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Noise and Exhaust Emission Characteristic of a Diesel Engine Fuelled with Natural Gas and Blends of Biodiesel and Diesel Fuels

Doğalgaz ve Biyodizel-Dizel Karışımları ile Yakıtlanan Dizel Bir Motorun Gürültü ve Egzoz Emisyonu Karakteristiği

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Abstract

High energy demand of modern society has led to environmental pollution which has become one of the biggest problems for almost all living creatures. Therefore, the effect of the energy sources on emissions has been investigated by researchers for decades. In this research, the effect of natural gas and biodiesel which was produced from corn oil on emissions of a diesel engine was experimentally investigated. In engine experiments, natural gas used at the engine as a secondary fuel while low sulphur diesel fuel and its blend with corn biodiesel (20% and 40% by volume) was used as a primary fuel. According to the results, compared to low sulphur diesel fuel, both natural gas and biodiesel usage improved the noise emission that was distributed from the diesel engine. Biodiesel blends resulted in lower CO emission of 4,05% and 7,63% for CoB20 and CoB40, respectively, whereas introduction of natural gas caused significant rise of the emission. However, increment of CO_2 emission caused by biodiesel addition into low sulphur diesel fuel was well compensated by the addition of natural gas. Moreover, 4,08%, 18,00% increment of NOx emissions caused by CoB20 and CoB40 usage was also compensated up to 33,0% by the introduction of natural gas.

Keywords: Corn biodiesel, Diesel engine, Exhaust emissions, Noise

Öz

Modern toplumun yüksek enerji talepleri, neredeyse tüm canlılar için en büyük sorunlardan biri haline gelmiş olan çevre kirliliğine yol açmıştır. Bu yüzden, enerji kaynaklarının emisyonlar üzerindeki etkileri onlarca yıldır araştırmacılar tarafından incelenmektedir. Bu araştırmada doğalgaz ve mısır yağından üretilmiş biyodizelin dizel bir motorun emisyonları üzerine etkileri deneysel olarak incelenmiştir. Motor deneylerinde doğalgaz motorda ikincil yakıt olarak kullanılırken, düşük kükürtlü dizel yakıtı ve mısır biyodizeli ile karışımı (hacimsel olarak %20 ve %40) birincil yakıt olarak kullanılmıştır. Sonuçlara göre düşük kükürtlü dizel yakıt ile karşılaştırıldığında hem doğalgaz hem de biyodizel kullanımı dizel motordan yayılan gürültü emisyonlarını iyileştirmiştir. Biyodizel karışımları CO emisyonunu, CoB20, CoB40 için sırasıyla %4,05 ve %7,63 daha düşük sonuç verirken doğalgaz ilavesi emisyonun önemli ölçüde artmasına neden olmuştur. Bununla birlikte, biyodizelin düşük kükürtlü dizel yakıtın içerisine eklenmesinden dolayı artan CO_2 emisyonu doğalgazın eklenmesiyle telafi edilmiştir. Ayrıca, CoB20 ve CoB40 kullanımından kaynaklanan sırasıyla %4,08 ve %18,00 oranındaki NOx emisyonu artışı da doğalgaz kullanımı ile %33,0'a kadar telafi edilmiştir.

Anahtar Kelimeler: Mısır biyodizeli, Dizel motor, Egzoz emisyonları, Gürültü

1. Introduction

Transportation has crucial importance on social and economic life of any country (Othman et al. 2017). Due to their reliability and easy to run, internal combustion engines (ICEs) fuelled with petroleum fuels are the most widespread engine in transportation vehicles for almost a century (Kumar et al. 2018). However, with the increment number of ICEs which operate with conventional fossil-based fuel such as diesel and gasoline fuels, the environmental pollution getting higher and higher in every year and started to thread human's health (Shah et al. 2018). Therefore, many countries

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have their own policies to promote to use of alternative fuels instead of fossil-based conventional diesel fuel (Capodaglio and Callegari 2017).

Diesel engines had gained great rate on transportation vehicles since they are cheaper to run. However, their major drawback that concern environmental pollution was realized by the community a few years before. This serious incidence impelling the researchers to find out alternative fuels to conventional fossil-based fuels for ICEs. One alternative fuel to conventional diesel fuel is natural gas (NG). Conventional ICE should be modified in order to use NG as primary fuel due to its high autoignition temperature (Li et al. 2016). Thus, NG can be used as secondary fuel without any modification on the ICEs. Therefore, in literature, NG fuel was generally used as secondary fuel. Wang et al. (2018) investigated the effect of NG usage in a diesel engine based on heat release rate under 10% and 25% load at 1335 rpm engine speed. In experiments, they found out that number of peak point of heat release rate curves vary with the NG quantities. According to the results of the experiment which was conducted by Mittal et al., (2015), nitrogen oxides (NO_x) emissions reduced at all engine loads, however, soot, hydrocarbon (HC) and carbon monoxide (CO) emissions were increased under dual fuel operation. In the study of Yousefi and Birouk (2017) a 3D CFD-chemistry model was developed to simulate the combustion and emission characteristic of a diesel engine which is fuelled with NG and diesel fuel. Their results also indicated that NO_x emissions reduced with NG addition.

