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Experimental Investigation on Emission Characteristics of a Marine Diesel Engine with Catalytic Convertor for Compliance with Marpol Regulations

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***Abstract* - In this paper, the study of methods to minimise SO_x , NO_x and particulate matter is done using a catalytic convertor. The dilution has been done for the emissions from an compression ignition engine i.e, a diesel engine . The validation of the diluted emissions gives a clear picture that the catalytic converter used is in compliance with the MARPOL Regulations . All the necessary equipment is a replica of a compression ignition engine that may be used onboard a ship and the fuel used in this engine is the similar fuel that is used onboard a ship for a diesel engine. The validation has been carried out in two different stages i.e, first for the emissions before dilution and second after the dilution and hence the results are compared to show the effectiveness of the current catalytic convertor.**

***Keywords:* Sox, Nox, Particulate Matter, Diesel Engine, MARPOL Regulations.**

I.INTRODUCTION

The oceans have become a dumping ground. Mercury emitted by land-based industrial plants finds its way back into our seafood with potentially serious consequences for fish and human health. Meanwhile, tons of concentrated fish waste from offshore fish farming gets deposited in the seafloor habitat by snuffing out oxygen and life. Oil spills, for which there is no reliable cleaning mechanism, continue to occur, and the global shipping fleet emits tons of carbon into the atmosphere with no regulations.

Marine pollution occurs when harmful, or potentially harmful, effects result from the entry into the ocean of chemicals, particles, industrial, agricultural and residential waste, noise, or the spread of invasive organisms. Most sources of marine pollution are land based. The pollution often comes from nonpoint sources such as agricultural runoff, wind-blown debris and dust. Nutrient pollution, a form of water pollution, refers to contamination by excessive inputs of nutrients. It is a primary cause of eutrophication of surface waters, in which excess nutrients, usually nitrogen or phosphorus, stimulate algal growth.

Many potentially toxic chemicals adhere to tiny particles which are then taken up by plankton and benthos animals, most of which are either deposit or filter feeders. In this way, the toxins are concentrated upward within ocean food chains. Many particles combine chemically in a manner highly depletive of oxygen, causing estuaries to become anoxic.

When pesticides are incorporated into the marine ecosystem, they quickly become absorbed into marine food webs. Once in the food webs, these pesticides can cause mutations, as well as diseases, which can be harmful to humans as well as the entire food web.

Toxic metals can also be introduced into marine food webs. These can cause a change to tissue matter, biochemistry, behaviour, reproduction, and suppress growth in marine life. Also, many animal feeds have a high fish meal or fish hydrolysate content. In this way, marine toxins can be transferred to land animals, and appear later in meat and dairy products.

A.Major Pollutants causing Marine Pollution

The following pollutants under lime light which are of greater concern:
(i) Sulphur Oxides (SO_X)
(ii) Nitrogen Oxides (NO_X)
(iii) Particulate Matter

The following description will give a better idea of the above mentioned pollutants and their effect on the environment.

B.Major Sources Of Pollutants

There are various locations, activities or factors which are responsible for releasing pollutants into the atmosphere. These sources can be classified into two major categories.

(i) Anthropogenic (man-made) sources: These are mostly related to the burning of multiple types of fuel.

a. Stationary Sources include smoke stacks of power plants, manufacturing facilities (factories) and waste incinerators, as well as furnaces and other types of fuel-burning heating devices. In developing and poor countries, traditional biomass burning is the major source of air pollutants; traditional biomass includes wood, crop waste and dung.
b. Mobile Sources include motor vehicles, marine vessels, and aircraft.
c. Chemicals dust and controlled burn practices in agriculture and forest management. Controlled or prescribed burning is a technique sometimes used in forest management, farming, prairie restoration or greenhouse gas abatement. Fire is a natural part of both forest and grassland ecology and controlled fire can be a tool for foresters. Controlled burning stimulates the germination of some desirable forest trees, thus renewing the forest.
d. Fumes from paint, hair spray, varnish, aerosol sprays and other solvents
e. Waste deposition in landfills, which generate methane. Methane is highly flammable and may form explosive mixtures with air. Methane is also an asphyxiant and may displace oxygen in an enclosed space. Asphyxia or suffocation may result if the oxygen concentration is reduced to below 19.5% by displacement.
f. Military resources, such as nuclear weapons, toxic gases, germ warfare and rocketry .

