitrogen oxides (NO_x) and sulfur oxides (SO_x) in gas phase oxy-combustion systems and investigated the use of Fourier transform infrared (FTIR) spectroscopy to quantify emission of NO_x and SO_x. Nujhat hope to add to by giving NO_x and SO_x speciation data, as well as elucidating the impact of nitric oxide (NO) on sulfur trioxide (SO_3) production [9].Because of its high carbon capture rate and low energy consumption, pressurized oxy-fuel combustion has recently been hailed amongst the most efficient strategies for carbon capture. Because circulating flue gas is part of the combustion-supporting environment, the steam concentration in the gas carrier is more than in traditional combustion. In most studies on this technology, steam has been disregarded. Using a lab-scale pressured oxy-fuel combustion system, Donghee Kim evaluated the properties of combustion, heat transmission, and Emissions of SO_x /NO_x at different loads. The use of a gaseous fuel made up of CO and H_2 as well as pure oxygen was proposed. To regulate the high oxy-flame temperature, the inner wall generates recirculation of internal flue gas. Even though the combustion temperature is less, the overall rate of heat recovery obtained using the water jacket is 3% greater at 10 bars than ambient conditions Because H2O's emissivity is greater than that of CO_2, a higher H2O component in flue gas enhanced the heat flow rate. In the presence of low H_2O in the flue gas, SO_x and NO_x both fell by nearly 50% and 63 percent at 10 bars, respectively. When compared to ambient circumstances, the amounts of SO_x and NO_x in flue gas with greater H_2O levels fell by 87 percent and 93 percent, respectively, at 10 bars. H radicals and the H_2O fraction have been found to have an impact on NOx and SO_x oxidation and reduction[10].

Regulations and statistics of ships emissions

IMO is the International Maritime Organization is the world's biggest and most remarkable oceanic association, with 174 part nations and a critical job in the administration of marine contamination [11]. It detailed that the aggregate sum of fossil oil devoured by ships all around the world is 300 million tons [12]. Additionally, Marine transportation emanates CO_2 approximately 36 million tons, which represents 2.21 percent of overall CO_2 discharges [13]. Beside ozone harming substance (GHG), sea delivers additionally discharge huge measures of toxin emanation like So_x and NO_x, which are the most supporters of air contamination. NO_x emanations developed from 18 to 21 million tons, while SO_x discharges approximately from 10 to 11 million tons somewhere in the range of 2014 and 2018 [14]. Besides, SO_x and NO_x respond with different components noticeable all around, bringing about corrosive downpour. Considering this, to control marine diesel motor discharges the International Maritime Organization (IMO) set up a bunch of severe guidelines. The last one Tier 3, which came full circle on first of January, 2016, it decreased NO_x emanation levels by 75.1% when contrasted with Tier 2[15]. Additionally, the latest sea concurrence on oil contamination (MARPOL), which became real on first of January 2020, diminished the sulfur content cutoff in fuel from 3.51% to 0.5% [16]. So, the IMO set up discharge control regions (ECAs). To decrease the ecological effect of emanations from specific spots Different limitations apply to better places; Fig. 2 portrays the suitable NO_x discharge limits. In addition, Table 1 shows the IMO's specific emanation esteems. Diesel motor NO_x outflow restrictions are set dependent on the motor's most extreme working rate. Unmistakably, the latest Tier 3 cuts NO_x outflow limitations by 80% when contrasted with the Tier 1[17]. In the fuel sulfur is changed to SO_2 and SO_3 during the burning system in the diesel motor. Thus, lessening the amount of sulfur in the fuel is a significant source control approach for decreasing SO_x emanations. Table 2 shows the guidelines and guidelines for the SO_x outflows. the amount of sulfur in the fuel is restricted to 0.10 % and to 0.50 % internationally by 2020 by the amount of SO_x outflow in control regions (SECAS) by 2015, as displayed in Fig. 3. The progress from base 44 to base 45 relaxed from Tier 1 to Tier 2 is, as outlined in Table 1. The progress from Tier 2 to Tier 3 is considerable from base 9 to base 44. Likewise, as demonstrated in Fig. 3, the last one Tier 3 brought down approximately 85 % of sulfur present in the fuel when contrasted with the Tier 2[18]. Thus, Tier 3 decreased SO_x and NO_x emanations while likewise uplifting the advancement of more control innovation.

