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EFFECT OF FLOW RATE AND CONCENTRATION OF CARBAMIDE ON THE REDUCING NO_x EMISSIONS IN PALM BIODIESEL FUELLED RESEARCH ENGINE

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ABSTRACT

This study examines the consequences of concentration and flow rate of carbamide (urea) to reduce NO_x emissions from a diesel engine propelled with biodiesel. Taguchi-Grey relational-based multi-response optimisation method was employed for test-plan. Results revealed that carbamide flow rate and its concentration have a positive impact on NO_x emissions reduction in unmodified diesel engine. The obtained results are also justified with results attained from ANOVA. It is also confirmed that the results obtained in the experimentations are in line with the calculated values obtained Taguchi technique. Hence, the usage of carbamide in tailpipe is an effective way in reducing NO_x emissions from diesel engine.

Keywords: palm biodiesel, NO_x emission, carbamide, Taguchi method.

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INTRODUCTION

Due to physical and socio-economical reasons, the decrease in petroleum and non-renewable sources has inevitably increased fuel prices. With the imminent lack of energy, biodiesel may serve as a seasonal solution to the issue (Yuvarjan *et al*., 2017; Appavu *et al*., 2018). Finding from literature justifies that the oxygen content in biodiesel is a major cause of higher NO_x emissions (Mahalingam *et al*., 2017; Yuvarajan *et al*., 2016 a,b; Devarajan *et al*., 2017). Hence, the effort to cut NO_x emission is the major concern for research diesel engine fuelled with biodiesel (Joy *et al*., 2017; Devarajan *et al*., 2018).

Previous literature has justified that the after-treatment in the exhaust system is an effective way to reduce NO_x emissions from a biodiesel-fuelled diesel engine and to maintain the standards (Devarajan e*t al*., 2017; Yuvarajan *et al*., 2016 c,d; Radhakrishanan *et al*., 2017). There are numerous after-treatment practice to decrease NO_x emissions. It was also detailed from many studies that the selective catalytic reduction (SCR) is the most advanced and promising technique for NO_x emissions in a biofuel-fuelled engine. Hence, most of the on-road heavy-duty diesel automobiles are operated with SCR-carbamide system for reduction of NO_x emissions (Biswas *et al*., 2009; Wang *et al*., 2011).

Many studies have detailed that the SCR-carbamide system is found to reduce the higher quantity of NO_x emissions (Devarakonda *et al*., 2010; Cho *et al*., 2012; Chol *et al*., 2007; Pandian *et al*., 2018). Appavu *et al*. (2018) found that the higher concentration of carbamide in the SCR system has a direct effect on drastic reduction in NO_x emissions for a biodiesel-fuelled diesel engine. Kim *et al*. (2015) found that the higher quantity of carbamide in the SCR system has a direct effect on drastic reduction in NO_x emissions for research engine.

All the previous works have been attempted in reducing NO_x emissions by SCR-carbamide system

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employing OFAT (one-factor-at-a-time) technique. Furthermore, no studies of late have detailed the effectual an optimal condition of carbamide injection factors. Hence, the objective of this study to analyse and arrive the effectual an optimal condition of carbamide injection to minimise NO_x emissions in biodiesel propelled engine.

EXPERIMENTAL MATERIALS AND PROCEDURE

Biodiesel

Biodiesel is prepared from raw oil through the transesterification method. This method utilises potassium hydroxide (catalyst) and methanol (alcohol). The raw oil is pre-heated to 65°C and mixed to a solution containing alcohol and catalyst. The standard molar ratio of oil and alcohol is 6:1. The resultant mixture is heated above 75ºC where the entire methanol present in the mixture gets evaporated for separation of ester and glycerol.