***Natural sources**:*

(a) Dust from natural sources, usually large areas of land with few or no vegetation.
(b) Methane, emitted by the digestion of food by animals, for example cattle.
(c) Radon gas from radioactive decay within the Earth's crust. Radon is a colorless,

Odourless, naturally occurring, radioactive noble gas that is formed from the decay of radium. It is considered to be a health hazard. Radon gas from natural sources can accumulate in buildings, especially in confined areas such as the basement and it is the second most frequent cause of lung cancer, after cigarette smoking.

a. Smoke and carbon monoxide from wildfires .
b. Vegetation, in some regions, emits environmentally significant amounts of VOCs on warmer days. These VOCs react with primary anthropogenic pollutants ,specifically, NO_x, SO_2, and anthropogenic organic carbon compounds, to produce a seasonal haze of secondary pollutants.
c. Volcanic activity, which produces sulfur, chlorine, and ash particulates .

II.MARPOL REGULATIONS

Marpol 73/78 is the International Convention for the Prevention of Pollution From Ships, 1973 as modified by the Protocol of 1978. ("Marpol" is short for marine pollution and 73/78 short for the years 1973 and 1978.) Marpol 73/78 is one of the most important international marine environmental conventions. It was designed to minimize pollution of the seas, including dumping, oil and exhaust pollution. Its stated object is to preserve the marine environment through the complete elimination of pollution by oil and other harmful substances and the minimization of accidental discharge of such substances.

The original MARPOL was signed on 17 February 1973, but did not come into force due to lack of ratifications. The current convention is a combination of 1973 Convention and the 1978 Protocol. It entered into force on 2 October 1983. As of May 2013, 152 states, representing 99.2 per cent of the world's shipping tonnage, are parties to the convention.

All ships flagged under countries that are signatories to MARPOL are subject to its requirements, regardless of where they sail and member nations are responsible for vessels registered under their respective nationalities.

In order for IMO standards to be binding, they must first be ratified by a total number of member countries whose combined gross tonnage represents at least 50% of the world's gross tonnage, a process that can be lengthy. A system of tacit acceptance has therefore been put into place, whereby if no objections are heard from a member state after a certain period has elapsed, it is assumed they have assented to the treaty.

All six Annexes have been ratified by the requisite number of nations; the most recent is Annex VI, which took effect in May 2005. The country where a ship is registered (Flag State) is responsible for certifying the ship's compliance with MARPOL's pollution prevention standards. Each signatory nation is responsible for enacting domestic laws to implement the convention and effectively pledges to comply with the convention, annexes, and related laws of other nations. In the United States, for example, the relevant implementation legislation is the Act to Prevent Pollution from Ships.

One of the difficulties in implementing MARPOL arises from the very international nature of maritime shipping. The country that the ship visits can conduct its own examination to verify a ship's compliance with international standards and can detain the ship if it finds significant noncompliance. When incidents occur outside such country's jurisdiction or jurisdiction cannot be determined, the country refers cases to flag states, in accordance with MARPOL. A 2000 GAO report documented that even when referrals have been made, the response rate from flag states has been poor.

TABLE I MARPOL REGULATIONS

Annexure	Title	Entry into force	No. of Contracting Parties/States	% of the World Tonnage
Annex I	Prevention of pollution by oil	2 October 1983	152	99.20
Annex II	Control of pollution by noxious liquid substances	2 October 1983	153	99.20
Annex III	Prevention of pollution by harmful substances in packaged form	1 July 1992	138	97.59
Annex IV	Prevention of pollution by sewage from ships	27 September 2003	131	89.65
Annex V	Prevention of pollution by garbage from ships	31 December 1988	144	98.47
Annex VI	Prevention of air pollution from ships	19 May 2005	72	94.70

III.MARPOL ANNEXURE VI

MARPOL 73/78 Annexure VI *Regulations for the prevention of Air Pollution from ships* entered into force on 19 May 2005, Basically the code covers the following.