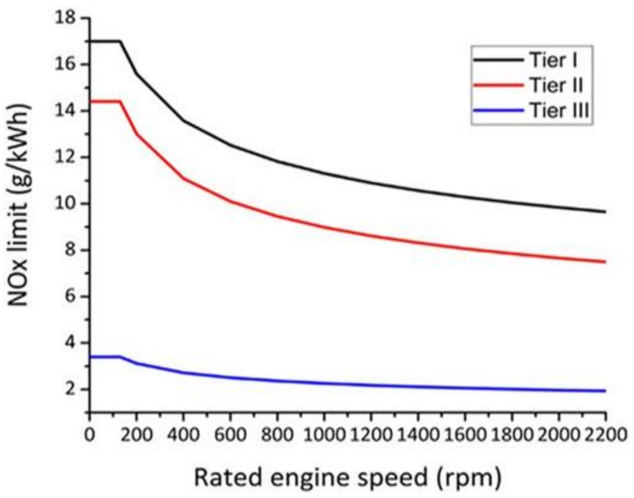

Fig. 2. Acceptable limit for NOx emissions

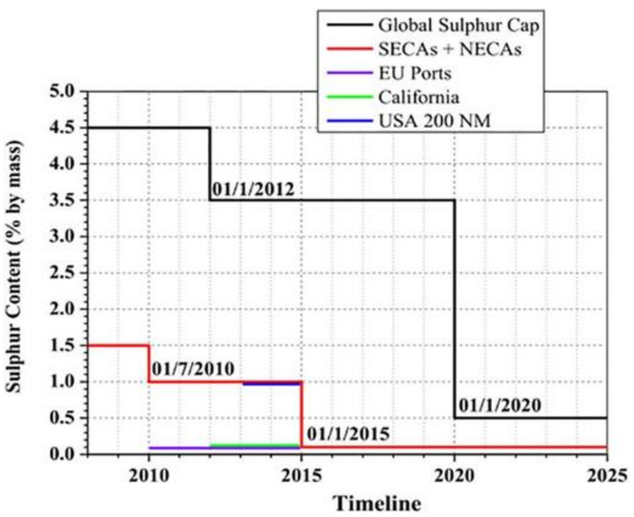

Fig. 3 Change of sulfur amount [11].

Table 1:NO_x emissions permissible limit for in IMO (g/kWh) [11,15].

Tier	Date of building of ships or after	emission limit of Total weighted (g/kWh) n= rated engine speed (rpm)		
		n < 130	n = 130 - 1999	n ≥ 2000
I	01/01/2000	17.0	45 $n^{(-0.2)}$	9.8
II	01/01/2011	14.4	44 $n^{(-0.23)}$	7.7
III	01/01/2016	3.4	9 $n^{(-0.2)}$	1.96

Table 2: Acceptable limits for sulfur concentration in fuel under various laws and regulations [11]

Regulation / Convention	Fuel Sulfur content (%m/m)	Effect. date	Effect area
Annex VI of MARPOL73/78 Convention	3.5	1.1.2012	Out of SECAs
	0.50	1.1.2020	
	1.00	1.7.2010	In SECCAs
	0.10	1.1.2015	
EU Law	0.10	1.1.2010	The EU ports
CARB Regulation	0.50	1.8.2012	California
	0.10	1.1.2014	waters

Ship emissions reduction technologies

IMO The International Maritime Organization held a diplomatic convention to restrict international emissions from marine diesel engines in 1997, which become codified as Annex VI of the MARPOL73/78 convention to restrict the emissions of marine diesel engines. [19] Much research on SO_x and NO_x emissions had been done to satisfy IMO policies. ERTS had been researched and up to date in 3 areas: exhaust after-treatment systems, fuel optimization, and pre-combustion control. As a result, the So_x and NOx emission discount answers could be explored with inside the following sub-sections in a methodical way primarily based totally on those 3 characteristics [20].

NOx emission reduction technologies

Many studies have shown that acceptable NO_x emission reductions are possible[21]. Adding water to the liquid fuel was one of the older approaches[22]. As a result, combining a product called puriNOx, which combines Lubrizol's unique additives with fuels to generate a new product, might be have NO_x and P.M reductions of nearly 20% and 50%, respectively[23]. Recently [24] demonstrated that internal engine improvements can reduce NO_x emissions by a significant percentage. Due to compatibility and durability most commercial ships use(SCR) the Selective Catalytic Reduction system is regarded the most efficient way of NO_x reduction among the other systems[25,26].

