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Performance and Emission Analysis of Bio Diesel Fuelled Engine with Selective Catalyst Reduction (SCR)

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ABSTRACT

Emission control is one of the biggest challenges in today's automobiles. The 3-way converter is expensive and can't work under oxygen rich environment. An attempt has been made to prepare low cost catalyst made from non noble metal for usage in diesel engine after treatment. The present investigation deals with the reduction of NOx with selective catalyst reduction (SCR) in a 0.5 litres Kirloskar TV-1 engine with newly developed catalysts. In order to study the emissions reduction potential of different catalysts experiments with Methyl Ester of Neem oil (MEON) have been conducted at various loads. For maximum engine load, the NOx emission without SCR is a maximum at 610 p.p.m, and it is reduced by 52% when Catalyst (zinc sulphate-sodium chloride) is used. With the catalyst potassium-sodium the emission reduction is 50%. The emission reduction for the catalyst magnesium Sulphate-sodium Chloride is 20%. Similarly at maximum engine load, the smoke emission without SCR is 37 HSU and it is being reduced by 42% when SCR (magnesium sulphate-sodium chloride) is used. Likewise for SCR (zinc sulphate-sodium chloride) the emission reduces to 37% and for SCR (potassium Silicate – sodium Chloride) the emission is 23%. For maximum engine load the CO emission is 0.1 (% by vol.) without SCR and it is being reduced by 0.025 (% by vol) when SCR (potassium Silicate- sodium chloride) and (zinc Sulphate- sodium Chloride) is used. There is a reduction of 0.01 (% by vol) when SCR (magnesium-sodium) is used.

Keywords: *Biodiesel, Catalyst, NOx, Potassium silicate, Sodium chloride, Zinc sulphate, Magnesium sulphate, SCR, MENO*

1. INTRODUCTION

The diesel engine cycle is the most efficient of the internal combustion power plants. NOx and PM are two of the major pollutants in CI engines**.** The biggest steps, toward a cleaner engine, have been achieved by optimization of the injection system with the electronic control of injection and use of turbo charger and after cooler technology. The recent developments of exhaust gas recirculation and variable turbo charging are other promising steps to cut down engine out emissions. Though it is very good if we remove them at their production stage itself (engine modification, EGR, injection timing alteration etc), they affect the efficiency and performance of the engine. But, the after treatment processes such as SCR can be better trade of between better efficiency and reduced emissions. As the combustion process is both homogeneous and diffusion the temperatures reached is high and hence more NOx emission. In addition to temperature the following parameters like: chemical reactions on the catalyst, the NOx to NH3 ratio, the space velocity of exhaust gases passing through the catalyst and the urea hydrolysis (ammonia generation) influence the NOx conversion parameters. The optimal NO2 to NO ratio is 1:1 [1-4]. As the world is witnessing energy crisis, alternative and newer fuels are gaining prominence. Even though these fuels address the energy shortage they also contribute to emission mainly NOx in the biodiesel fuelled engines. Straight vegetable oils or their blends with diesel pose various long-term operational and durability problems in compression ignition engines, e.g., poor fuel atomization, piston ring-sticking, fuel injector coking and deposits, fuel pump failure, and lubricating oil dilution, etc. Many researchers have [5] taken effort to study the technical aspects of biodiesel production by transesterification. He has explained various methods of preparation of biodiesel with different combination of oil and catalyst. There is a concern that the decreased calorific value of the bio-diesel fuel may result in reduced power density. However this is not a big handicap using this type of fuel in IC engine as the reported reduction in engine power from various literatures [6-8] does show that this power reduction does not go down below 8% of conventional diesel fuelled engine. However, NOx concentration must be measured without delay from exhaust manifold to control amounts of urea solution. Spraying of aqueous urea solution in the upstream of the exhaust gas is an attractive solution. The aqueous urea dissociates into ammonia and carbon dioxide. The ammonia reacts with NOx to produce harmless nitrogen gas and water vapour. The SCR technology with urea as reducing agent has already been applied successfully to stationary applications and to mobile Diesel engines in applications such as ships and locomotives. Though, the SCR technology is three decade sold, it is still an establishing technology. This method shows an excellent reduction in emissions and the reduction in efficiency of the engine is negligible. This paper reports a fully developed after-treatment process based on injection of urea in the upstream of the exhaust gas. The Urea-SCR system was developed to meet the demand for low NOx emissions without compromising the engine efficiency from the existing diesel vehicles.

