Experimental Study of Selective Catalytic Reduction System On CI Engine Fuelled with Diesel-Ethanol Blend for NO_x Reduction with Injection of Urea Solutions

R. Praveen [1], S. Natarajan [2]
[1] Post Graduate Student, Department of Mechanical Engineering ,
Sri Venkateswara College of Engineering , Sriperumbudur , India.
[1] praveenrajendran5@gmail.com
[2] Assistant Professor, Department of Mechanical Engineering ,
Sri Venkateswara College of Engineering , Sriperumbudur , India.
[2] natraj@svce.ac.in

Abstract— Nowadays exhaust emission control from internal combustion engines have become one of the most important challenges. Oxides of nitrogen (NO_x) are one of the major hazardous pollutants that come out from diesel engines. There are various techniques existing for NO_x control but each techniques has its own advantages and disadvantages. Technologies available for NO_x reductions either increase other polluting gas emission or increase fuel consumption. The objective of this paper is to determine the maximum reduction of NO_x emissions by varying concentration of urea solution with reduction catalyst. An aqueous solution of urea was injected in engine exhaust pipe for reducing NO_x emissions in single cylinder light duty stationery DI diesel engine fuelled with diesel and diesel- (10%) ethanol blend. A concentration of urea solution varying from 30 to 35% by weight with constant flow rates and tested with fitting Titanium dioxide (TiO_2) coated catalyst which controls by products of ammonia and water vapour. Results indicated that a maximum of 70 % of NO_x reduction was achieved an engine fuelled with diesel-ethanol blend and constant flow rate of 0.75 lit/hr with an urea concentration of 35% and 66% NO_x of reduced with neat diesel using Titanium dioxide catalyst in Selective Catalytic Reduction system.

Keyword- Engine Emission, SCR, NO_x, Urea, Catalyst-TiO_2

I. INTRODUCTION

The energy requirement has increased exponentially over the past decades due to industrialisation and the changes of subsequent lifestyle. Most of this energy is generated from fossil fuels such as coal, natural gas, gasoline, and diesel.[2] Almost 90% of the present energy source is based on the combustion of fossil fuels and biomass. In the last few decades, the environmental effects of pollutant emission from combustion sources have becoming increasingly serious. Diesel engines are widely used in many areas like automobiles, locomotives marine engines power generations etc.., due to its high power output and thermal efficiency.[3] Even though the diesel engines give more benefits, the human discomfort caused by pollutant emission of these engines has to be considered. [7]

The major pollutant emissions of the diesel engines are NO_x , particulate matters, smoke and soot particles. Although all other emissions, NO_x is one of the most important emission from diesel engine. It plays an important role in the atmospheric ozone destruction and global warming. It is also most precursors to the photochemical smog.[4] Component of smog irritate eyes and throat, stir up asthmatic attacks, decrease visibility and damages plants and materials as well. By dissolving with water vapour NO_x from acid rain which has direct and indirect effects both on human and plants. [6]

SCR technology permits the NO_x reduction reaction to take place in an oxidising atmosphere. It is called selective because the catalytic reduction of NO_x with ammonia(NH_3), urea, monomethylamine, dimethylamine, trymethylamine, cyanuric acid, carbamates, ammonium carbonate, ammonium bicarbonate, etc.. as a reductant occurs preferentially to oxidation of NH_3 with oxygen with oxides of nitrogen.[5]

SCR is a process for reducing the concentration of NO_x from the combustion exhaust, which involves the injection of aqueous solution of urea in the tail pipe of a four stroke, constant speed DI diesel engine. Ammonia has been ruled out as a reducing agent, due toxicity and handling issues. So urea has been selected for reductant of choice for most applications, stored on board in an aqueous solution. To overcome the difficulties associated with pure ammonia, urea is selected. Urea can be hydrolysed and decomposed to generate ammonia. An injected aqueous solution of urea solution is decomposed into ammonia and water vapour, then decomposed ammonia reacts with oxides of nitrogen and reduced into eco-friendly nitrogen and water vapour.

$(NH_2)_2CO + 7H_2O \rightarrow [(NH_2)_2CO.7H_2O]$ [1]

$[(NH_2)_2CO.7H_2O] \rightarrow HNCO + NH_3 + 7H_2O$ [2]

$4NH_3 + 4NO + O_2 \rightarrow 4N_2 + 6H_2O$ [3]

$4NH_3 + 3O_2 \rightarrow 2N_2 + 6H_2O$ [4]

The idea of using urea SCR systems for the reduction of NO_x emissions in diesel engines are two decades old. Since then, many applications have been developed, some of which have reached commercially. But, it is still a challenge for researchers.

