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NO_X REDUCTION FOR UREA-SCR SYSTEM

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Abstract - *Exhaust after-treatment Selective Catalytic Reduction (SCR) systems based on urea-water solution are state of the art technologies mitigating NO_x emissions for diesel engine. Major challenges for implementing the systems are high NO_x reduction performance. This study presents a detailed analysis of the urea-water spray wall impingement and influences on reducing agent distribution formation, thus system performance [13]. So in this review we have according to studies SCR by urea has been reported to be the most promising method for the control of NO_x emissions from diesel engines. Catalytic decomposition of urea over a fixed flow reactor system has been examined for the selective catalytic reduction (SCR) of NO_x from mobile sources. The conversion of urea into NH_3 the major product from the thermal decomposition of urea, increased with the reaction temperature [1].*

Keyword: *Selective Catalytic Reduction (SCR), Urea, NO_x, Emission treatment, pollution, Urea Water spray.*

Nomenclature		***Sub/Super scripts***	
SCR	*Selective Catalytic Reduction*	*Bp*	*Brake power*
DEF	*Diesel emission fluid*	*FC*	*Fuel Consumption*
DPF	*Diesel particulate filter*	*SFC*	*Specific Fuel Consumption*
N_2	*Nitrogen*	*FP*	*Friction Power*
NO	*Nitric oxide*	*IP*	*Indicated Power*
NO_2	*Nitrogen dioxide*	*BTE*	*Brake Thermal Efficiency*
NO_x	*Nitrogen oxides*	*ITE*	*Indicated Thermal Efficiency*
NH_3	*Ammonia*	*F*	*Fuel*
HC	*Hydrocarbons*		
CO_2	*Carbon dioxide*		
O2	*Oxygen*		

I. INTRODUCTION

Selective catalytic reduction (SCR) is a means of converting nitrogen oxides, also referred to as NOx with the aid of a catalyst into diatomic nitrogen (N_2), and water (H_2O). A gaseous reduction, typically anhydrous ammonia, aqueous ammonia or urea, is added to a stream of flue or exhaust gas is adsorbed onto a catalyst. Commercial selective catalytic reduction systems are typically found on large utility boilers, industrial boilers, and municipal solid waste boilers and have been shown to reduce NO*x* by 70-95%. More recent applications include diesel engines, such as those found on large ships, diesel locomotives, gas turbines, and even automobiles.

Selective catalytic reduction (SCR) of NO by NH_3 is a well-developed technique and the most common technology for the control of nitrogen oxides emitted from stationary sources. NH_3 might not be a suitable reducing agent for mobile sources mainly because of difficulties in its storage, handling, and transportation. As an alternative to overcome these problems associated with NH_3, urea is currently being considered as an NH_3 carrier for automotive emission control applications. It is generally accepted that urea decomposes into NH_3 as follows. When urea solution is atomized into a hot exhaust gas stream, the primary step for the decomposition is the evaporation of water from the droplets of urea solution [1].

Urea SCR method is suitable for heavy duty and low duty applications due to its higher NOx reduction potential. In urea SCR, the chemical reactions take place at lower temperature of 200- 400ºC with the aid of catalyst bed. Urea is injected in liquid form.

In equation (1) the water droplets evaporate from the urea water solution and results in molten urea.

$$NH_2\text{-}CO\text{-}NH_2\ (aqueous) \rightarrow NH_2\text{-}CO\text{-}NH_2\ (molten)\ H_2O\ (gas) \quad (1)$$

Equation (2) represents the thermal decomposition of molten urea to NH_3 and HNCO. This process starts around 152°C.

NH_2-CO-NH_2(molten)→NH_3(gas)+HNCO(gas) (2)

The above two reactions do not require any catalyst and takes place in the decomposition tube. Equation.3 represents the hydrolysis of isocyanic acid to NH_3 and CO_2 in the presence of a catalyst.

HNCO(gas)+H_2O(gas)→NH_3(gas)+ CO_2(gas) (3)

In general, one mole of urea generates 2 moles of NH_3. Also, the exhaust conditions of the engine vary. The major drawback of this method is handling of large quantities of NH_3 because NH_3 is toxic and corrosive.

