Experimental Analysis of Blended Fuel with EGR on Agriculture Based Diesel Engine

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Received 04.09.2022, received in revised form 25.09.2022, accepted 01.10.2022
DOI: ***10.47904/IJSKIT.12.2.2037.76-84***

***Abstract*- The use of biofuels and additives can limit the exhaust emission from IC engines. The current study explores the possibility of using Nitromethane (NM) as additive in 20% n-butanol-diesel blend along with application of EGR to limit exhaust smoke and NOx emissions of a diesel engine. The objectives of this study is to find out suitable ratio of NM in BU20 (20% butanol in diesel) and flow rate of EGR for improved engine performance and reduced emissions. An experimental examination was done on a vertical-single cylinder, 4-stroke, constant-speed, water cooled, DI diesel engine. Different combinations of NM-BU20 blends of range NM (1 – 3%) and EGR rate (10-30%) Have been prepared and investigations were performed according to design matrix created by design expert software. A complete comparison of various combination of fuel and EGR was done to find the most appropriate combination of NM-BU20 blend and EGR for reduced emissions with reasonable performance.**

***Keywords:* Diesel engine; Additives; Performance; Emissions; Exhaust gas recirculation.**

1. INTRODUCTION

The current industrial economy is built on energy, which gives the majority of human tasks a substantial gradient. It offers manufacturing, food production, heating of the water, lighting, transportation services, etc. Today, their quantity, comfort, and promise are essential to both our personal and social life. Based on the global data on energy production and consumption, policies, possibilities, and problems, the IEA has generated many energy scenarios. According to the scenario of the new policies, the use of all recent fuels is predicted to increase rapidly until 2040. The projected demand of petroleum oil rise to 103.5 million barrels/day (Mb/d) by the year 2040; and the demand of gas is projected to rise by approx. 50%. By 2050 the incremental projection in renewable energy is 18% to 30% in power segment [1]. By region, all growth in energy demand led by India and China, comes from fast–growing developing economies. The share of oil in the energy consumption will major contribution till 2050 [2]

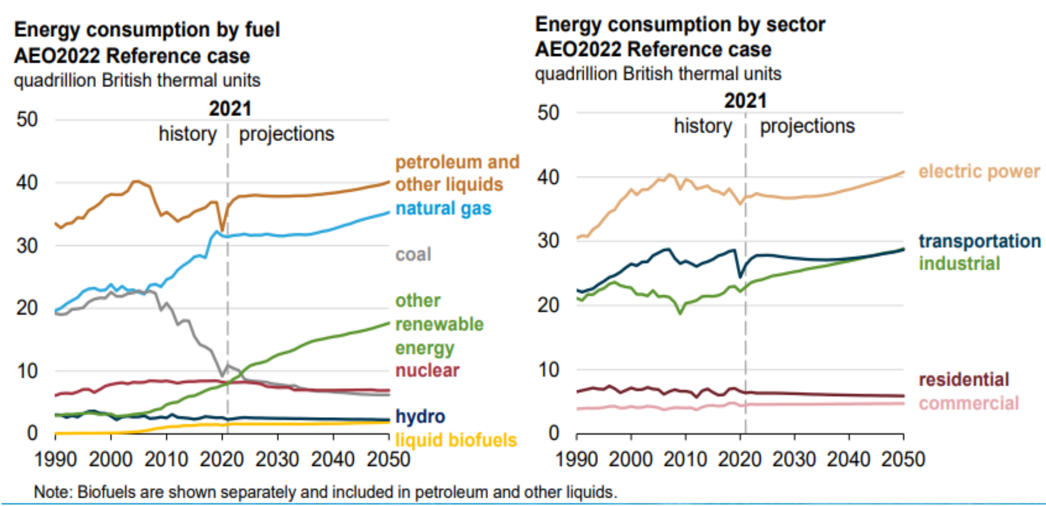

Figure 1. Energy consumption by fuel [2]

Figure 1 shows world energy consumption by energy source in the transport sector by 2050 and it is clear from the figure that light-duty vehicle sales by fuel are much higher than others till 2050 [3]. Diesel engines are preferred as than that of SI engine because of better fuel economy, lesser emissions of carbon monoxide (CO) and hydrocarbon (HC) [4-5]. Though, nitrogen-oxides (NO_x) & smoke emissions are higher in compression ignition (CI) engines as compared to spark ignition engine [6-9].