(Chithambaramasari et al.,2011), investigated that injection of aqueous solutions of urea in theexhaust for the reduction of NO_x in a single cylinder light duty DI diesel engine. Several kinds of concentration of urea solution varying from 10 to 40% by weight with different flow rates of urea solution varying from 250ml/hr to 750ml/hr were tested by fitting vanadium as catalyst which improved the chemical reactions even at a lower temperature of 190°C. Results showed that a maximum of 27.46% of NO_x reduction was achieved with an optimised flow rate of 0.75lit/hr with 10% urea concentration. [1]

(Ghosh et al.,2013), evaluated the injection of aqueous solutions of urea in the tail pipe of a diesel engine. Four observations were made for the exhaust emission NO_x analysis of concentration of urea solution 0 to 30% by weight with different flow rates of urea solution as reductant by fitting marine ferromanganese nodule as SCR catalyst. It was observed that 64% of NO_x reduction was achieved. [8]

(Koebel et al.,2000), studied that urea –SCR, the selective catalytic reduction using urea as reducing agent has been investigated for about 10 years in detail and today is a well established technique for $DeNO_x$ of stationary diesel engines. The paper discusses the fundamental problems and challenges if urea-SCR is extended to mobile applications. [9]

(Himangshu Sekhar Brahma et al.,2013), investigated that the use to fully understand the impacts of biodiesel on the diesel engine combustion process and pollutant formation. This paper is more concerned with an experimental investigation to study the diesel engine emission characteristics using Mahua biodiesel with the help of a Three Way Catalytic converter with Diesel Exhaust Fluid (DEF) by running the engine. Almost 90% NO_x emissions got reduced and the emission values recorded were much less when compared to Bharat stage- IV Norms for selected engine at all operated loads with retrofit arranged. [10]

(Ghosh et al.,2013), studied the efforts of Pongamia pinata methyl ester (PPME) chosen as an alternative fuel for diesel engines. Injection of aqueous solutions of urea in the tail pipe of a diesel engine fuelled with Pongamia pinata methyl ester (PPME) for the reduction of oxides of nitrogen (NO_x). Four observations were made for various concentration of urea solution 0%, 10%, 20%, and 30% by weight with different flow rates of urea solution as reductant by fitting Marine Ferromanganese nodule as SCR catalyst which improves the chemical reactions. 64% NO_x reduction achieved with the urea flow rate 0.60 lit/hr, 30% concentration of urea solution and marine ferromanganese nodule as SCR. [11]

(Gowthaman et al.,2012), investigated that the performance, combustion and emission characteristics on CI engine fuelled with cotton seed oil blends of 25%, 50% 75% and 100% in volume. Due to increase of oxides of nitrogen compared to neat diesel, the Selective catalytic Reduction system was implemented in exhaust pipe. The results indicated that the amount of oxides of nitrogen, was decreased rapidly on injection of 30% concentration of urea solution. [12]

(Ioannis Gekas et al.,2002), discusseed the choice of catalyst types to reduce the NO_x emissions down to Euro V level. A novel urea injection system is also presented, which is based on a mass produced dosing pump that is combined with an electronic control unit. The results indicated that it is possible to have a NO_x conversion above 80% with ammonia slip below 10ppm using 30 litres of urea solution on 130 cpsi catalysts for a 12 cylinder diesel engine. [13]

(Chun Lee et al.,2004), investigated that Selective Catalytic Reduction technology increasingly is being applied for controlling emissions on oxides of nitrogen from coal-fired boilers. The vanadium and titanium oxides, used commonly in the vandia-titania SCR catalyst for NO_x reduction. [14]

II. EXPERIMENTAL SETUP

The experiment was conducted in a light duty stationary single cylinder, four stroke, air cooled, direct injection Kirloskar Engine as shown in the Fig.1 and photographic image of the setup is shown in Fig.2. The engine was connected to an electrical dynamometer and CRYPTON 205 five gas analyser and AVL smokemeter. The torque can be varied from the control panel. Table 1 indicated that an engine specifications.