SOx emission reduction technologies

Some efforts have been made to improve marine fuel oil to reach the best SO_x emission reduction for a cleaner environment and to keep operating costs as low as possible. Mixing HFO with thermal oil made from waste plastics was one of these initiatives, but it proved too difficult in practice due to technological issues [27]. The ships emission of SO_x is a source of globally concern. So worldwide push to use cleaner lower-sulfur fuels instead of high-sulfur marine residual oil. (MGO) marine Gas Oil and(MDO) Marine diesel oil are two fuels being considered as potential replacements for residual oil[28].Additionally, a seawater scrubbing system looked to be an efficient way to reduce SO_x emissions [29,30]. Seawater scrubbing's widespread adoption will almost certainly be dependent on a successful new solution of the problem of its impact on ship operating cost and water quality [31].Except for a few minor differences, the US Environmental Protection Agency (EPA regulations, the IMO, the European Union (EU) laws and MARPOL regulations are all in sync. They all agreed of using the scrubbers, which is Exhaust Gas Cleaning Systems (EGCS).All ships must reach the same SO_x content limits in the exhaust regardless what type of the fuel used also if the ships were used a fuel less than 0.1 % of sulfur concentration of Each scrubber must also be accepted as an equivalent by the vessel's flag administration; therefore some flag state regulations may apply [32].

Experimental methods

In the recent years, the numbers of ships increased due to its huge role in the transportation. Therefore, the amount of the emissions increased so in this paper we study the most efficient way to reduce the emissions on ship Aida IV Fig (4). The ship was using MDO (Marine Diesel oil) we add Selective Catalytic Reduction SCR to the exhaust line and compare the emissions with normal system without SCR. Moreover, we add liquefied natural gas LNG system and compared it with MDO with SCR to get which more efficient in reduction the emission all measurement done on load 85%. Table 3 represent the main ship technical data.

Fig.4 Aida IV Training ship

Table 3 Aida IV ship technical data.

ITEMS	Description
Type of Ship	SEA TRAINING/SUPPLY VESSEL
Shipbuilder	Miho Shipyard Co., Ltd.
Number of engines	2 DE
Type of engine	4 SA 6 CY
Stroke	320 mm
Bore	220 mm
Power (kW)	2,660 (1,330 x 2)
Revolution (rpm)	900.0
Manufacturer	Yanmar Co., Ltd. Manufacturing Management Dept.

The measurement device (Sensonic2000) which take the measurements of the exhausts using these type of fuel (MDO, MDO+SCR and LNG). The exhaust gases sampling measured from the exhaust stack of the engine. The place of taking the sampling was in the exhaust line there is sample port shown in Fig (5). All the measurements taken on same stabled conditions as Humidity and room temperature. Moreover, the engine running on the load for 20mins to recognize if there is any unstable in readings, the Sensonic device reads the amount of sulfur oxide (SO_x), nitrogen oxides (NOx), Mono-Oxide (CO) and exhaust temperature (T_{ext}).

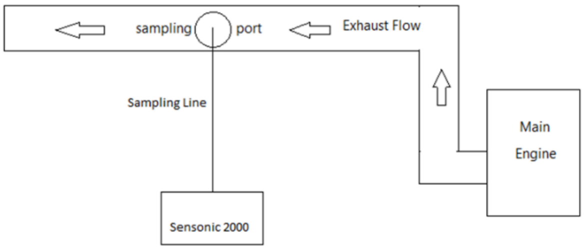

Fig.5 Experimental RIG

The device was calibrated but we made a test with small generator shown in Fig (7) single stage air cooled engine with 7.5 brake power (BW) and 1500 rpm. In Fig (8) show the measurement device (Sensonic2000) which take the measurements of the exhaust gases in the ship and for the small generator. The specification of the generator shown in table 4.