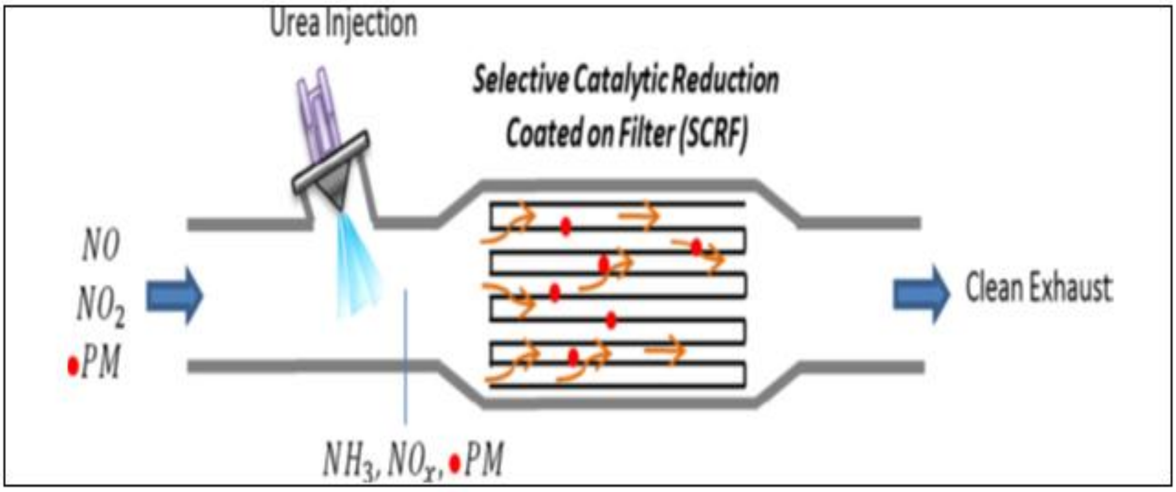


Fig.1 Urea-SCR operational principle

$NH_3 + 4\ NO + O_2 \rightarrow 4N_2 + 6\ H_2O$ **(4)**

$8NH_3 + 6\ NO_2 \rightarrow 7N_2 + 12\ H_2O$ **(5)**

$4\ NH_3 + 2NO + 2NO_2 \rightarrow 4N_2 + 6\ H_2O$ **(6)**

$2\ NH_3 + 2NO_2 \rightarrow NH_4NO_3 + N_2 + H_2O$ **(7)**

Equation (4) represents standard SCR reaction in which the ratio of NH_3 and NO is 1:1 and some moles of O_2 are consumed. Equation (5) represents slow SCR reaction where pure NO_2 takes place in the reaction. Equation (6) represents fast SCR reaction with NO and NO_2 ratio of 1:1. Besides these reactions, certain undesirable reactions also occurs which limits the NOx conversion. At lower temperatures below 200º C, NO_2 in the exhaust gas forms Ammonium Nitrate according to the reaction in equation (7).

The commonly used SCR catalysts are vanadium based. They demonstrate good NOx reduction at 300-450ºC, high temperature tolerance and superior resistance to sulphur poisoning. Improve the performance at high temperature. Vanadium demonstrates high temperature good performance at low temperature conditions and high efficiencies. NO_2/NOx ratio improves the low temperature performance of SCR. Ammonia storage capacity is more for these catalysts at low temperature and less at higher temperature. The oxidation of NH_3 in the absence of NOx leads to formation of NO and N_2O (undesirable side reaction) [14].

II. LITERATURE REVIEW

Sung Dae Yim et al. (2004) Urea was completely decomposed into NH_3. As two main reactions including of urea and catalytic convert oxidation of ammonia during the results of urea into NH_3 occurs the thermal decomposition route, whereas subsequent the oxidation of ammonia is mainly caused by catalytic reaction.

Xiaobo Song et al. (2015) The SCR outlet NOx distribution with urea injection rate have a effect on reduces the NOx reduction efficiency by up to 7%. SCR inlet NH_3 distribution reduces the urea usage by up to 15% to achieve the NOx reduction efficiency of 90%.

Azael Capetillo et al. (2017) Urea–water injection for an automotive SCR system using for the operation point under analysis, Results showed predicted performances and the CFD calculated performances. DoE techniques can be used as a design improvement and improve the performance of the system.