The thermal decomposition, hydrolysis, and chemical reactions of urea solution before converter can be described as following [10]:

The evaporation of urea solution:

$$(NH_2)_2CO_{(aq)} --> (NH_2)_2CO_{(s)} + H_2O_{(g)} \quad (1)$$

The thermal decomposition of urea:

$$(NH_2)_2CO_{(s)} --> NH_{3(g)} + HNCO_{(g)} \quad (2)$$

The hydrolysis of hydrocyanic acid:

$$HNCO_{(g)} + H_2O_{(g)} --> (NH_3)_{(g)} + CO_{2(g)} \quad (3)$$

1.1 Non Noble Metal Catalysts

The high cost of precious metals, their limited availability and their sensitivity to high temperatures have long motivated the search for alternate catalysts. Metal oxides are an alternative to noble metals as catalysts for total oxidation /reduction. They have sufficient activity, though they are less active than noble metals at low to medium temperatures [10]. Many oxides of metal Mn, Fe, Na, Mg and Zn are prepared and used in the experiments by many researchers. But not much research has been done on the sulphates and silicates of metal combination mentioned above.

2. PREPARATION OF CATALYST

In the chemical coating the catalyst (potassium silicate) was coated with salt (sodium silicate) and then the binder (sodium chloride) was added to the catalyst. The molecular weight of the catalyst is 154.2803 g/mol. One litre of water mixes well with 122.06g of catalyst and 20ml of ammonium hydroxide is added. The mixture is allowed to dry for 2 days and kept in a furnace at the temperature of 700^0 C for several hours. The same procedure is carried out with the catalysts zinc and magnesium.

The quantity of ammonia to be injected is calculated using the following formula.

$$G_{exhaust} = \frac{Mass\ of\ air + (mass\ of\ Fuel \times NO_x\ in\ ppm \times Mol.wt.of\ NO_x \times 2)}{Mol.wt.of\ air \times power\ per\ load}$$

Ammonia- (1 to .9)

$NH_3/NO_x = \alpha$

G exhaust= $(1000 \times 3600) \div 10^6$

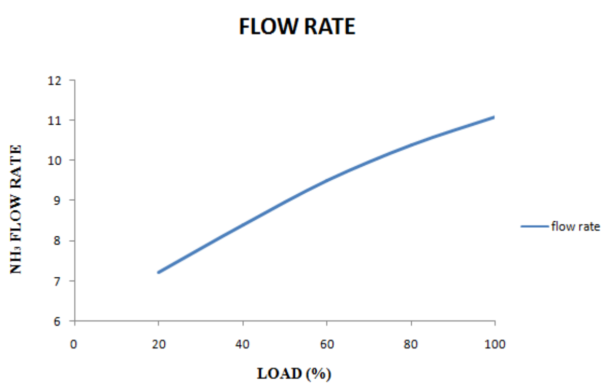

Fig.1 Mass flow rate of Ammonia Vs Load

3. EXPERIMENTAL SETUP

The engine used for the present investigation is kirloskar TV-1,single cylinder, four stroke, constant speed, vertical, water cooled, high speed compression ignition diesel engine. The kirloskar Engine is mounted on the ground. The test engine was directly coupled to Eddy current dynamometer for loading the engine. The liquid fuel flow rate was measured on the volumetric basis using a burette and a stopwatch. AVL smoke meter was used to measure the CO and HC emissions from the engine. An aqueous solution of urea in water is prepared which is called Adblue. The quantity of adblue solution injected is calculated from the emission characteristics of the base engine. Fig.1 shows the mass flow rate of ammonia required for the reduction reaction. The NOx emission from the test engine was measured by five gas analyser. For the measurement of cylinder pressure, a pressure transducer was fitted on engine cylinder head and a crank angle encoder was used for the measurement of crank angle. The sound from the engine was measured by Rion sound level meter. The experimental setup is shown in the Fig.2. The specifications of the engine are given in Table-1. Figure 3 shows the photograph of the actual engine setup.