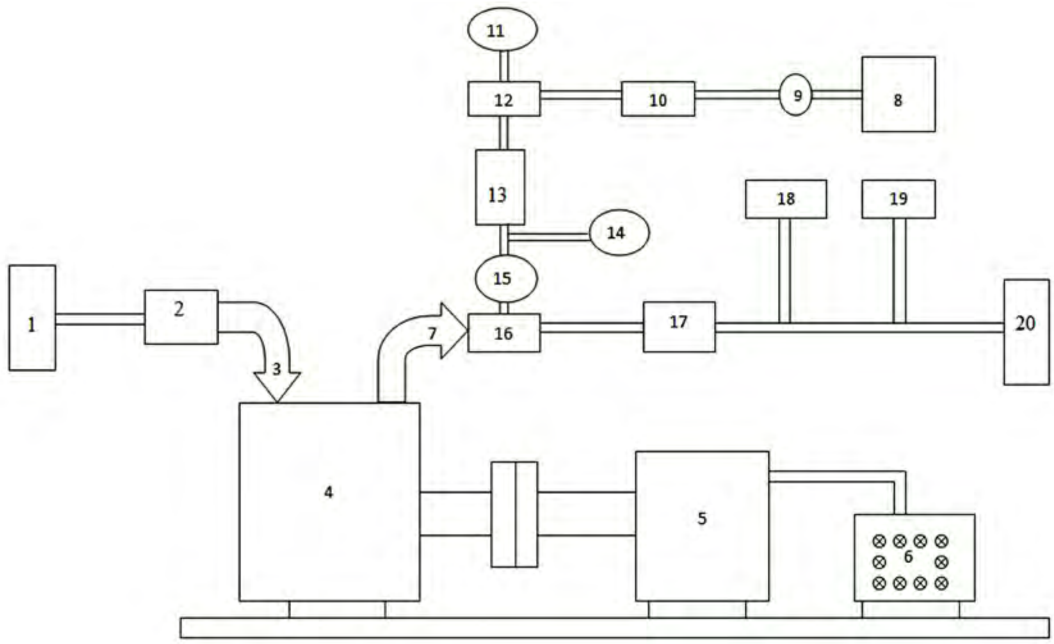

Fig No: 1 Schematic diagram of selective catalytic reduction system

1. Air Tank
2. Air Filter
3. Inlet Valve
4. Engine
5. Electrical Dynamometer
6. Loading Device
7. Exhaust Valve
8. Urea Tank
9. Motor
10. Pressure Relief Valve
11. Battery
12. Relay
13. Heater
14. Pressure Gauge
15. Solenoid Valve
16. Mixing Chamber
17. SCR Catalyst
18.CRYPTON 295 Five Gas Analyser
19. AVL Smokemeter
20. Exhaust Gas

Fig No.2 Photographic View of SCR Catalyst.

TABLE I

Engine Specification	
Type	Air Cooled, Four stroke Kirloskar Engine
Bore, d (mm)	87.6
Stroke Length, l (mm)	110
Compression Ratio, r	17.5:1
Capacity, cc (cm^3)	661.5
Max. Power (kw)	4.4
Rated Speed (rpm)	1500
Fuel injection	Direct Injection
Dynamometer Type	Electrical Dynamometer

III. METHODOLGY

Before starting the engine, urea solution should be prepared for different concentration varying with 30% , 32.5% and 35% by weight and also prepared diesel blend with 10% of ethanol. By adjusting the flow control valve and pre-set of injection pressure 5 bar should be fixed and maintained constant throughout a set of experiment. The heater and solenoid valve is actuated by relay controller through 12V battery. The purpose of heater was evaporation of urea solution and spraying time of urea solution is control by 12V solenoid valve. The below given table 2 shows that properties of aqueous urea solution.

TABLE II
Properties of Aqueous Urea Solution

S.NO	TERMS	VALUES
1	Chemical Formula	$(NH_2)_2CO.7H_2O$
2	Molecular Weight (g/mol)	60.06
3	Concentration (%)	32.5
4	Density (15 º C) (kg/lt)	1.085
5	Appearance	Clear Transparent
6	Smell	Odourless
7	Acidity (P_H)	9-11
8	Freezing Point(º C)	-11
9	Self Ignition Temperature (º C)	630

Initially the engine was started and allowed the engine with constant speed for some period of time. The engine was loaded gradually in the order of 25%, 50%, 75% and 100% of full load. For every loading the emission of HC, CO, CO_2, O_2, NOx and smoke density were recorded. Repeated the experiment for different concentration of urea solution with constant flow rate of urea solution and also for diesel-ethanol (10%) blend. The given table 3 shows that the compared properties of neat diesel and ethanol fuel. From the table 3, it clearly tells the ethanol fuel is reduced oxides of nitrogen readily by complete combustion due to presence of own oxygen atom in it compared to neat diesel fuel.

TABLE III
Properties of Ethanol

S.NO	TERMS	NEAT DIESEL	ETHANOL
1	Molecular Formula	$C_{10}H_{22}$	C_2H_5OH
2	Density (kg/m^3)	840	789
3	Boiling Point (ºC)	180-330	78
4	Cetane Number	46	6
5	Calorific Value (KJ/Kg)	42500	27000
6	Flash Point (ºC)	75	16.6
7	Oxygenate, Wt %	-	35
8	Carbonate, Wt %	87	52
9	Hydrogen, Wt %	13	13
10	Cloud Point (ºC)	-5	-
11	Viscosity(cst)	4.59	1.59

IV. RESULTS AND DISCUSSIONS

Fig 2 to 9 indicates variations of various engine emissions with respect to engine load for various concentration of urea solution.

Figure:2 shows that variations of NO_x emissions with engine load, on fuelled with diesel and various concentration on injection of urea solution. From the graph it shows that the NO_x emissions decrease gradually upto 66% due to various concentration of urea solution.