1.1 Use of additives:

Many organic compounds are suitable to use as additives in diesel that improve combustion and emission properties of fuel [10-13]. Oxygenated additives are more prominent among all accessible additives because they have more oxygen in their molecular structures, which promotes better combustion. It was discovered that 10–20% of oxygenated additives can be mixed with diesel fuel to reduce exhaust emission [14-16].

n-Butanol: In the present scenario the use of bio extenders in diesel engine are promoted. The higher alcohol such as n-butanol is considered a better choice for blending in diesel than methanol and ethanol [17-18]. Various research studies [19] have claimed that due to superior fuel properties of n-butanol it may overcome the harms allied with the blending of ethanol and methanol in diesel (Butanol is completely miscible in diesel without any surface reactant. Having high cetane number, high oxygen to carbon ratio and oxygen to hydrogen ratio, heat capacity, the butanol presents the opportunity towards the researchers to investigate its performance in IC engines. These properties will be supportive in reduction of exhaust emissions without any contrary effect on the power performance of engine [20-21].

In recently published studies the experimental results of butanol-diesel blends in diesel engine (10, 15, 20, 25% vol. of butanol) were reported [22]. In that study other than blending ratio, inputs like engine loads, compression ratio, injection pressure and injection timing were also addressed. The predicted optimal value of n-butanol concentration in diesel (The 19.82 % volume of n butanol in diesel at part load and 18.84% volume of n butanol in diesel at full load were predicted as optimal values and these results are in very vicinity with experimental value (20% by vol.).

Nitromethane (NM): The chemical formula for nitrogenized organic additives is CH_3NO_2. NM is a highly polar liquid with a viscosity just slightly higher than that of diesel. As an extraction solvent, reaction medium, and cleaning solvent, nitromethane is typically utilized in a variety of industrial applications. NM is frequently used as a racing fuel for I.C. engines and drag racing vehicles. The other used of NM are for making explosives, pharmaceuticals, fibers, pesticides and coatings [4].

The NM is obtained by treating the propane with nitric acid at particular temperature (350–450°C). This reaction produces (exothermic reaction) four kind of industrially important nitroalkanes: 1-nitropropane, 2-nitropropane, nitromethane and nitromethane, although all are easily and cheaply available in market. The various combustion and physico–chemical properties of diesel, n-butanol and NM are compared in Table 1 [5-9].

N-butanol and nitromethane have high oxygen content. The viscosity of both additives is close to that of diesel. Nitromethane acts as a cetane number improvisation. Therefore, n-butanol and nitromethane can be used as additives with diesel for C.I. engines due to superior physico–chemical and combustion properties. Diesel-additive mixed fuel with EGR system could be used in CI engines. The rising demand for diesel fuel (oil demand is expected to peak in the next five years) and the limited supply (mainly export) motivate to explore new and renewable fuels [11-14].

Same time the increasing environmental pollution and its hazardous effect on living organism on the earth present a challenge to control it. The global warming and diseases due to carcinogenic exhaust gases pushes researchers to attempt a safe limit of exhaust emissions from stationary engines or automobile engines. It can be seen that n-butanol and nitromethane have a high potential to improve the ignition quality of the engine by comparing various combustion and physico-chemical parameters with those of diesel [17]. In this study evaluate the performance and emission of a stationary diesel engine using nitromethane-diesel blends and application of exhaust gas analyzer (EGR)

Table 1. Various properties of diesel, n-butanol and NM [4, 17, 18]

Properties	Diesel	n-butanol	NM
Chemical Formula	$C_{10}H_{20}$–$C_{15}H_{28}$	C_4H_9OH	CH_3NO_2
Molecular Weight (g/mol)	170	74	60
Cetane Number	50	25	NA
Density (kg/m^3) (25°C)	845	810	1138