Regulation 12 - Emissions from Ozone depleting substances from refrigerating plants and fire fighting equipment.
Regulation 13 - Nitrogen Oxide (NOx) emissions from diesel engines
Regulation 14 - Sulphur Oxide (SOx) emissions from ships
Regulation 15 - Volatile Organic compounds emissions from cargo oil tanks of oil tankers
Regulation 16 - Emissions from shipboard incinerators.
Regulation 18 - Fuel Oil quality.

These will apply to all ships of 400 gross tons and above which will have to carry an International Air Pollution Prevention Certificate (IAPP Certificate). This certificate must be on board at delivery for a ship constructed (keel laid) after 19 May 2005. For ships constructed before this date, the IAPP certificate must be on board at the first scheduled dry-docking after 19 May 2005, but not later than 19 May 2008. Ships constructed (keel-laid) before 1 January 2000 need to comply with operational requirements in MARPOL Annexure VI from 19 May 2005. Unless existing engines are subject to major modification, or new engines or incinerators are fitted, the requirements in Regulation 13 and constructive requirements in Regulation 16 do not apply to vessels constructed before 1 January 2000.

Ships of less than 400 tons will still have to comply with the legislation where applicable, but in their case the Administration may establish appropriate measures in order to ensure that Annex VI is complied with.

Specifications of IC Engine

BHP – 5 HP
Number of cylinders – 1
Compression ratio – 16.5 : 1
Bore – 80 mm
Stroke – 110 mm
Type of cooling – Water cooled
Speed – 1500 RPM
Air drum orifice – 20 mm
Make – Kirloskar
Method of starting – Crank start
Method of loading – Rope brake

Fig.1 Experimental setup of current test RIG

IV.VARIABLE PERFORMANCE PARAMETERS

Engine performance is an indication of the degree of success of the engine performs its assigned task, i.e. the conversion of the chemical energy contained in the fuel into the useful mechanical work.

The basic performance parameters are the following:
(a) Power and Mechanical Efficiency.
(b) Mean Effective Pressure and Torque.

(c) Specific Output.
(d) Volumetric Efficiency.
(e) Fuel-air Ratio.
(f) Specific Fuel Consumption.
(g) Thermal Efficiency and Heat Balance.
(h) Exhaust Smoke and Other Emissions.
(i) Specific Weight.

(a) Power and Mechanical Efficiency

The main purpose of running an engine is to obtain mechanical power. Power is defined as the rate of doing work and is equal to the product of force and linear velocity or the product of torque and angular velocity. Thus, the measurement of power involves the measurement of force (or torque) as well as speed. The force or torque is measured with the help of a dynamometer and the speed by a tachometer. The power developed by an engine and measured at the output shaft is called the brake power (bp) and is given by,

$BP = 2\pi NT / 60$

Where, T is torque in N-m and N is the rotational speed in revolutions per minute.

The total power developed by combustion of fuel in the combustion chamber is, however, more than the bp and is called indicated power (ip). Of the power developed by the engine, i.e. ip, some power is consumed in overcoming the friction between moving parts, some in the process of inducting the air and removing the products of combustion from the engine combustion chamber.

(b) Indicated Power

It is the power developed in the cylinder and thus, forms the basis of evaluation of combustion efficiency or the heat release in the cylinder.

$IP = P_m LANk / 60$

Where, Pm = Mean effective pressure, N/m^2,
L = Length of the stroke, m,
A = Area of the piston, m^2,
N = Rotational speed of the engine, rpm (It is N/2 for four stroke engine),
k = Number of cylinders.