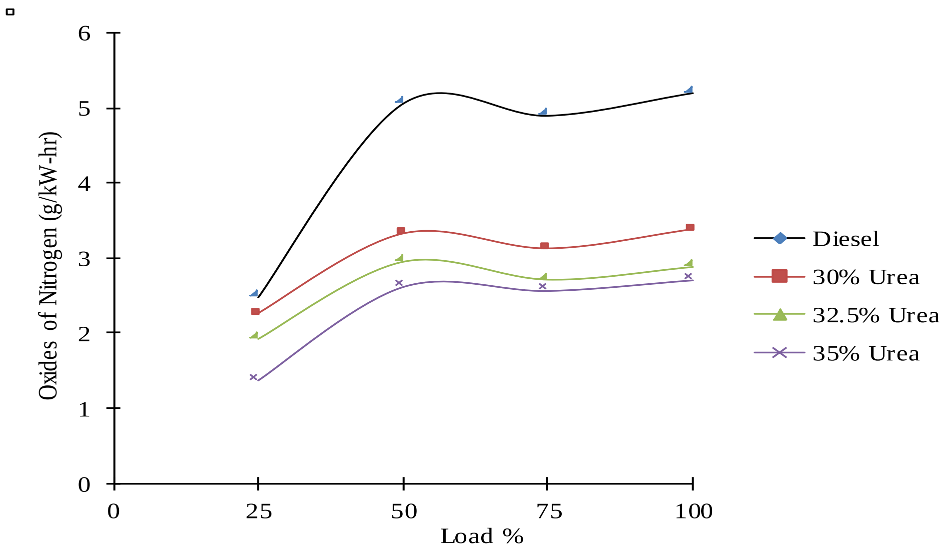

Fig.2 Variation of Oxides of Nitrogen (NO_x) Vs Engine Load.

Figure:3 shows that variations of unburned Hydrocarbon (HC) emissions with engine load, on fuelled with diesel and various concentration on injection of urea solution. From the graph, it shows that HC emissions gradually decreases upto 23% drastically due to presence of excess oxygen.

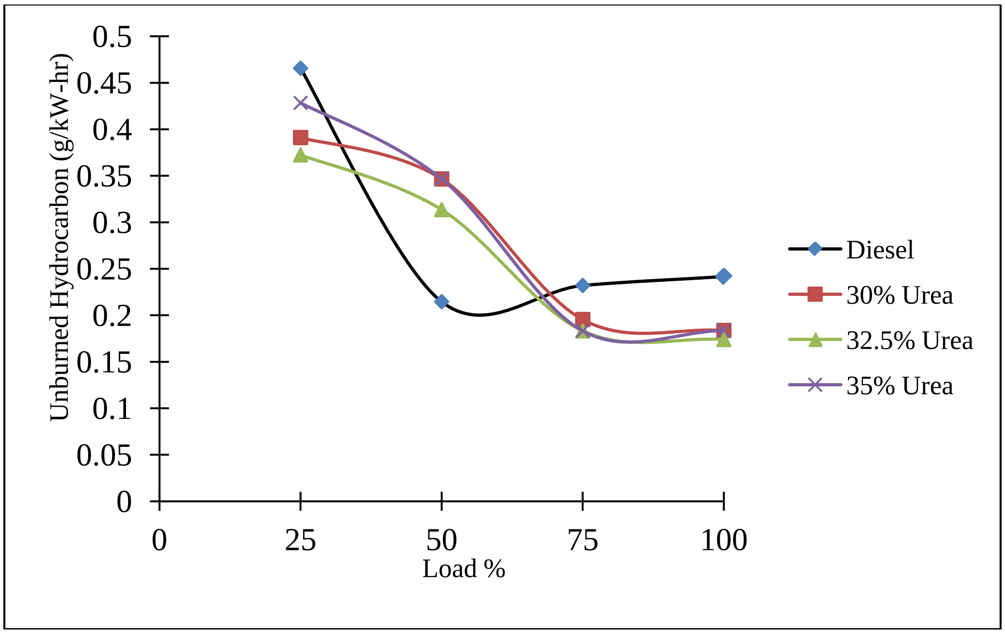

Fig.3 Variation of unburned HC Vs Engine Load.

Figure:4 shows that variations of Carbon Monoxide (CO) emissions with engine load, on fuelled with diesel and various concentration on injection of urea solution. From the graph it shows that the CO emissions decreases with the increase of the concentration of urea solution upto 50% due oxidation of excess oxygen.