Boiling Point (°C)	190	118	101
Viscosity (40°C) cSt	2.54	2.20	0.62
Auto–ignition temperature (°C)	315	385	418
Lower heating value (MJ/kg)	45	33	11.4
Specific Gravity (g/cm^3)	0.827	0.713	1.138
Latent heat of vaporization (kJ/kg)	245	585	561
Oxygen Content (wt%)	0	22	50

2. MEASUREMENT OF PERFORMANCE PARAMETER

2.1 Blend preparation

The experiment's initial task was to prepare the blend combination. On a volume basis, three mixtures of diesel, n-butanol, and nitromethane were developed. The pure diesel fuel was first measured out into glass containers according to the blending ratio, and then n-butanol was added while the mixture was being continuously agitated with a magnetic stirrer. Nitromethane was similarly poured according to the mixing ratio in the diesel–n-butanol blend following the mixing of n-butanol in pure diesel. For various fuel blends, all the measures above were repeated. Before experimentation, the consistency of fuel blends was . also tested and no settling was seen for around 96 hours.

2.2 Engine set up

For experimentation, a four stroke, water cooled, single cylinder, direct injection, diesel engine was used as shown in Fig. 2. Fuel pump received fuel from fuel tank through fuel filter. The engine was lubricated with fresh oil before to the experiment. Splash lubrication systems are utilized to lubricate the different engine components. The engine was started by a battery with a 12 V and 45 Amp rating. A calibrated protector that is attached to the injection nozzle and allows for nozzle pressure adjustment can vary the IP of a diesel engine

Figure.2 Pictorial view of experimental setup

3. RESULT AND DISCUSSION

3.1 Engine performance evaluation with NMBU-diesel Blends and EGR:

The performance parameters of experiments for BSFC and BTE are offered via factor-response graphs and 3d-surface diagrams.

Brake specific fuel consumption (BSFC): Figure 3 (a) & (b) shows that the BSFC increases with higher percentage of NM in blends and with increase rate of EGR. It can also be noted that the rate of increment of BSFC with EGR variation is higher as compared to increment of BSFC with NM blending. The probable reason of increased BSFC with nitromethane blending is higher rate of burning and less time available for conversion of heat into piston work

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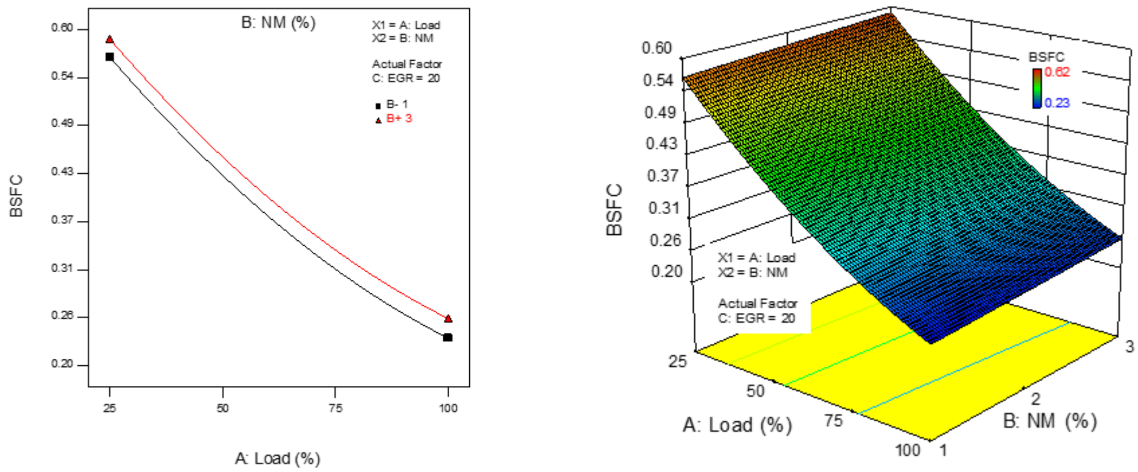