Thus, we see that for a given engine the power output can be measured in terms of mean effective pressure. The difference between the ip and bp is the indication of the power lost in the mechanical components of the engine (due to friction) and forms the basis of mechanical efficiency; which is defined as follows:

Mechanical efficiency = (bp/ip)

The difference between indicated power (ip) and brake power (bp) is called friction power (fp).

fp = ip − bp

Mechanical efficiency = bp / (bp + fp)

(c) Mean Effective Pressure and Torque

Mean effective pressure is defined as a hypothetical/average pressure which is assumed to be acting on the piston throughout the power stroke. Therefore,

$P_m = ip \times 60 / LANk$

Where,
Pm = Mean effective pressure, N/m2,
ip = Indicated power, Watt,
L = Length of the stroke, m,
A = Area of the piston, m^2,

N = Rotational speed of the engine, rpm (It is N/2 for four stroke engine), and
k = Number of cylinders.

If the mean effective pressure is based on bp it is called the brake mean effective pressure (bmep) and if based on ip it is called indicated mean effective pressure (imep). Similarly, the friction mean effective pressure (fmep) can be defined as,

fmep = imep − bmep

The torque is related to mean effective pressure by the relation $bp = 2\pi NT / 60$

$p = P_m LANk / 60$

$2\pi NT/60 = (bmep . A . L .K/60)$

Or,

$T = (bmep . A . L . k) /2\pi$

Thus, the torque and the mean effective pressure are related to the engine size. A large engine produces more torque for the same mean effective pressure. For this reason, torque is not the measure of the ability of an engine to utilize its displacement for producing power from fuel. It is the mean effective pressure which gives an indication of engine displacement utilization for this conversion. Higher the mean effective pressure, higher will be the power developed by the engine for a given displacement. Again we see that the power of an engine is dependent on its size and speed. Therefore, it is not possible to compare engines on the basis of either power or torque. Mean effective pressure is the true indication of the relative performance of different engines.

(d) Specific Output

Specific output of an engine is defined as the brake power (output) per unit of piston displacement and is given by,

Specific output = bp / (A× L) = Constant × bmep × rpm

The specific output consists of two elements – the bmep (force) available to work and the speed with which it is working. Therefore, for the same piston displacement and bmep an engine operating at higher speed will give more output. It is clear that the output of an engine can be increased by increasing either speed or bmep. Increasing speed involves increase in the mechanical stress of various engine parts whereas increasing bmep requires better heat release and more load on engine cylinder.

(e) Volumetric Efficiency

Volumetric efficiency of an engine is an indication of the measure of the degree to which the engine fills its swept volume. It is defined as the ratio of the mass of air inducted into the engine cylinder during the suction stroke to the mass of the air corresponding tothesweptvolume of the engine at atmospheric pressure and temperature. Alternatively, it can be defined as the ratio of the actual volume inhaled during suction stroke measured at intake conditions to the swept volume of the piston.

$$\text{Volumetric Efficiency, } \eta v = \frac{\text{Mass of charge actually sucked in}}{\text{Mass of charge corresponding to the cylinder intake P and T conditions}}$$

The amount of air taken inside the cylinder is dependent on the volumetric efficiency of an engine and hence puts a limit on the amount of fuel which can be efficiently burned and the power output. For supercharged engine the volumetric efficiency has no meaning as it comes out to be more than unity.

(f) ***Fuel-Air Ratio (F/A)***

Fuel-air ratio (F/A) is the ratio of the mass of fuel to the mass of air in the fuel-air mixture. Air-fuel ratio (A/F) is reciprocal of fuel-air ratio. Fuel-air ratio of the mixture affects the combustion phenomenon in that it determines the flame propagation velocity, the heat release in the combustion chamber, the maximum temperature and the completeness of combustion. Relative fuel-air ratio is defined as the ratio of the actual fuel-air ratio to that of the stoichiometric fuel-air ratio required to burn the fuel supplied. Stoichiometric fuel-air ratio is the ratio of fuel to air is one in which case fuel is completely burned due to minimum quantity of air supplied.