V. Praveena et al. (2017) Urea SCR methods are used to control the excess of NOx and NH_3. In cold conditions, a mixer is used which vaporization of the spray by impaction on its walls. A common issue in Urea SCR is the NH_3 slip. Pre-saturation of the system with NH_3, thermal management and urea dosing helps the system to achieve 98% NOx conversion.
Jibing Jiang et al. (2015) NOx emissions reduction after the temperature control was evaluated by the simulated SCR model validated by specific experimental factors. The improved NOx emissions reduction efficiency can exceed 90% with more steady working performance.
In all read summary, to following conclude for developed and process experimental setup for engine in Urea SCR catalytic system used for operation under analysis. The improved NOx emissions reduction efficiency can exceed more steady working performance, Urea SCR outlet NOx distribution with urea injection rate have a effect on reduces the NOx reduction for increased efficiency.

III. EXPERIMENTAL SETUP

The engine was started by hand cranking with diesel fuel supply, and allowed to get to steady state (for about 30 minutes). Water to engine cooling jacket flow rate was maintained and water flow pressure to eddy current dynamometer was maintained throughout the experiments. Water flow pressure was maintained using a ¼th HP water pump. The software was run and operated in online mode with to record the data online, software was logged every time and data will be stored in the computer hard disk. . The first experiments was conducted about diesel engine for number of load 1kg, 3kg, 5kg, 7kg, 9kg and 11kg without urea SCR converter operation and second experiment was same number of load with urea SCR converter system was arranged after diesel engine operation. I have taken reading to measure the exhaust gas emissions of gases like CO, CO_2, O_2, NOx and HC which were coming from urea SCR system. The readings have been taken by Exhaust Gas analyser.

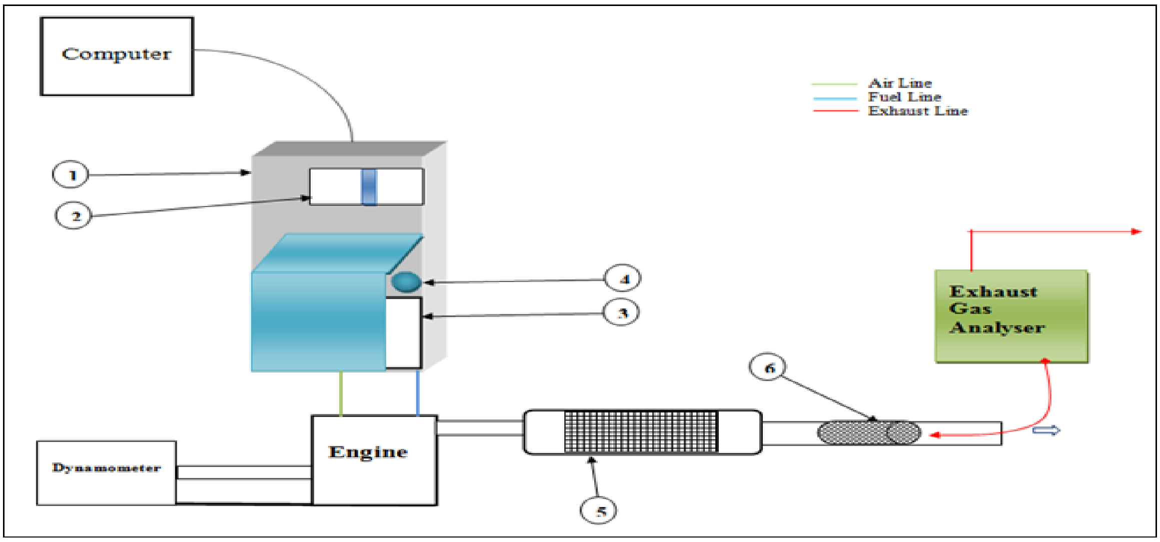


Fig.2 Schematic diagram of experimentation with Urea SCR converter

1. Variable Compression Ratio (VCR) Engine
2. RPM Indicator, Load Indicator
3. Water flow Indicator
4. Loading knob
5. SCR converter
6. Urea Solid Mesh

Model	TV1
Make	Kirlosker Oil Engines
Type	Four stroke, Water cooled, Diesel
No. of cylinder	One
Bore	87.5 mm
Stroke	110 mm
Combustion principle	Compression ignition
Cubic capacity	0.661 litres
Compression ratio 3 port	18:1

Table 1 Test engine specification from engine manual

IV. OBSERVATIONS AND RESULT

Observation was done by taken reading for exhaust NO_x emission. Different data comes from the observation in this experiment with their results data was shown in tables for pure diesel for steady state condition. We used two different conditions for finding the best result of C.I. Engine significant of the total emission output.