Figure 3 (a) BSFC variation with engine-load for blends of NM-diesel

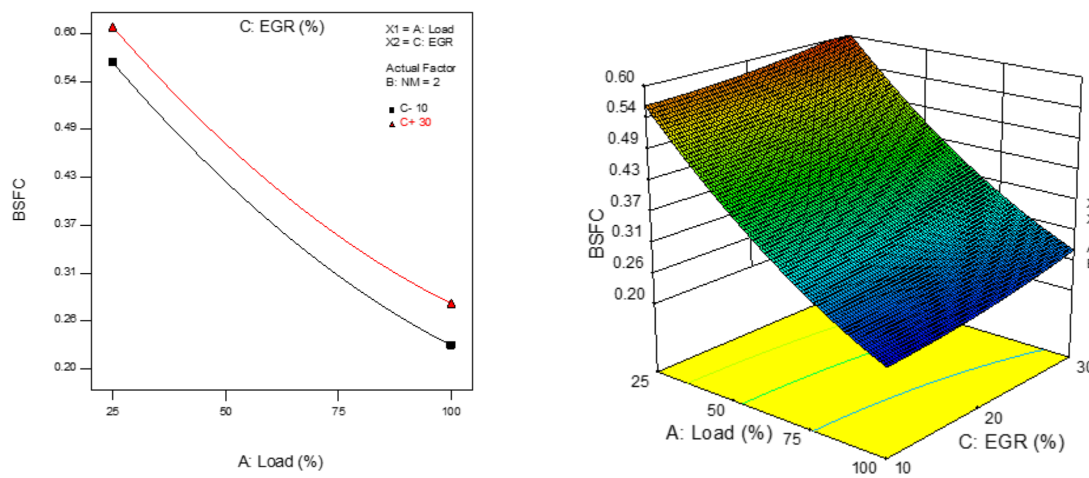

Figure 3 (b) BSFC variation with engine-load with EGR

Brake Thermal Efficiency (BTE): Figure 4 (a) & (b) shows variations of BTE with nitromethane blending and change rate of EGR. It can be observed from the figure that the BTE increased with higher ratio of NM and decreaed with higher rate of EGR. The fast burning quality of NM contribute towards improvement the efficiency. The dilution of charge will increse demand of fuel quantity for same amount of power results in decreased efficiency at higher EGR rates

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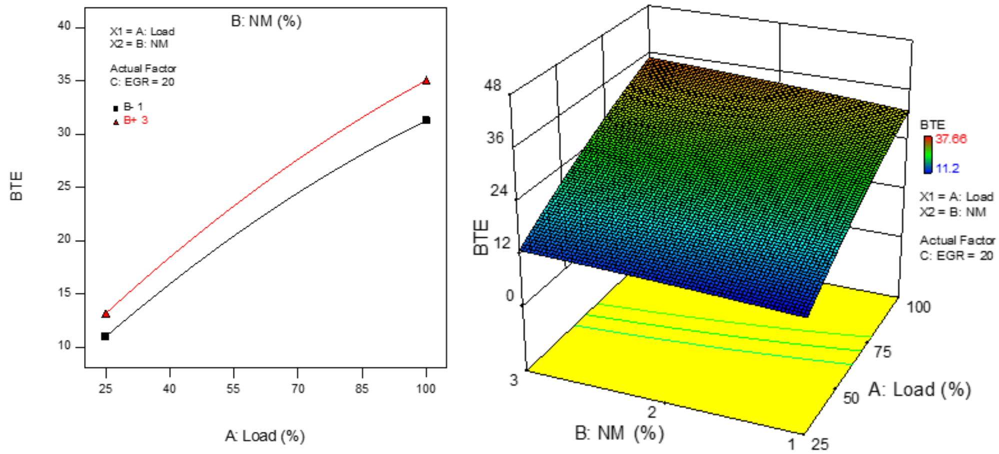