Relative fuel-air ratio, FR = actual fuel − Air ratio

Stoichiometric fuel − Air ratio

(g) Brake Specific Fuel Consumption (bsfc)

Specific fuel consumption is defined as the amount of fuel consumed for each unit of brake power developed per hour. It is a clear indication of the efficiency with which the engine develops power from fuel.

$$\text{Brake specific fuel consumption (bsfc)} = \frac{\text{Actual fuel} - \text{Air ratio}}{\text{Stoichiometric fuel} - \text{Air ratio}}$$

This parameter is widely used to compare the performance of different engines.

(h) Thermal Efficiency and Heat Balance

Thermal efficiency of an engine is defined as the ratio of the output to that of the chemical energy input in the form of fuel supply. It may be based on brake or indicated output. It is the true indication of the efficiency with which the chemical energy of fuel (input) is converted into mechanical work. Thermal efficiency also accounts for combustion efficiency, i.e., for the fact that whole of the chemical energy of the fuel is not converted into heat energy during combustion.

Brake thermal efficiency = BP× mf × Cv

Where Cv = Calorific value of fuel, kJ/kg, and mf = Mass of fuel supplied, kg/sec.

The energy input to the engine goes out in various forms – a part is in the form of brake output, a part into exhaust, and the rest is taken by cooling water and the lubricating oil. The break-up of the total energy input into these different parts is called the heat balance. The main components in aheat balance are brake output, coolant losses, heat going to exhaust, radiation and other losses.Preparation of heat balance sheet gives us an idea about the amount of energy wasted in various parts and allows us to think of methods to reduce the losses so incurred.

(i) Specific Weight

Specific weight is defined as the weight of the engine in kilogram for each brake power developed and is an indication of the engine bulk. Specific weight plays an important role in applications such as power plants for aircrafts.

V. GAS ANALYSIS OF THE EXHAUST GASES

Analysis Carried Out Without A Catalytic Convertor

Here we used the same setup that has been used to carry out the Performance Analysis Experiment but the analysis of the exhaust has been carried out .So there is only one new equipment that has been added to this current setup that is the Exhaust Gas Analyser 5 probe. The details of this gas analyser has been covered below.

Exhaust Gas Analyser 5-Probe:

This 5-gas analyzer is available with several different options. The base unit includes sensors for: O_2, CO_2, CO, HC, and NO_x .The unit can be upgraded to send the display values to Bluetooth compatible units where it can be monitored and recorded. Optional PC interface also allows remote display and recording of the data as well. For lower cost, a 4-gas model (no NOx measurement) is available. This 5-gas unit uses electrochemical sensors for the O_2 and NO_x measurements. Life of these sensors varies with use, but in general they last ~ 1-2 years. Error codes will flash on the display when the sensors need replacement. The other measurements for HC, CO, and CO_2 are done with a NDIR cell. Calibrations are claimed to last up to a year, but periodic checking should be done with a calibration gas. Re-calibrating the unit is done using a Bar 97 gas mixture. All sensors are calibrated at once.

There are few programmable parameters on the unit, which makes it very simple to operate for almost any user. Attach 12V power to the lighter-style power plug and after a short warm up period the analyzer will display current exhaust concentrations. The analyzer will turn off after it senses CO levels below 3% for more than 15 minutes. It will also perform an “auto zero” periodically when exhaust gases aren’t present.

The manual for the 5-gas is about 20 pages long, and easy for a non-technical audience to follow. It does not use technical jargon, and does a good job explaining the purpose and meaning behind its features – even for users not very familiar with emission sampling equipment. The optional PC software allows recording data, and information about the run. You can save vehicle descriptions and perform a few different kinds of automated tests while connected to a PC. Recorded data can be played back, but pulling the data out to a useful format (text or spreadsheet file) is not a simple task. Data can be exported to a Microsoft Access database, but it comes without column or page descriptions.

Recently this 5-gas unit has been interfaced with other engine testing hardware. The serial communications port on the 5-gas can communicate with several of the more common dynamometer data acquisition systems. This allows real-time data streams from the analyzer, so recording emissions along with any other parameter from the dyno data acquisition is seamless.