[1] Engine without Urea-SCR System.
The observed data and table find out steady state condition by experiment on diesel engine without joined Urea SCR converter as results data are shown in table. The given data obtained to Find Fuel Consumption (Kg/hr) and use to gas analyser with measured emissions of main unborn hydrocarbons (HC) and Nitrogen oxides (NO_x) at different load.

100% diesel									
Load (kg)	**RPM**	**Torque (Nm)**	**FC kg/h**	**SFC kg/kWh**	**Mech.Eff. (%)**	**BTE (%)**	**ITE (%)**	**HC ppm**	**NO_X Ppm**
1	1480	1.81	0.62	2.22	10.53	3.86	36.69	26	91
3	1477	5.44	0.67	0.80	26.05	10.71	41.11	23	111
5	1469	9.07	0.77	0.55	36.87	15.46	41.94	34	154
7	1481	12.70	0.90	0.46	45.19	18.79	41.59	41	215
9	1521	16.33	1.05	0.40	52.12	21.27	40.81	35	348
11	1507	19.96	1.17	0.37	56.86	23.02	40.48	43	373

Table 2 Observation and Result data for Diesel engine at without Urea SCR System condition

[2] Urea SCR System condition.
The observed data find out by experiment on diesel engine with connect Urea-SCR catalytic converter as a working system and measured exhaust gas reading for Gas analyzer at steady state condition. Gas analyzer measured emissions of main unborn hydrocarbons (HC) and Nitrogen oxides (NO_x) at different load.

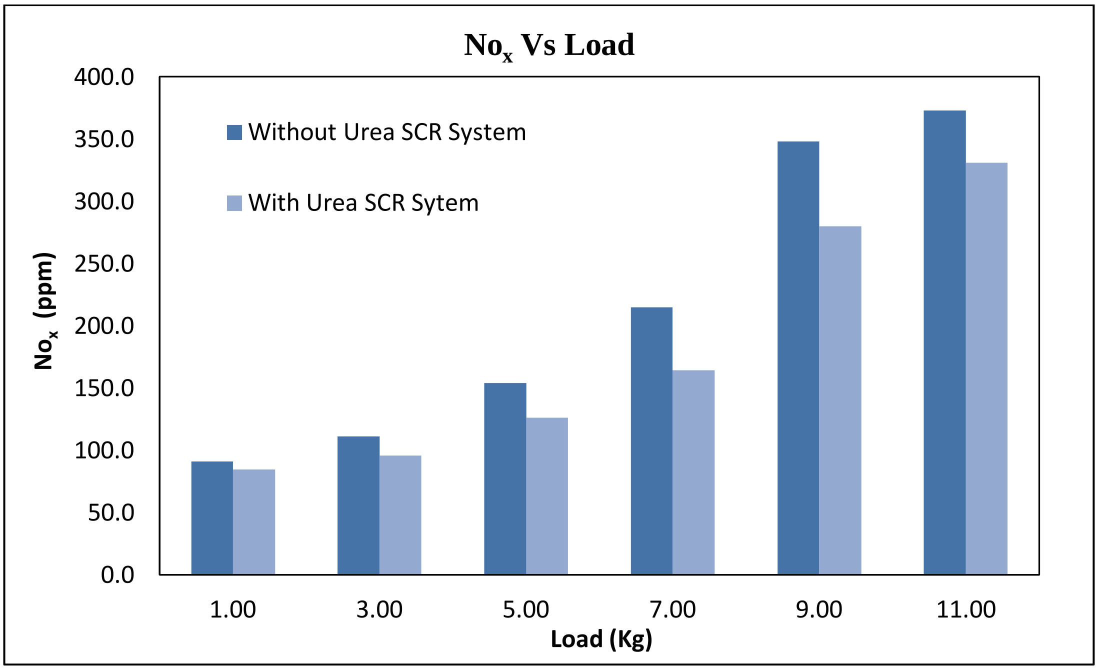
100% diesel with Urea SCR System									
Load (kg)	**RPM**	**Torque (Nm)**	**FC kg/h**	**SFC kg/kWh**	**Mech.Eff. (%)**	**BTE (%)**	**ITE (%)**	**HC ppm**	**NO_x (ppm)**
1	1482	1.81	0.63	2.23	10.41	3.84	36.88	23	84.54
3	1487	5.44	0.67	0.79	25.90	10.78	41.63	26	95.68
5	1501	9.07	0.75	0.52	37.03	16.33	44.09	30	126.14
7	1507	12.70	0.88	0.44	45.26	19.56	43.22	33	164.05
9	1502	16.33	1.02	0.40	51.44	21.62	42.03	37	262.29
11	1500	19.96	1.20	0.38	56.39	22.43	39.78	41	330.81