Figure 4 (a) BTE variation with engine-load with NM blending

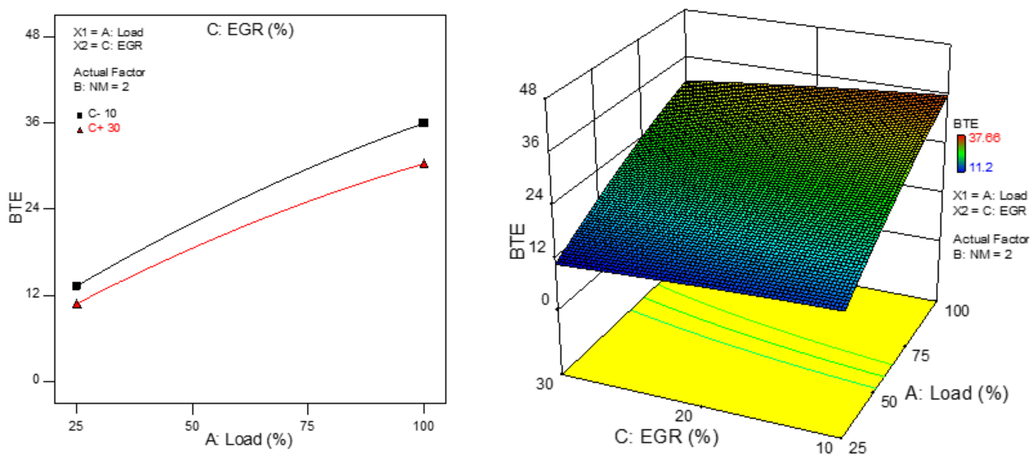

Figure 4 (b) BTE variation with engine-load with EGR

3.2 Emissions characteristics using nitromethane-n-butanol-diesel (NM-BU20) blends

Smoke emission: The variations of smoke emission for blends of NMBU-diesel with EGR for observed data and predicted model are shown by Figure 5 (a) & (b)