Fig.7 Generator -engine

Table 4 Specification of engine

ITEMS	Specifications
Model	Apan Diesel India
Brake power	7.5
Rated speed (rpm)	1500
NO. of cylinder	1 cylinder
Stroke	110 mm
Bore	102 mm
Cycles	4 stroke engine
Cooling system	Air cooler
Compression Ratio	16.5

Fig.8 The measurement device

The measurement of generator done on four loads represented by (0%-25%-50%-75%-100%). The engine running on diesel oil D.O the measurement taken on each load for 20 minutes to neglect any unstable reading. The result of nitrogen oxide (NO_x) using was taken close to reference [33] which shows in Figure (9), the NO_x was increasing close to referred experiment until reach 50% load then due to the small difference between two engines you will find a gapes in results from 70% to 75% load then they will get close again at 80% load until full load. Additionally, the results of sulfur dioxide (SO_2) was taken close to reference [34] which shows in Figure (10).

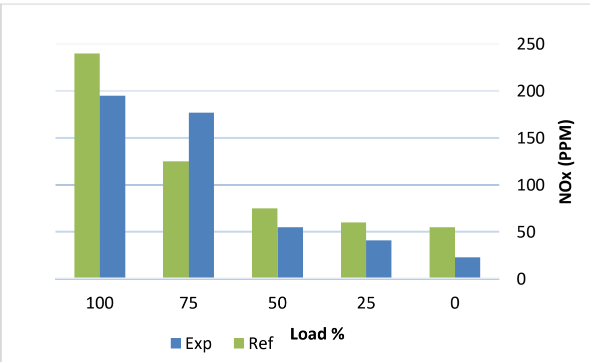

Fig.9 Validation of NO_x measurement [33]

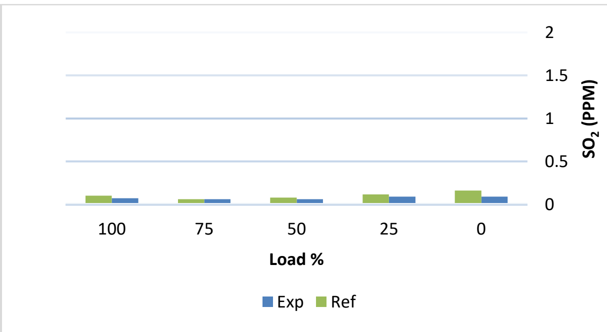

Fig.10 Validation of SO_2 measurement [34]

Results and discussions

Referring to the generator test we start our experiment by measuring the exhaust of Aida IV ship main engine using it main system of fuel which is Marine diesel oil (MDO) we left the engine running for 45 minutes to warm up then start to increase the load of the engine to 85% which is the main load of the ship in sailing then we start to measure the emissions (nitrogen oxide NO_x, sulfur oxide SO_x, carbo di-oxide CO_2, particular matter PM_{10}, hydrocarbon HC and carbon mono-oxide Co) Table 5 shows the amount of exhaust emitted by MDO.

Table 5 Emission emitted by MDO

Engine	Diesel engine	
Load 85% (KW)	2261	
Fuel consumption MDO (m^3/hr)	0.37	
Engine emission factor	NO_x	4.9
	SO_x	0.94
	CO_2	254.5
	PM_{10}	0.2
	HC	0.19
	Co	0.6

To change the engine from diesel engine to liquefied natural gas engine there is many parts should change as (valves, fuel injectors, etc.) and added such as storage bottle with supply pipes and gas detection system with alarms to detect any leaking of LNG with ventilation system. we start running the engine with liquefied natural gas (LNG) for 45 minutes the reading was stable and shown in Table 6.

Table 6 Emission emitted by LNG

Engine	**LNG engine**	
Load 85% (KW)	2261	
Fuel consumption LNG (m^3/hr)	450.7	
Engine emission factor	NO_x	0.95
	SO_x	0.098
	CO_2	204.3
	PM_{10}	0.0055
	HC	0.33
	Co	0.22

To neutralize NO_x in the exhaust, Selective Catalytic Reduction (SCR) technology employs a simple chemical process. At the comparatively low temperatures of an exhaust stream, the catalyst facilitates the interaction between NO_x and a reducing agent such as ammonia. By inject solution from water and urea in the exhaust line due to high temperature of exhaust the solution evaporates, and urea converted to ammonia which made a chemical reaction with nitrogen oxides in the exhaust gases. The dangerous components in exhaust gases are converted to inert nitrogen gas and harmless water vapor by a catalytic converter. the SCR system comprises of a titanium-vanadium catalyst and a nozzle that sprays urea water onto the top side of the catalyst as represented in figure 11. SCR is a very efficient system that can remove up to 99 percent of NO_x emissions. The technique has been widely used to reduce NO_x emissions from power plants, and it has also become the industry standard for eliminating NO_x emissions from truck engines. From the 1990s, SCR has been employed in maritime applications and has become the most used technologies.