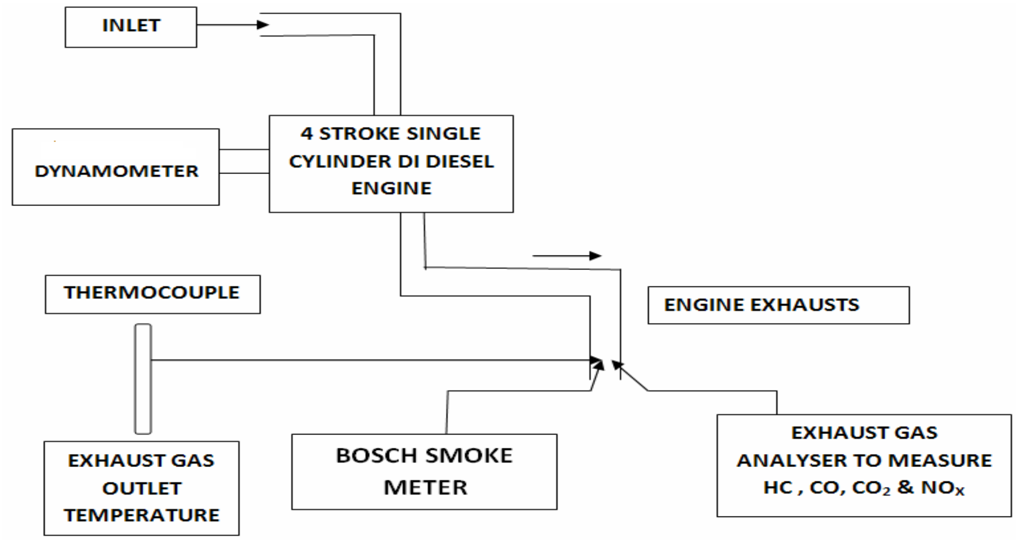

Fig. 2 Line Diagram of the Experimental Setup

Fig. 3 Photographic view of engine setup

Table 1- Engine specification

Type	Single cylinder, vertical, water cooled, 4 stroke Kirloskar TV-1 Diesel engine
Bore	87.5mm
Stroke	110mm
Cylinder diameter	0.0875m
Stroke length	0.11m
Compression ratio	17.5:1
Orifice diameter	0.02m
Dynamometer arm length	0.195m
Power	5.2kw (7 HP)
Speed	1500rpm

Loading device	Eddy current Dynamometer

Fig.4 Horiba Five Gas Analyser

Figures 5 and 6 show the cut sectional view of the core of the catalyst and the actual setup that was used in the experimentation. The Density of the cell is 100 cells per square inch (CPSI).

4. RESULTS & DISCUSSION

In order to find the emission characteristics from the engine, baseline readings were measured without any after treatment system for the engine load ranging from no load to full load with fuel MEON (Methyl Ester of Neem Oil). Three set of experiments were also carried out involving Urea SCR with three different metal catalysts using fuel MEON. The subsequent paragraphs discuss the results obtained there in.

4.1 Brake Thermal Efficiency

The Fig. 7 shows the internal combustion engine emission control by SCR system. It is seen that the installation of after treatment system does not affect the engine brake thermal efficiency for all loads. Therefore the engine performance will not be affected by after treatment method. Hence it can be assumed that the after treatment system does not create any appreciable increase in the engine back pressure.

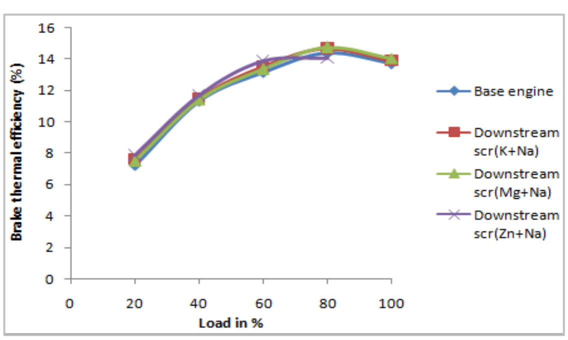

Fig.7 Brake thermal efficiency Vs Load for Three Different Metal Catalysts

4.2 NOx Emissions

The removal of NOx is especially difficult because of the excess oxygen associated in the diesel engine operation.