The following are the results obtained after carrying out the gas analysis with out a catalytic convertor (the results include only the required gases i.e., NOx

NO_x :

LOAD	NO_x (ppm)
No load	104
25 %	270
50 %	357
75 %	630

Analysis Carried Out With A Catalytic Convertor

Here we used a little different setup from that which has been used to carry out the Performance Analysis Experiment but the analysis of the exhaust has been carried out. So there is a little difference in this setup. This setup includes a Catalytic Convertor and the Exhaust Gas Analyser 5 probe. Below is the experimental setup

Fig. 2Analysis Carried Out With A Catalytic Convertor

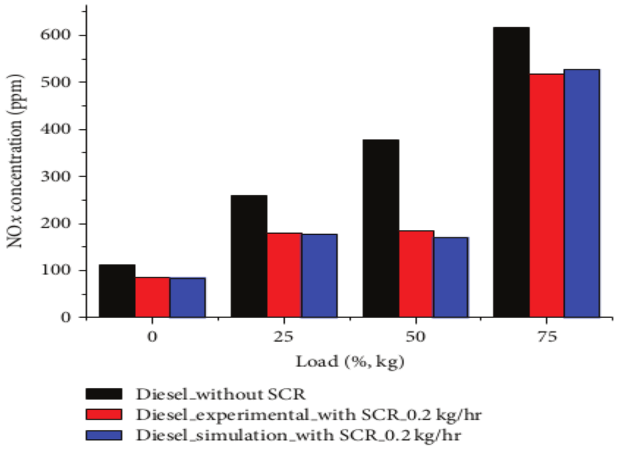

Fig. 3 Experimental setup

Experimental Work

Whole set of experiments were conducted at the designed injection timing of 27 deg bTDC, speed of 1500 rpm, and 17.5 compression ratio on test rig as shown in Figure 1. Airflow measurement was done by the conventional method U-tube manometer as well as by air intake DP unit in the control panel. Engine speed measurement was sensed and inducted by inductive pickup sensor in conjunction with digi- tal RPM indicator, which is a part of eddy current dynamome- ter controlling unit. The dynamometer shaft rotates close to inductive pickup sensor as an arrangement to send voltage pulse whose frequency is converted into RPM and displayed by digital indicator in the control panel. To measure the load on the engine, an eddy current dynamometer is attached to the crankshaft of the engine. An AVL-made exhaust gas analyzer was used to measure the exhaust gas emissions. With the analyzer, NOx (ppm), CO (%vol.), UBHC (ppm), and CO2 (%vol.) emissions were measured. A rotameter specially calibrated for ammonia was used to measure the flow rate of ammonia. The experiments were conducted at no load, 25% of full load, 50% of full load, and 75% of full load condition with diesel fuel.

The following are the results obtained after carrying out the gas analysis with a catalytic convertor (the results include only the required gases i.e., NO$_x$)

For 0.2 kg/hr ammonia injection

NO$_x$:

LOAD	*NOx (ppm)*
No load	78
25 %	174
50 %	180
75 %	550

For 0.8 kg/hr ammonia injection

NO$_x$:

LOAD	*NOx (ppm)*
No load	55
25 %	145
50 %	150
75 %	490

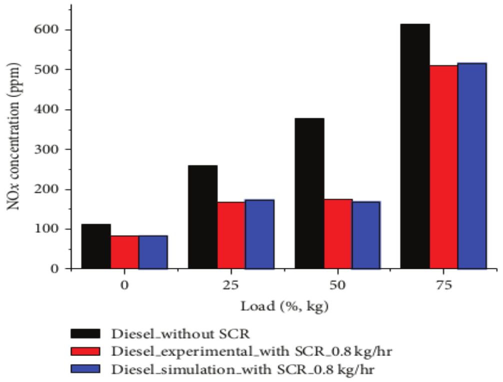

Fig.4 comparison of the results obtained from both the experiments viz., without a catalytic convertor and with a catalytic convertor.