Experimental Set-up

A 5.2 kW naturally aspirated DI diesel engine is utilised for the experimentation. Engine specification is shown in *Table 1*. Eddy current dynamometer (water-cooled) was employed for loading the research engine. The load (kg) applied to the engine was digitally displayed by receiving the load signal from sensor built-in dynamometer. Rota-meter was employed to compute the water flow rate. The exhaust gases, such as CO, CO_2, NO_x, and HC are quantified by using AVL Digas 444 five-gas analyser. Carbamide solution in a liquid state is gently sprayed in the tailpipe just before the catalytic reduction system. Carbamide is fed to the tailpipe by means of injection nozzle from the carbamide tank by a pump.

Experimental Procedure

The levels and parameters obtained in the investigations (carbamide-SCR system) are shown in *Table 2*. Taguchi technique is employed for experimental planning. It has been experimentally proven that the number of experiments can be minimised drastically by employing the Taguchi optimisation method. Taguchi optimisation techniques have gained much attention for solving many optimisation problems. An L_9 (3^4) Taguchi orthogonal array is followed by the test plan.

TABLE 1. SPECIFICATION OF THE TEST ENGINE

Engine	Kirloskar
Cylinder	Two
Bore (mm)	87.50
Stroke (mm)	110
Injection pressure (bar)	210
Diameter of the nozzle (mm)	0.32
Displacement (cc)	661.45
Compression ratio	18.5
Cooling source	Water
Power (kW)	5.2
Speed (rpm)	1 500

TABLE 2. CARBAMIDE CONCENTRATION AND FLOW RATE AT DIFFERENT LEVEL

Level	Carbamide concentration (%)	Carbamide flow rate (ml min^{-1})
1	40	20
2	45	40
3	50	60

RESULTS AND DISCUSSIONS

Post collection of the orthogonal array, plan derived from Taguchi technique was employed to conduct the experimental study. *Table 3* shows the experimental data and plan for all the working condition. The impact of design factors on the response of the system is measured by SN (signal to noise) factor in Taguchi technique. As per this technique, SN ratio is classified into three categories namely, 'larger-better'; 'nominal-better' and 'smaller-better' (Kackar, 1985).

TABLE 3. NUMBER OF EXPERIMENTS

Experiment No.	Carbamide concentration (%)	Carbamide flow rate (ml min^{-1})	NO_x emission (ppm)
1	40	20	94.3
2	40	40	86.5
3	40	60	71.3
4	45	20	69.4
5	45	40	65.6
6	45	60	61.5
7	50	20	56.6
8	50	40	50.8
9	50	60	46.4

A higher value of SN factor favours the better quality characteristics. The objective of this study also focuses on finding the effectual and optimal condition of carbamide injection to reduce NO_x emissions in biodiesel propelled engine. Minitab software was utilised to find out the impact of design factor for optimisation with respect to the observations collected during the study. *Figures 1, 2* and *Table 3* replicates the observations collected during the study. Observation from *Figures 1, 2* and

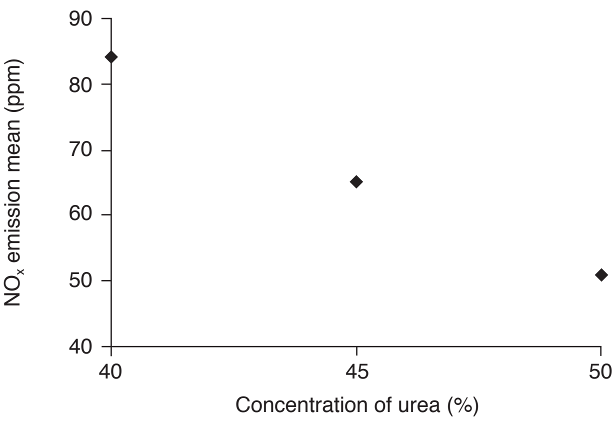

Figure 1. The effect of carbamide concentration on the mean of NO_x emission.