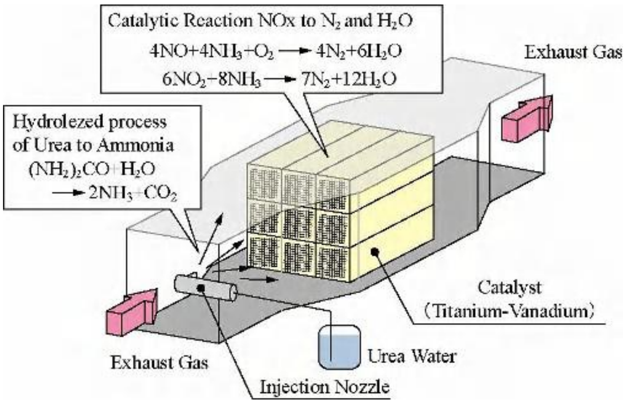

Fig. 11 SCR system

A design flowchart for the SCR system is shown in Figure 12. Flow rate, temperature, and NOx content of exhaust gas is required as design requirements for the SCR system. Due to the early design stage, certain data could not be gathered, thus we evaluated the SCR performance using assumed values. At rated power, the space velocity, SV, is set at 11000 h-1, which is defined as the ratio of exhaust gas flow rate [m3/h] to catalyst volume [m3]. The number and length of catalysts are determined by the diameter of the exhaust tube and the available laboratory space. The SCR's Predicted performance and characteristics are listed in Table 7.

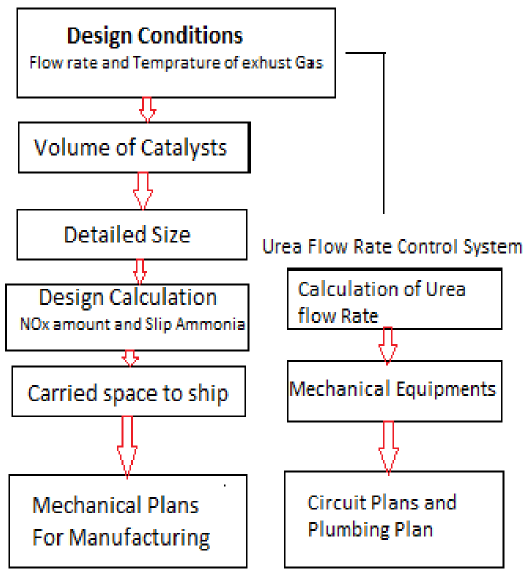

Fig.12 Design flowchart for the SCR system

Table 7 Predicted performance and characteristics of SCR

Catalyst Type	Titanium-Vanadium
Number	8
Size	60x60x90mm
Cell (Mesh Num.)	25(per 1 edge)
Number	8
Space Velocity, SV	$11000h^{-1}$ (At rated power)
Urea Flow Rate	30~ 60 mL/min
Solution	45%UreaWater
NOx conversion rate	65~ 70% (at68.5%ofequivalentratio)
Solution	45%UreaWater
Urea Flow Rate	30~ 60 mL/min

To reduce the amount of NO_x in Aida IV ship using (MDO + SCR) to be allowable as IMO tier3 limits for NO_x Figure 13 depicts the Selective Catalytic Reduction (SCR)'s connection to the ship main engine. On the top side of the engine, a catalyst case and a urea injection nozzle are situated in the straight section of the exhaust pipe. To ensure enough time for urea to be converted to ammonia, the distance between the catalysts and the nozzle should be kept as long as feasible. However, both the catalysts and the nozzle must be placed in the straight section of the 1 m in the case of the engine room free space due to the length of exhaust tube and the available space is restricted.