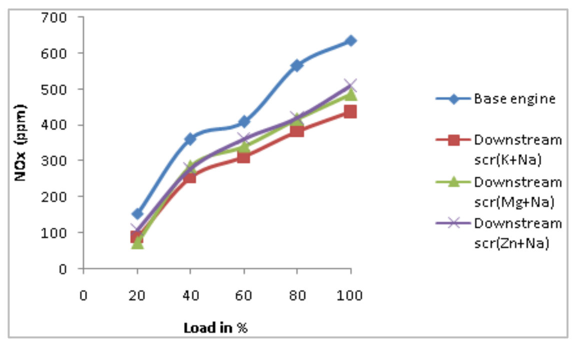

Fig.8 Effects of engine load in percentage on NOx emissions

Fig. 8 shows the NO_x emission from the engine for four scenarios: Engine without any after-treatment system installed and three set of results with three different catalysts installed in it. It is seen from the base engine (only bio-fuel and no after-treatment system) that the NO_x emission increases with increase in engine load. This is due to the fact that the engine temperature increases with increase in load, producing more NO_x. For the maximum engine load, the NO_x emission of diesel engine without SCR is maximum i.e. 610 ppm (Base engine) while there is a reduction of 52% of emission when SCR (zinc-sodium) is used. Further there is a reduction of 50% of emission when SCR (potassium-sodium) is used. There is a reduction of 20% of emission when SCR (magnesium-sodium) is used. Hence for the NO_x reduction Zinc-Sodium catalyst is more effective than the other catalysts.

4.3 HC Emissions

Since the diesel or bio diesel engines run always on the oxygen rich mode there is a very low emission of HC and CO emission. Even though their emission level is insignificant an attempt has been made to quantify the effects of these metal catalysts on the HC emission reduction.

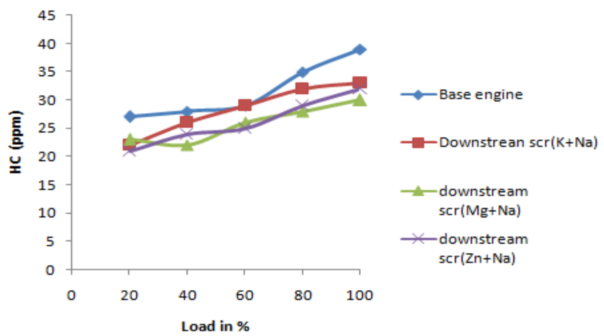

Fig.9 Effects of engine load in percentage on HC emissions

Fig. 9 shows the HC emission for three different catalysts. It is noted that when load is increased, the hydrocarbon emission also increased without SCR (Base engine) due to heterogeneous combustion of diesel engine. Since the engine is quality governed the engine is tending towards lower oxygen concentration and hence more HC emission. For maximum load HC emission is nearly 40 ppm. But with the introduction of SCR (potassium-sodium) or (zinc-sodium) it reduces approximately by 25%. Similarly with SCR (magnesium-sodium) the emission reduction is maximum at 43% reduction in ppm. Here again the combination of potassium- Sodium performs better than the other two catalysts.

4.4 CO Emissions

The emission levels of CO from the diesel engines are usually very low compared to gasoline engines. Fig 10 shows the variation of CO emission for various loads with three different catalysts. It is noted from the Fig. when load is increased, the carbon mono oxide emission also increased due to heterogeneous combustion of diesel engine. It is observed that for maximum load the CO emission of diesel engine without SCR setup is 0.1 (% by vol) whereas it is 0.025 (% by vol) with SCR (potassium & sodium) & (zinc & sodium), While it is 0.01 (% by vol) with SCR (magnesium & sodium).

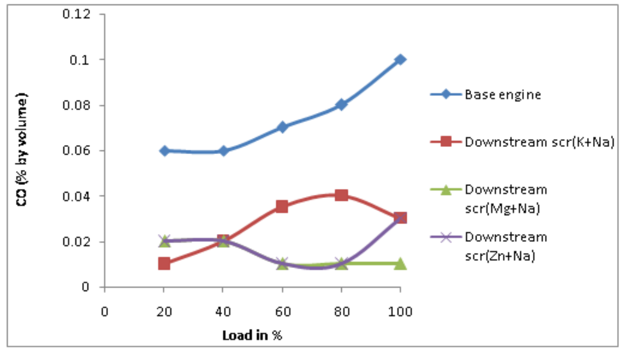

Fig.10 Effects of engine load in percentage on CO emissions

4.5 CO2 Emissions

It is observed from the Fig.11 that the increasing load leads to a increase in the CO2 emissions. This is because of availability of excess oxygen for complete combustion of fuel. Moreover the hydrolysis reaction of Hydrocyanic acid will result in the more production of CO_2 and hence there is more production of CO2. For the maximum load, the CO2 emission of diesel engine with base engine is 2 (% by vol).When SCR is introduced (zinc-sodium) the emission is increased by 3.3 (% by vol).With SCR (magnesium & sodium) the emission is 3 (% by vol), and with SCR (potassium-sodium) the emission is 2.7 (% by vol)