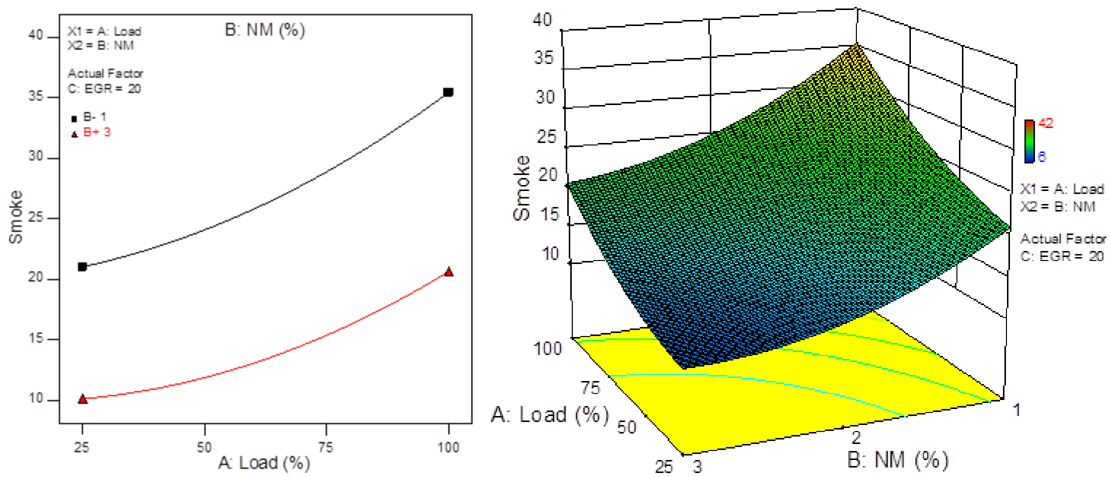

Figure 5 (a) Smoke variation with engine-load and NM blending

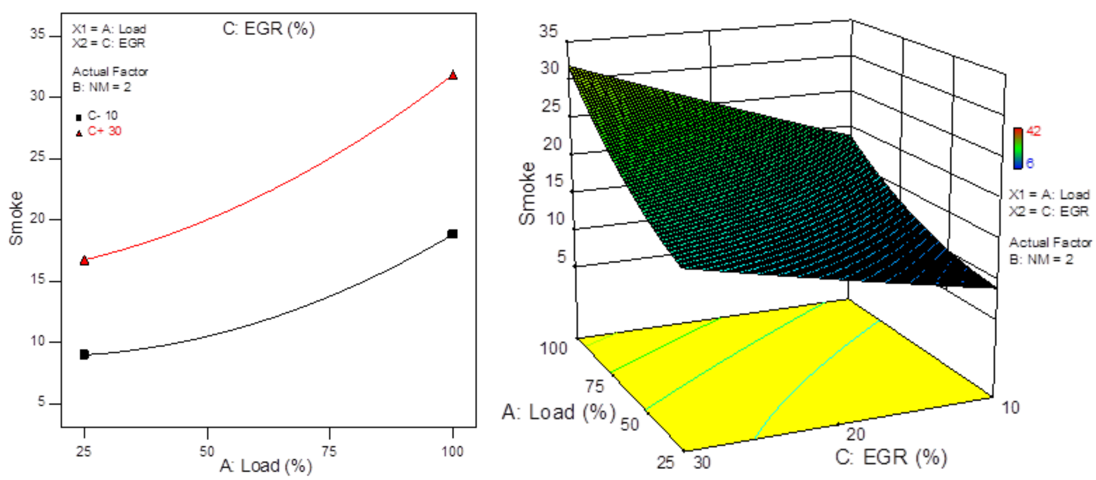

Figure 5 (b) Smoke variation with engine-load and EGR

Substantial drop in smoke emission was noted for NMBU-diesel blends. For NMBU blends smoke emission reduced by 28.8% as compared to BU20 at rated load. Two factors are influnced the smoke emission: (i) The higher content of oxygen (52.4%) in structure of nitromethane. Premixed burning reactions are not able to break bond between O_2 and carbon atom; thus carbon atom is not taking part in combustion process which produces soot & smoke. (ii) The high latent heat for vaporization of NM-diesel blends is the another factor that affect the smoke formation. To achieve self-ignition temperature by fuel-air mixture some more warm air is supplied to vaporize the fuel, this lessens the equivalence ratio (thus forms leaner mixture). Above discussed both aspects (oxygen enhancement and high latent heat for vaporization) obstruct the smoke production in premixed-combustion and overall emission of smoke is reduced for NMBU blends [49, 50].

NO_x emission: The Load vs NO_x emission trends is shown by Figure. 6 (a) & (b) for NM-BU20 blends with EGR for observed data and predicted model.