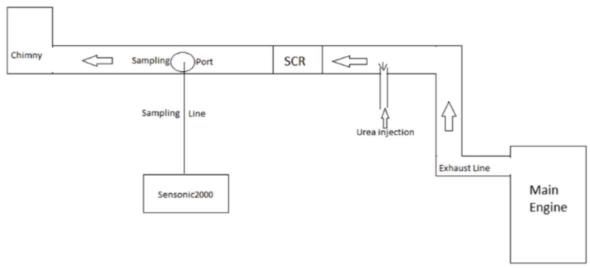

Fig. 13 SCR rig

Before installation of the SCR, we had done test to the Urea nozzle to ensure that it work perfect and check all the diesel engine conditions. Table 8 shows the amount of emissions emitted by Aida IV ship main engine applying both reduction technologies and normal ship system (LNG, MDO+SCR and MDO)

Table 8 Engine emissions factors for different fuels

Engine fuel		MDO	LNG	MDO+SCR
Load 85% (KW)		2261		
Fuel consumption (m3/hr)		0.37	450.7	
Engine emission factor	NO_x	4.9	0.95	0.588
	SO_x	0.94	0.098	0.063
	CO_2	254.5	204.3	254.5
	PM_{10}	0.2	0.0055	0.0023
	HC	0.19	0.33	0.19
	CO	0.6	0.22	0.6

As shown in figure 14 the percentage of reduction the emission emitted which is (nitrogen oxide NO_x, slufer oxide SO_x, carbo di-oxide CO_2, particluar matter PM_{10}, hydrocarbon HC and carbon mono-oxide Co) by the main engine of Aida IV ship by using different type of reductions as alternative fuel which represent in this paper as liquefied natural gas(LNG) and reduction technology which represented as selective catalytic reduction (MDO+SCR) technology comparable with the ship main system using Marine diesel oil MDO

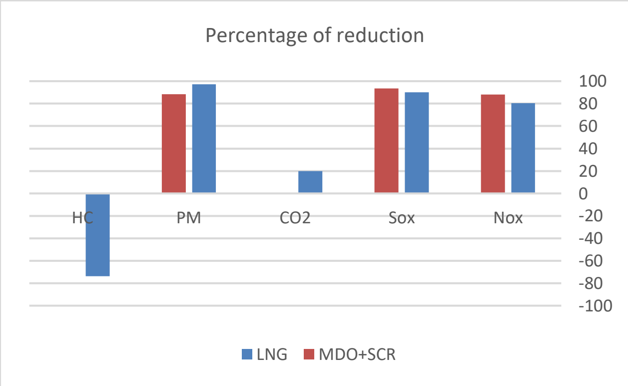

Fig. 14 the percentage of reduction

Economically, we found that the marine diesel oil with selective catalytic reduction (MDO+SCR) is much efficient than liquefied natural gas system (LNG). Due to LNG has high rate of consumption and need engine modify like change parts of the engine such as valves, piston, compressors, pipelines installation and fuel injectors moreover need free space to storage bottles and detector systems with alarms for safety. Additionally, the marine diesel oil with selective catalytic reduction has low consumption and no need to modify the engine just add the SCR system to the exhaust line which is easily and cheapest. Moreover, the differences between them in the emission not so big as shown in this paper.

Conclusions

Ship emissions are one of the most pressing concerns among individuals engaged in the maritime field, as they have a harmful influence on the marine ecosystem. The current paper examined the different techniques which could complete to diminish those emissions by using different reduction technologies as alternative fuel which is liquefied natural gas (LNG) and reduction technology which represented as selective catalytic reduction (MDO+SCR) technology which is the most common technologies used in this but as represented in this paper there is criteria to apply one of these methods such as cost, main engine free space and time of sailing. After our experiment on Aida IV ship, we found that MDO+SCR is the more efficient technology as training and supply ship. The experiment study the amount of sulfur dioxide (SO2), nitrogen oxides (NOx) and Carbon Mono-Oxide (CO) due to their effect on the environment. However, the study adds Selective Catalytic Reduction (SCR) to the exhaust line to reduce the amount of Nitrogen Oxide (NOx) to meet with the International Maritime Organization (IMO) rules and requirement to reduce the ships emission by 50% at 2030 comparable to 2008. The experiment shows a possibility of using marine Diesel oil (MDO) with low sulfur with (SCR) the Selective Catalytic Reduction as treatment method onboard ship to achieve valuable emission reduction percentage. Additionally, it can be adding sea water scrubber system to the MDO +SCR system to reduce more sulfur oxide SO^x which will give higher amount of emission reduction.

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