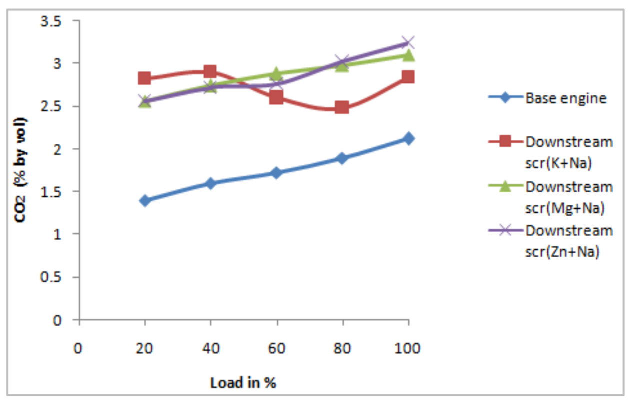

Fig.11 Effects of engine load in percentage on CO2 emissions

4.6 Smoke Emission

It can be observed from the Fig.12, when the load is maximum the smoke level with base engine is 37 HSU. For test engine the emission is reduced to 23% when SCR (potassium-sodium) is used. The emission is 37% when SCR (zinc-sodium) is used. Further there is a reduction of 42% of emission when SCR (magnesium-sodium) is used.

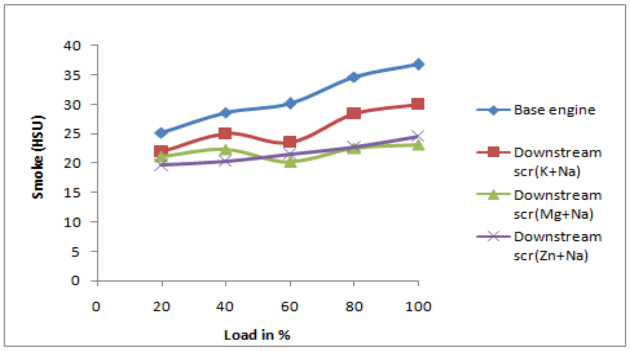

Fig.12 Effects of engine load in percentage with Smoke emission

5. CONCLUSION

Experiments were conducted on a 0.5 litre DI Diesel engine to reduce the NOx emission with after- treatment system. Different catalysts like (Potassium Silicate – Sodium Chloride), (Zinc Sulphate-Sodium Chloride) and (Magnesium Sulphate & Sodium Chloride) is used.

The result reveals that:

- There is apparently no change in brake thermal efficiency while using all the SCR.
- NOx is reduced 52% by using Zinc Sulphate-Sodium Chloride catalyst SCR with methyl ester of neem oil. There is a reduction of 50% with the Potassium Silicate –Sodium Chloride catalyst, and a reduction of 20% with Magnesium Sulphate & Sodium Chloride catalyst.
- HC is reduced 43% by using Magnesium Sulphate & Sodium Chloride catalyst SCR with methyl ester of neem oil. There is a reduction of approximately 25% of hydrocarbon when both Potassium Silicate – Sodium Chloride, and Zinc Sulphate-Sodium Chloride are used.
- CO is reduced 0.01 (% by vol) by using Magnesium Sulphate & Sodium Chloride catalyst SCR with methyl ester of neem oil. There is a reduction of 0.025 (% by vol) with Potassium Silicate –Sodium Chloride, Zinc Sulphate-Sodium Chloride catalysts.
- Smoke is reduced 42% by using Magnesium Sulphate & Sodium Chloride catalyst SCR with methyl ester of neem oil. There is a reduction of 37% when Zinc Sulphate-Sodium Chloride catalyst is used. Similarly there is a reduction of 23% with Potassium Silicate – Sodium Chloride.

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