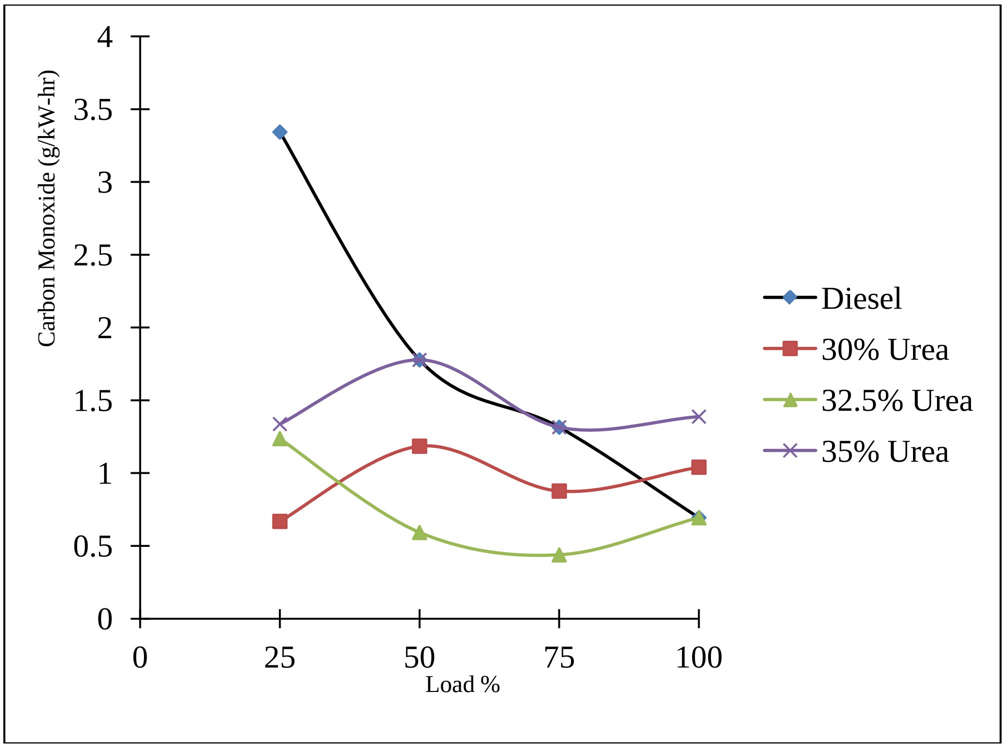

Fig.4 Variation of CO Vs Engine Load

Figure:5 shows that variations of Smoke emissions with engine load, on fuelled with diesel and various concentration on injection of urea solution. From the graph it shows that the Smoke emissions decreasing upto 60% due lower exhaust gas temperature.

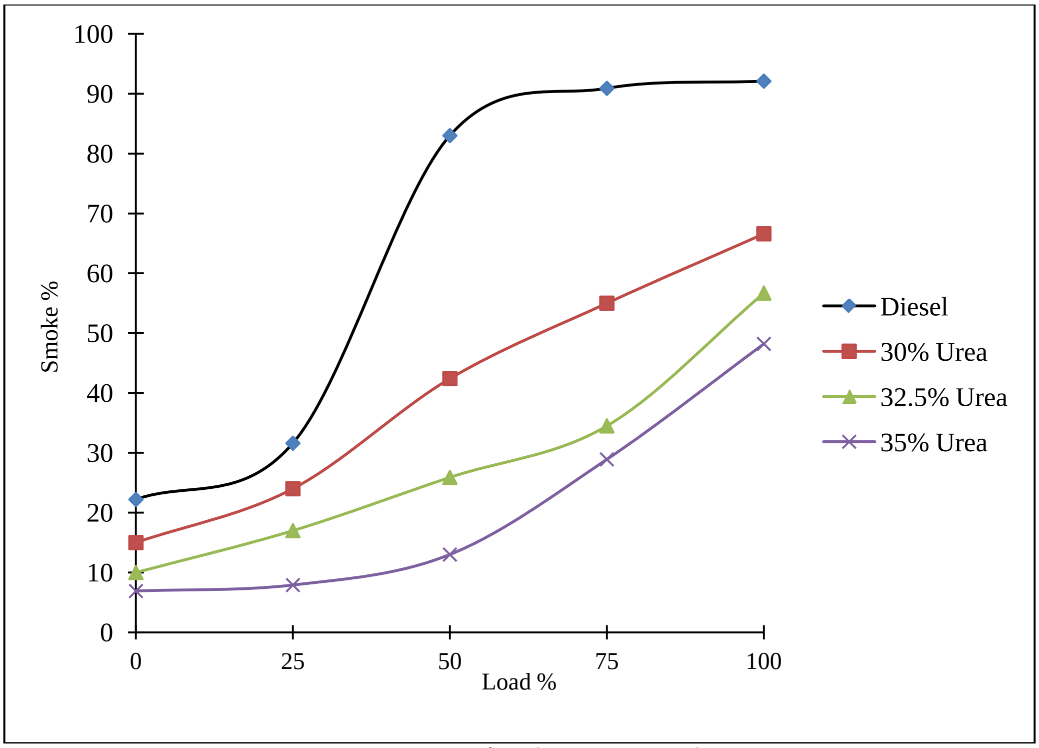

Fig.5 Variation of Smoke Vs Engine Load

Figure:6 shows that variations of Oxides of Nitrogen (NO_x) emissions with engine load, on fuelled with diesel-ethanol blend and various concentration on injection of urea solution. From the graph it shows that the NO_x emissions decreasing upto 70% due to complete combustion.