Table 2 Observation and Result data for Diesel engine at with Urea SCR System condition

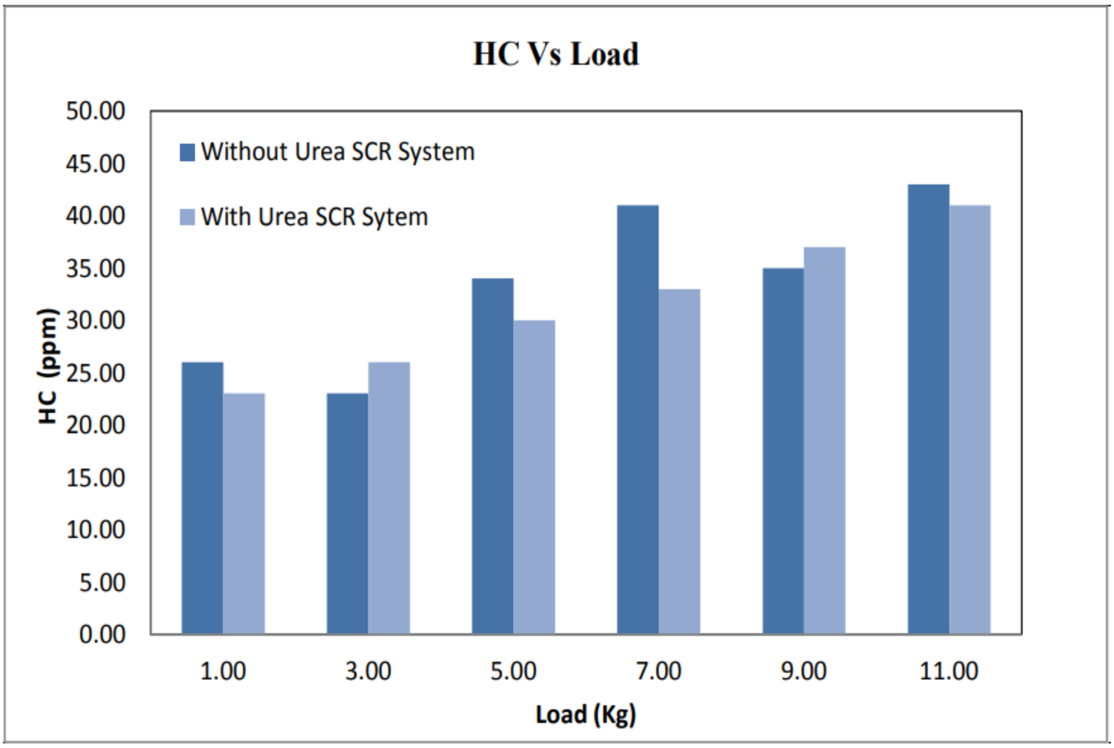
I. RESULTS AND DISCUSSION

1)No_x Vs Load
From the above table and graph 1, we can see the reading of Nitrogen oxides (NO_x) different between without Urea SCR system and With Urea SCR system at different load 1kg, 3 kg, 5 kg, 7 kg, 9 kg and 11 kg are accordingly 7.10%, 13.80%, 18.09%, 23.7%, 19.58% and 11.31%. The maximum saturation condition at load of 7 Kg after that deferens is decreasing. Means resonance reading is at 7 Kg load percentage is 23.7%.