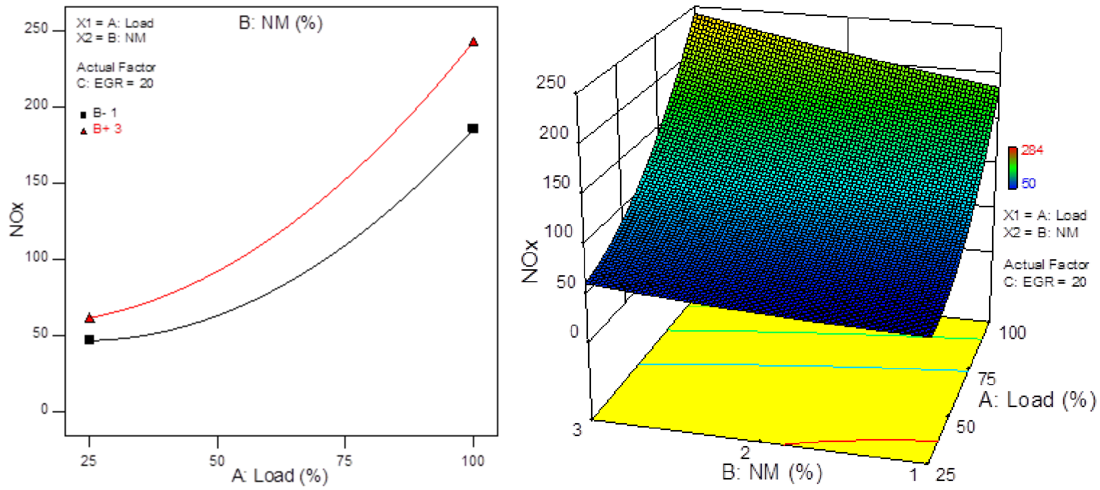

Figure 6 (a) NO_x variation with engine-load and NM blending

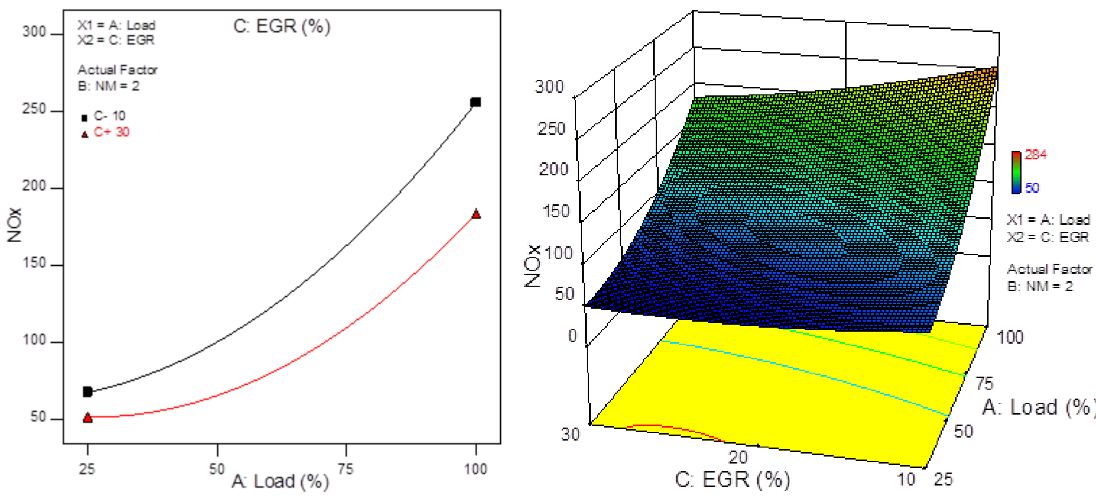

Figure 6 (b) NO_x variation with engine-load and EGR

Figure. 6 (a) and (b) show increment in NO_x with load & NMBU-diesel blends and reduction in NO_x with EGR. A substantial growth in NO_x emission can be detected for 3% NM at rated load. The rise of peak temperature for the duration of the combustion because of improved combustion with NM leads to upturn in NO_x generation (this is also replicated by improved BTE). The augmented NO_x is essentially due to thermally produced NO_x, and not because of the nitrogen content of NM [5]. The fast burning property of NM increased peak temperature. Different proportion of NO and NO_2 in total NO_x may be another possible reason of total NO_x increment in case of NM [14] . The NO_x is reducing with increased percentage of EGR. Due to dilution of charge the peak temperature in combustion is reduced this in turns reduces the formation of NO_x. Also the rate of reduction of NO_x is higher at higher loads. From Figure. 5 (a & b) it can be seen that the rate of reduction of NO_x due to EGR is also higher than rate of increment of NO_x due to blending of Nitromethane. The net effect of NM and EGR is reduced NOx by 15.7% at 3% NM and 30% EGR as compared to 1% NM and 10% EGR.

3.3 Validation and optimization of responses

The parameters were optimized for preferred values of outputs (responses). Table 2 presented the optimum value of NM blending & EGR rate and resulted predicted data of responses. To confirm the predicted results, the confirmation test was performed on optimum values (Round off) of load (85.0 Nm), blend (2% NM) and EGR (10%). The results obtained are:

BSFC=0.271kg/kWh; BTE=32.86%; smoke =14.93HSU; NO_x=204.48ppm. From Table 2 it is seen that the percentage errors of these results are within tolerable range. It proves the precision of predicted model. The NM2 (2% Nitromethane in diesel) and 10% EGR rate were selected (B20NM2EGR10) as the optimum inputs on the basis of the validation of experimental data by mathematical modelling