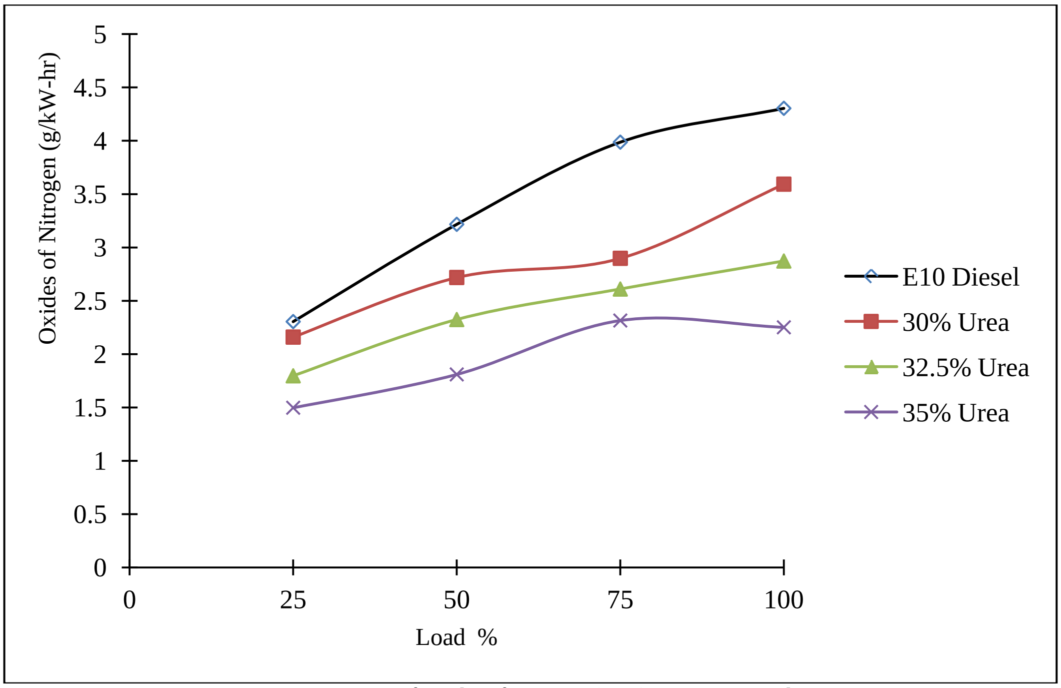

Fig.6 Variation of Oxides of Nitrogen (NO_x) Vs Engine Load.

Figure:7 shows that variations of unburned Hydrocarbon (HC) emissions with engine load, on fuelled with diesel-ethanol blend and various concentration on injection of urea solution. From the graph, it shows that HC emissions gradually decreases upto 40% drastically due to presence of own oxygen atom.

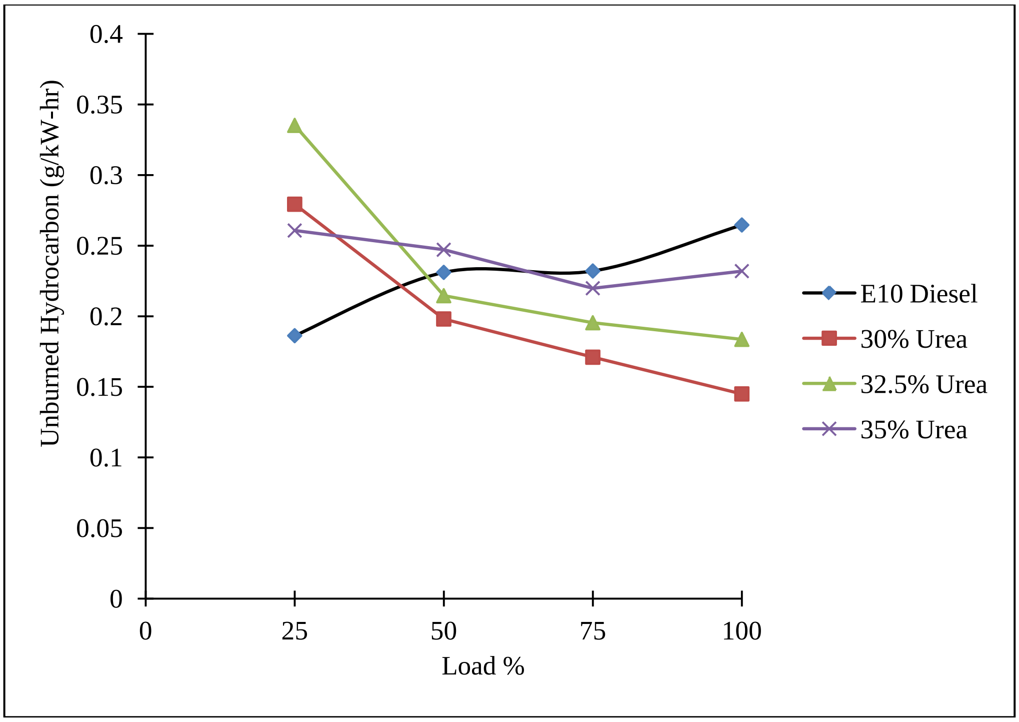

Fig.7 Variation of unburned HC Vs Engine Load.

Figure:8 shows that variations of Carbon Monoxide (CO) emissions with engine load, on fuelled with diesel-ethanol blend and various concentration on injection of urea solution. From the graph it shows that the CO emissions decreases with the increase of the concentration of urea solution upto 30% due oxidation of excess oxygen.