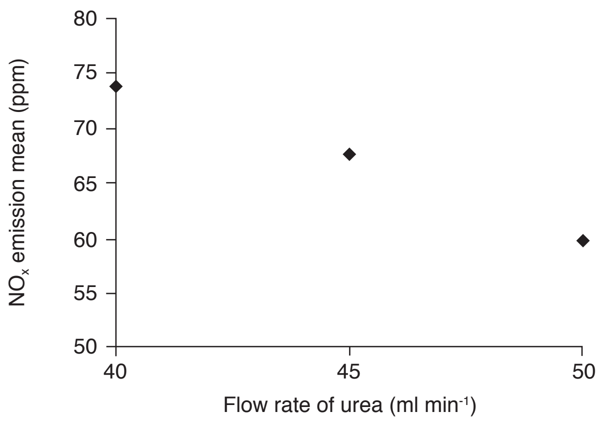

Figure 2. The effect of carbamide flow rate on the mean of NO_x emission.

Table 3 clearly signifies that by increasing flow rate and concentration of carbamide in the carbamide-SCR system, a drastic reduction in NO_x emissions was noticed. The possible reason is due to higher residue-time for the reaction of carbamide with exhaust gas at grater flow-rate and concentrations.

Minimal reduction in NO_x emissions was observed at third level for carbamide flow rate and concentration in the carbamide-SCR system. The difference among minimum and maximum SN ratio for every factor are represented by the delta parameter in *Table 4*. It suggests the design factor's sequence as per the efficacy. *Table 5* lists the most favourable state for all factors with reference to SN factor obtained from *Table 4*.

TABLE 4. SIGNAL TO NOISE (SN) RATIO RESPONSE LEVEL

Level	Carbamide concentration (%)	Carbamide flow rate (ml min^{-1})
1	-44.96	-44.54
2	-43.05	-43.12
3	-41.41	-41.76
Delta	1.23	0.48
Rank	1	2

TABLE 5. OPTIMAL LEVEL OF DESIGN PARAMETERS

Parameter	Optimum level	Optimum value
Carbamide concentration	3	50 %
Carbamide flow rate	3	60 ml min^{-1}

Table 6 represents the variance analysis for SN factor. Contribution ratio in *Table 6* represents the impact of all the design factors with reference to the reduction in NO_x emissions on a percentage basis (Yuvarajan *et al.*, 2016d). It also computes the domination level of each factor to minimise the change in system response.

Inference from *Table 6* clearly shows that the concentration of carbamide contributes to 85% reduction in NO_x. Further, flow rate of carbamide is another dominating factor for 15% reduction in NO_x. The validation of obtained results from the Taguchi technique is verified by the confirmation experiment conducted at the optimal design parameters.

The difference among the values obtained with confirmation test (real) and forecasted value from the response of the system (forecasted) evaluated with Minitab software is shown in *Table 7*. Since the error

TABLE 6. ANALYSIS OF VARIANCE FOR SIGNAL TO NOISE (SN) RATIOS

Source	Degrees of freedom	Adjusted sum of squares	Adjusted mean square	Contribution ratio (%)
Carbamide concentration	2	150.442	75.221	85
Carbamide flow rate	2	50.836	25.418	15
Total	8	206.038	103.019	100

TABLE 7. CONFORMATION ANALYSIS

Response	Unit	Value		Error (%)
		Predicted	Real	
NO_x emission	ppm	44.4	45.2	1.7

obtained are very marginal, the optimal conditions are authenticated for maximum reduction in NO_x emissions.

CONCLUSION

The objective of this work is to analyse the effectual and optimal condition of carbamide injection to reduce NO_x emissions in the biodiesel-propelled engine. From the extensive trial, the following result was arrived:

- carbamide concentration is the most dominating factor for reducing NO_x emissions in the biodiesel-propelled engine. NO_x reduction varies inversely with a concentration of carbamide;
- carbamide flow rate is the subsequent dominating factor for reducing NO_x emissions in the biodiesel-propelled engine. NO_x reduction varies inversely with flow rate of carbamide;
- the optimum setting for reducing NO_xemissions is obtained at the highest level of carbamide concentration, and carbamide flow rate. Optimum setting or maximum NO_x reduction were obtained at the highest level of concentration and flow-rate of carbamide; and
- the error obtained is very marginal, the optimal conditions are authenticated for maximum reduction in NO_X emissions.

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