2)HC Vs Load
From the above table and graph 2, we can see the reading of Hydrocarbons (HC) different between without Urea SCR system and With Urea SCR system at different load 1Kg, 3 Kg, 5 Kg, 7 Kg, 9 Kg and 11 Kg are accordingly 11.54%, -13.04%, 11.76%, 19.51%, -5.71% and 4.65% . The maximum saturation condition at load of 7 Kg but it is not in sequence at anyway. It is random and Zigzag.



Graph.1 No_x (ppm) Vs Load (kg) graph reading between without Urea SCR System and with Urea SCR System



Graph.2 HC (ppm) Vs Load (Kg) graph reading between without Urea SCR System and with Urea SCR System

II. CONCLUSIONS

This paper has presented on principle and based on this simplified model. The main conclusions and achievements of this method is successful model so that the model is able to predict the Urea SCR catalytic converter output during a NO_x and HC emission test in diesel engine. We found that the emission in NO_x is decreased at any load and sequentially decreased up to 7 Kg load and maximum deferent 23.7% at 7 Kg load. In HC emission is not fixed in sequence but it is also found at 7 Kg load getting emission is deferent maximum 19.51%. Also we found that at 7 Kg load achieved resonance decreased in emission in both NO_x and HC. After all, when load is not fixed and it is variable from 1 Kg to 11 Kg the average emission of NO_x in percentage 15.60% and in HC percentage is 4.78%. Thus we are getting reduce emission of NO_x and HC with use of Urea and SCR system.

REFERENCES

[1] Yim, Sung Dae, et al. "Decomposition of Urea into NH3 for the SCR Process." Industrial & engineering chemistry research43.16 (2004): 4856-4863.
[2] Ström, Henrik, Andreas Lundström, and Bengt Andersson. "Choice of urea-spray models in CFD simulations of urea-SCR systems." Chemical Engineering Journal 150.1 (2009): 69-82.
[3] Song, Xiaobo, Jeffrey D. Naber, and John H. Johnson. "A study of the effects of NH3 maldistribution on a urea-selective catalytic reduction system." International Journal of Engine Research 16.2 (2015): 213-222.
[4] Kumar, AP Manoj, J. S. Sreekumar, and P. Mohanan. "Experimental and CFD Analysis of Selective Catalytic Reduction System on DeNOx Efficiency of Single Cylinder Diesel Engine Using NH3 as a Reducing Agent." Procedia Technology 14 (2014): 116-124
[5] Ström, Linda, et al. "Quantification of Urea-spray Non-uniformity Effects on the H2-assistedNO Reduction and NH3 Slip over an Ag/Al2O3 Catalyst." Energy Procedia 75 (2015): 2317-2322.
[6] Åberg, Andreas, et al. "Parameter estimation and analysis of an automotive heavy-duty SCR catalyst model." Chemical Engineering Science 161 (2017): 167-177
[7] Jiang, Jibing, and Dinggen Li. "Theoretical analysis and experimental confirmation of exhaust temperature control for diesel vehicle NOx emissions reduction." Applied Energy 174 (2016): 232-244.
[8] Millo, Federico, et al. "Application of a global kinetic model on an SCR coated on Filter (SCR-F) catalyst for automotive applications." Fuel 198 (2017): 183-192.
[9] Capetillo, Azael, and Fernando Ibarra. "Multiphase injector modelling for automotive SCR systems: A full factorial design of experiment and optimization." Computers & Mathematics with Applications 74.1 (2017): 188-200.
[10] Lee, Changhee. "Numerical and experimental investigation of evaporation and mixture uniformity of urea–water solution in selective catalytic reduction system." Transportation Research Part D: Transport and Environment (2017).
[11] Ruggeri, Maria Pia, et al. "Novel method of ammonium nitrate quantification in SCR catalysts." Catalysis Today (2017).
[12] Stephenson, Nancy D. "Selective catalytic reduction for reduced NO x emissions." Heat Recovery Steam Generator Technology. 2017. 145-172.
[13] Liao, Yujun, et al. "Characterization of the urea-water spray impingement in diesel selective catalytic reduction systems." Applied Energy 205 (2017): 964-975.
[14] Praveena, V., and M. Leenus Jesu Martin. "A review on various after treatment techniques to reduce NOx emissions in a CI engine." Journal of the Energy Institute (2017).