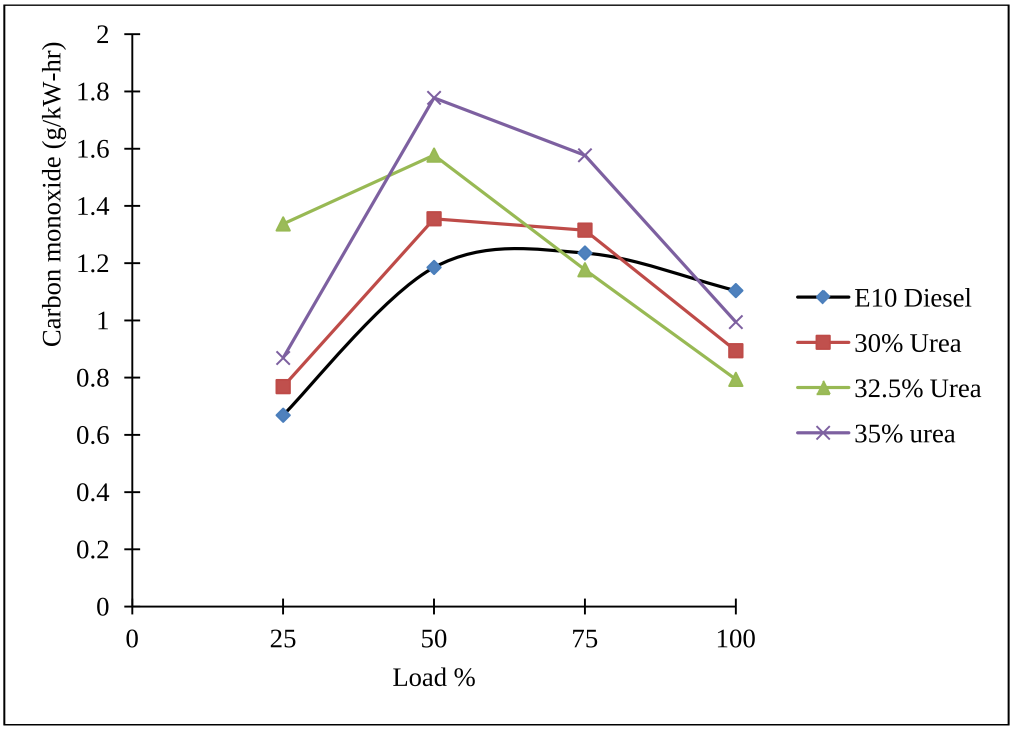

Fig.8 Variation of CO Vs Engine Load

Figure:9 shows that variations of Smoke emissions with engine load, on fuelled with diesel-ethanol blend and various concentration on injection of urea solution. From the graph it shows that the Smoke emissions decreasing upto 40% due lower exhaust gas temperature.

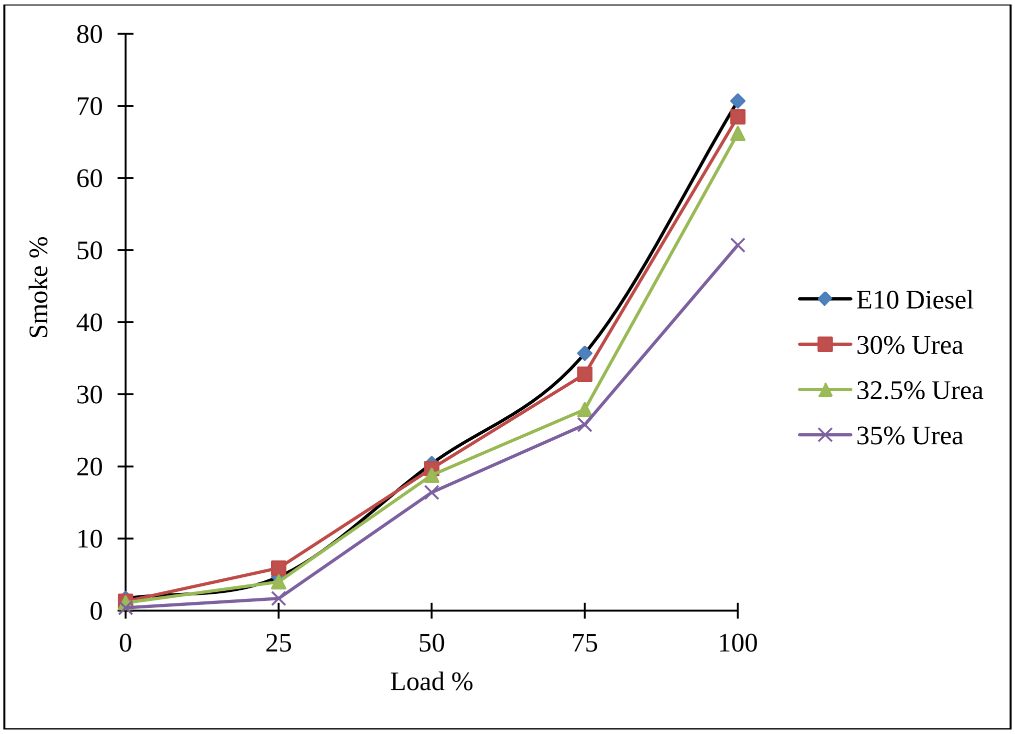

Fig.9 Variation of Smoke Vs Engine Load

V. CONCLUSION

From the study it concluded that urea injection with titanium dioxide as SCR in the exhaust pipe :