Table 2: Optimization table for blends of NM-BU20 with EGR

Number	Load	NM	EGR	BSFC	BTE	Smoke	NOx	
1	85.914	2.124	10.000	0.272	32.765	14.970	203.059	Selected
2	85.929	2.116	10.000	0.272	32.757	15.022	202.905	
3	85.961	2.131	10.000	0.272	32.790	14.932	203.438	
4	85.864	2.142	10.000	0.272	32.782	14.844	203.379	
5	85.964	2.101	10.001	0.272	32.741	15.126	202.617	
6	85.944	2.093	10.000	0.272	32.724	15.173	202.339	
7	85.802	2.159	10.000	0.273	32.793	14.730	203.607	
Confirmation test	85.0	2.0	10.0	0.271	32.861	14.938	204.486	
Error Percentage (× 100)				0.368	-0.293	0.214	-0.703	

3.4 Performance and emission of NM-diesel blends with EGR at optimum load condition

The bar diagram in Figure 8 shows the comparison of optimum outputs of mathematical analysis (of NM2BU20EGR10) with baseline reading of engine fueled with diesel only and 20% butanol-diesel blend.

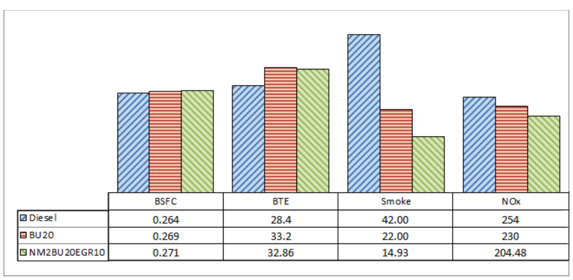

Figure 8 Overall comparison of NM2BU20EGR10 with diesel and BU20

It is observed that from this fig the BSFC of NM2BU20EGR10 (2% NM blending in 20% butanol-diesel blend with 10% EGR rate) is increased by 2.65% and 0.74% as compared to diesel and BU20 respectively. The thermal efficiency of NM2BU20EGR10 is increased by 15.7% as compared to diesel and decreased by 1.02% as compared to BU20 respectively. The blending of NM increases the BTE and on the other hand application of EGR causes reduction in BTE. In the present research the decline in efficiency is the net effect of these two factors. The increased fuel consumption and decreased efficiency with NM2BU20EGR10 in comparison to base fuel (BU20) is very tolerable (0.74%).

The reduction in smoke with NM2BU20EGR10 is 64.45% as compared to diesel and 32.14% as compared to BU20 respectively on the optimum load conditions. The NO_x is decreased by 19.5% and 11.10% for NM2BU20EGR10 as compared to diesel and BU20 respectively.

4. CONCLUSION

The conclusions reported in past studies presented in literature review and the results obtained in the present study are consistent. The closeness of experimental results and predicted data from the generated mathematical models is exhibited by confirmation test. It can be stated that the developed models are fairly dependable and can be applied for guessing outputs of similar type of cases without conduction of experiments. Following conclusions were drawn from current study:

1. With NM2BU20EGR10 (2% NM blending in 20% butanol-diesel blend with 10% EGR rate) BSFC is increased by 2.65% and 0.74% as compared to diesel and BU20 respectively.
2. The thermal efficiency of NM2BU20EGR10 is increased by 15.7% as compared to diesel and decreased by 1.02% as compared to BU20 respectively.
3. The reduction in smoke with NM2BU20EGR10 is 64.45% as compared to diesel and 32.14% as compared to BU20 respectively on the optimum load conditions. The NOx is decreased by 19.5%

and 11.10% for NM2BU20EGR10 as compared to diesel and BU20 respectively.

4. On the basis of above results it can be stated that the use of NM2BU20EGR10 is useful to control smoke and NO_x simultaneously with a tolerable change in performance.
5. The variation in engine operating parameters with blended fuel and endurance testing will further support the suitability of NM2BU20EGR10 for existing engine.

Nomenclature

BTE- Brake thermal efficiency
BSFC- Brake specific fuel consumption
CO- Carbon monoxide
CI- Compression ignition
EGR- Exhaust gas recirculation
HC- Hydrocarbon
IC- Internal combustion
NM- Nitromethane
NOx- Oxides of nitrogen

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