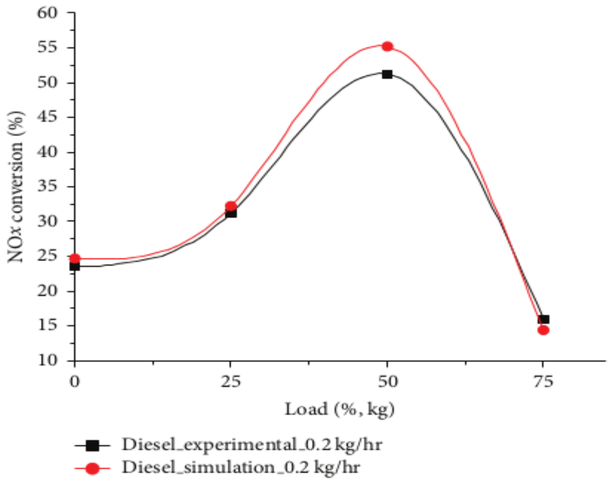

Fig. 5 NOx conversions / load

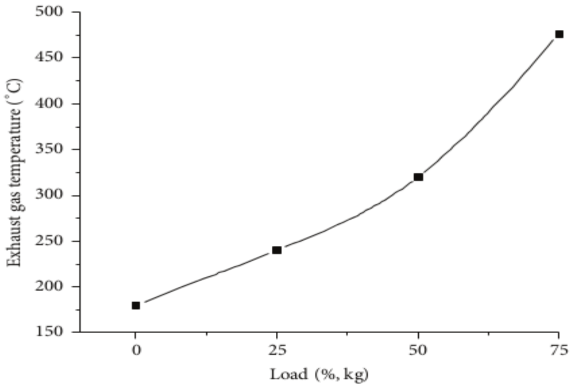

Fig.6 variation of exhaust gas temperature with respect to varying load conditions

Figure above explains the variation of exhaust gas temperature with respect to varying load conditions. It shows that as the percentage load increases, the exhaust gas temperature also increases. At no load condition 180◦ C temperature was observed, whereas at 25% of full load, at 50% of full load. And at 75% of full load 260◦ C, 378◦ C, and 486◦ C temperatures have been observed. From the graph it can be clearly observed that, at 50% of full load for all the ammonia flow rates, maximum conversion has been observed, where NOx concentration was reduced from 378 ppm to 169 ppm. This is because the catalyst exhibited the maximum selectivity at the temperature of 378◦ C. The minimum conversion is observed at 75% of full load, where NOx concentration was reduced from 615 ppm 526 ppm .