- An engine fuelled with diesel, gives a maximum reduction upto 66% Oxides of Nitrogen (NO_x) on part load condition with 0.75 lt/hr constant flow rate and 5 bar constant pressure of urea solution.
- An engine fuelled with diesel-ethanol, gives a maximum reduction upto 70% Oxides of Nitrogen (NO_x) on full load condition with 0.75lt/hr constant flow rate and 5 bar constant pressure of urea solution.
- An engine fuelled with diesel, gives a more or less same amount of emissions like carbon monoxides, unburned hydrocarbon and smoke due reduction catalyst.
- An engine fuelled with diesel-ethanol blend, gives a less amount of carbon monoxides and unburned hydrocarbon due presence of own oxygen atom present in fuel.
- Thus it indicates that the catalyst used in the test engine commercially effective method for controlling NO_x from Diesel Engines.

ACKNOWLEDGMENT

The author thanks Mr. R. Senthamarai Kannan, PNR Technologies and Dr.K.Pitchandi, Head of Department, Mechanical Engineering Department, Sri Venkateswara College of Engineering for providing facilities and constant support was gratefully acknowledged.

REFERENCES

[1] K. Chithambaramasari, N.V. Mahalakshmi and K. Jayachandran, " Application of SCR technique in NOx reduction of Diesel Engine Emission by Urea Injection Method ", Canadian Journal on mechanical sciences & Engineering, (December 2011), Vol.2 No.8.

[2] Mary Kay Camarillo, William T. Stringfellow, Kyle A.Watson and Jereny S. Hanlon, " Investigation of selective catalytic reduction for control of nitrogen oxides in full-scale dairy energy production ", Applied energy, (June 2013), Vol.106,Pg. 328-336.

[3] Sounak Roy, M.S.Hedge and Giridhar Madras, " Catalysis for NOx abatement – Review ", Applied Energy, (Nov-2009), Vol.86, Pg. 2283-2297.

[4] Zengying ziang, Xiaoqian Ma, Hai Lin and Yuting Tang, " The Energy Consumption and Environmental impacts of SCR technology in china ",Applied energy, (April 2011), Vol.88, Pg. 1120-1129.

[5] Lei Jiang, " Unregulated emissions from a diesel engine equipped with vanadium-based urea-Selective Catalytic Reduction System catalyst ", Journal of Environmental Sciences 2010, 22(4) 575–581.

[6] Hidekatsu Fujishima, Kenichi Takekoshi, Tomoyuki Kuroki, Keichi Otsuka, Masaaki Okubo and Atsushi Tanaka, " Towards ideal NOx control technology for Bio-Oils and a gas multi-fuel boiler system using a plasma-chemical hybrid process", Applied energy, (Nov 2013), Vol.111, Pg. 394-400.

[7] M.R.Rahimpour, M.R.Dehnair, F.Allahgholipour, D.Iranshahi and S.M.Jokar, " Assessment and Comparsion of different catalytic coupling exothermic and endothermic reactions – A review ", Applied Energy, (Nov 2012), Vol.99, Pg. 496-512.

[8] S. Ghosh, Dr. S.N. Chaudhuri and D. Dutta, " Reduction of NOx emission by urea injection and marine ferromanganese nodule as SCR of diesel engine ", International Journal of Engineering Research & Technology, (January 2013), Vol.2 issue 1.

[9] M. Koebel, M. Elsener and M. Kleemann, “ Urea-SCR: a promising technique to reduce NOx emissions from automotive diesel engines ”, Elsevier catalysis today, (2000), Pg. 335-345.
[10] Himangshu Sekhar Brahma and Dr.A. Veeresh Babu, “ An experimental investigation on emission of neat Mahua biodiesel using urea-SCR ”, International Journal of Scientific & Technology Research, (August 2013), Vol.2 issue 8.
[11] S. Ghosh, S.N. Chaudhuri and D. Dutta, “ NOx reduction by using urea injection and marine ferromanganese nodule as SCR of a diesel engine fuelled with pongamia pinnata methyl ester ”, International Journal of Modern Engineering Research, (April 2013), Vol.3 issue 2.
[12] S. Gowthaman and K. Velmurugan, “ Performance and Emission characteristics of direct injection diesel engine using Bio-diesel with SCR Technology ”, International Journal of Engineering Research and Applications, (October 2012), Vol.2 issue 5,Pg. 1083-1089.
[13] Ioannis Gekas, Par Gabrielsson and Keld Johansen, “ Urea-SCR catalyst system selection for fuel and PM optimized engines and a demonstration of a novel urea injection system ”, Society of Automotive Engineers, (2002-01-0289).
[14] Chun W. Lee and Ravi K. Srivastava, “ Investigation of SCR impact on mercury speciation under simulated NOx emission control conditions ”, Air & Waste Mangement Association, (2004), Pg. 1560-1566.