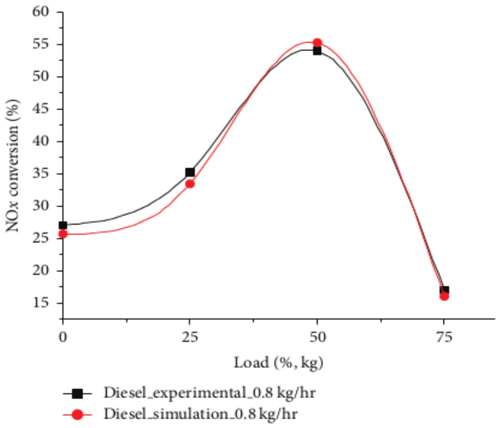

Fig.7 NOx conversions/load

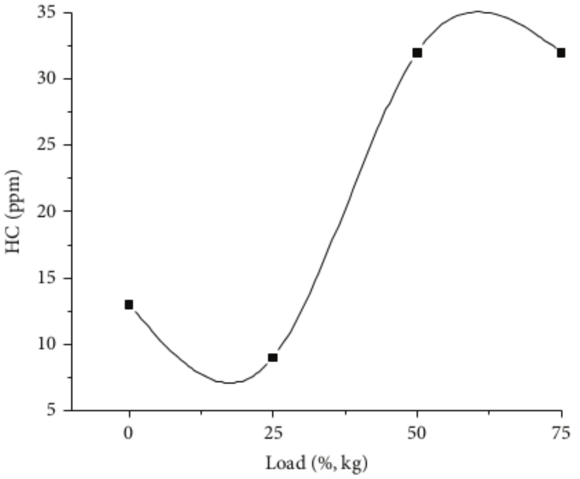

Fig.8 concentration of unburnt hydrocarbons for different load conditions

Figure above explains the concentration of unburnt hydrocarbons for different load conditions. At 75% load 34 ppm of HC can be liberated, when compared with no load where just 13 ppm of HC emission is found. When there is more emission of HC at higher temperature, the carbon particles deposit at the pores of the catalyst, which results in lower NOx conversion. The NH3 conversion is another parameter, which will greatly influence NOx conversion. The concentration of ammonia can be calculated in different ammonia flow rate. Four samples of 1 N HCL acid had been taken in beakers. Ammonia gas was passed through these samples for different ammonia flow rates varying from 0.2 kg/hr to 0.8 kg/hr. The titration was carried out against 1 N NaOH. Also a blank titration was carried out for 1 N HCL acid without ammonia gas passing through it, against 1 N NaOH. The readings were tabulated and the concentration is calculated by subtracting both the readings. It has been found that, as the ammonia flow rate increases, the concentration of ammonia also increases .

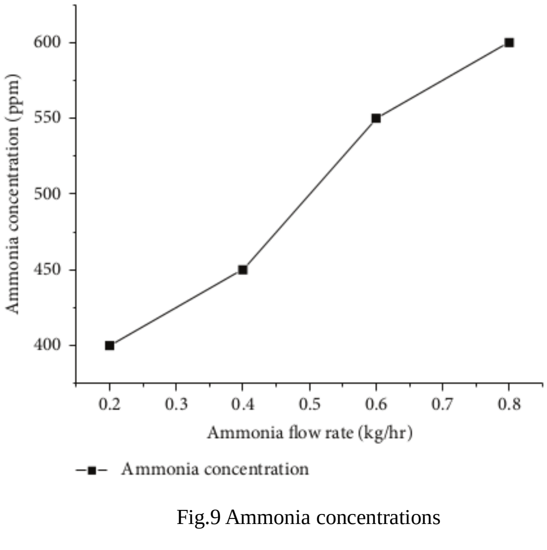

Fig.9 Ammonia concentrations

From the above Figure , it can be noted that, for 0.2 kg/hr ammonia flow rate, 400 ppm ammonia concentration is obtained. Similarly for 0.4 kg/hr, 0.6 kg/hr, and 0.8 kg/hr ammonia flow rate, 450 ppm, 550 ppm, and 600 ppm ammonia concentrations are obtained. Ammonia slip is the major disadvantage in SCR system, which will harm the environment and cause health problems. Hence, NH3 conversion is the major focus of study in the current work.

VI. CONCLUSIONS

1. From the study, it has been found that for 0.6 kg/hr ammonia induction rate the maximum conversion is achieved, whereas, for 0.8 kg/hr, conversion is reduced due to desorption of ammonia.
2. It has been found that, at 75% of load, for all mass flow rates of ammonia the conversion was

drastically reduced due to higher exhaust gas tmission of unburnt hydrocarbons.

3. More than 55% of NOx conversion was achieved using Cordierite/Pt catalyst at a temperature of 320∘ C.temperature and higher emission of unburnt hydrocarbons.
4. Engine works smoothly on biodiesel with performance comparable to diesel operation.
5. Brake Specific Fuel Consumption of engine with biodiesel is increased by 6.44% from that of diesel.
6. Break thermal efficiency of engine with biodiesel is reduced by 3.96% from that of diesel.
7. The exhaust gas temperature with diesel is 465°C and for biodiesel it is increased to 483°C at full load conditions.
8. Unburned hydrocarbon emission is significantly reduced with biodiesel. The percentage decrease in unburned hydrocarbon with biodiesel is 47% from that of diesel.
9. Carbon monoxide emission with biodiesel is 0.62% by volume which is higher than that of diesel whose Carbon monoxide emission is 0.48% by volume. When compared to diesel, NO_x emission is reduced by 16.6% with biodiesel.
10. The smoke emission of biodiesel is 15.3% higher than that of diesel.
11. In particulate emission, the biodiesel is inferior to diesel, the emission increases by 14.3%.

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