Another popular alternative fuel to conventional diesel fuel is biodiesel which derived from animal fat or vegetable oil by methanolysis in the presence of a catalyst (van der Westhuizen and Focke 2018). Biodiesel usage offers many advantages on environment since it is renewable, non-toxic and biodegradable (Wei et al. 2018) (Szabados and Bereczky 2018). In literature, there are studies about the effect of biodiesel from various feedstocks on diesel engine. In the studies; Alloune et al. 2018 investigated the effect of *Citrullus colocynthis L.* biodiesel on diesel engine. They found out that B30 and B100 had earlier start of combustion than conventional diesel fuel. However, combustion characteristics of three fuels were the resemble. From the viewpoint of emission characteristic, experiments indicated that HC, NO_x and particulate matter emissions were decreased by using biodiesel. Uludamar et al. (2017) were investigated the vibration characteristic of a diesel engine. In the experiments, they fuelled the engine with conventional diesel, biodiesel fuels and hydroxy gas. According to their findings, compared to conventional diesel fuel, the engine vibration severity diminished with the usage of alternative fuels. Artificial neural network model was also developed by the researchers in order to predict the data of the effect of fuel properties and HHO amount. Çalık (2018) was used biodiesel from waste cooking oil in order to evaluate the vibration of diesel engine. Li et al. (2018) numerically studied the effect of biodiesel on combustion and emission characteristic of a diesel engine. Increment of NO and soot emission and decrement of CO emission were calculated in the results. Also, shorter ignition delay was observed in the results.

In this study, combined effect of NG and biodiesel in a diesel engine was investigated in terms of emission characteristic. In experiments, the engine was fuelled with natural gas through intake manifold and biodiesel that produced from corn oil. The results were compared with pure low sulphur diesel (LSD) fuel, LSD-NG fuels, and LSD-biodiesel blend. The measured emission characteristic not only include the exhaust emissions but also noise emission of the diesel engine.

2. Material and Methods

In the study, two different types of fuel were utilized in the engine experiments. The mixed air filled the cylinder while the liquid fuel, conventional diesel or its blend with corn biodiesel was directly injected inside the cylinders as atomized liquid fuel. The combustion started shortly after the liquid fuel had been injected inside the cylinders. After the first kernel, the combustion expended with the aid of NG which was injected into the intake air.

Biodiesel that fuelled the experimental engine was produced by transesterification method. The steps of the biodiesel production steps are as follows;

- Firstly, the oil was heated to 55 ^{o}C while the catalyser was poured into and dissolved inside the alcohol.
- After dissolving, the alcohol was poured into the volumetric flask that includes heated oil.
- The transesterification reaction was carried out continuously at 50 ^{o}C for 90 minutes long by stirring.
- After the reaction, crude methyl ester was taken into a separation funnel to apart the methyl ester from the glycerine.
- After 8 hours, the separated glycerine was dropped from the separation funnel to get methyl ester.

- The methyl ester was washed four times with warm water. Water was added so that volume of the water was at least the half of the biodiesel volume.
- To vaporize the water which remains from washing operation is removed by vaporization process. The process was performed at 105 °C for 40 minutes by stirring.
- Lastly, the methyl ester was got through filtering operation in order to remove remaining participles inside the methyl ester.

Noise measurement of the engine was conducted with a GRAS 46AF 1/2” LEMO Microphone Set. In the setup, the microphone was placed one meter away from the test engine. The data collected via microphone set was analysed with the aid of SAMURAI v2.6 software. Sound Pressure level (SPL) of the engine was filtered according to A-weighting filter since the filter is similar to the response of human ear.

During the engine experiments, exhaust emissions were measured via MRU Delta 1600-V gas analyser on a four-stroke, four-cylinder diesel engine. The properties of the experimental engine presented in Table 1 and Figure 1 illustrates the experimental setup.

Table 1. Technical specifications of the test engine.

Brand	Mitsubishi Canter
Model	4D34-2A
Configuration	In line 4
Type	Direct injection diesel with glow plug
Displacement	3907 cc
Bore	104 mm
Stroke	115 mm
Power	89 kW@3200 rpm
Torque	295 Nm@1800 rpm
Weight	325 kg

3. Results and Discussions

Fuel properties

In experiments, the diesel engine was fuelled with pure low sulphur diesel fuel, low sulphur diesel - biodiesel blend, and natural gas. Table 2. presents the fuel properties of test fuels and pure corn biodiesel as well as European diesel and biodiesel standards. According to results, density and kinematic viscosity which may cause poorer atomization of the fuel spray of biodiesel is higher than conventional diesel fuel. Moreover, cetane number which is related with ignition quality of a fuel and gross heating value of corn biodiesel was found to be lower (Giakoumis and Sarakatsanis 2018)

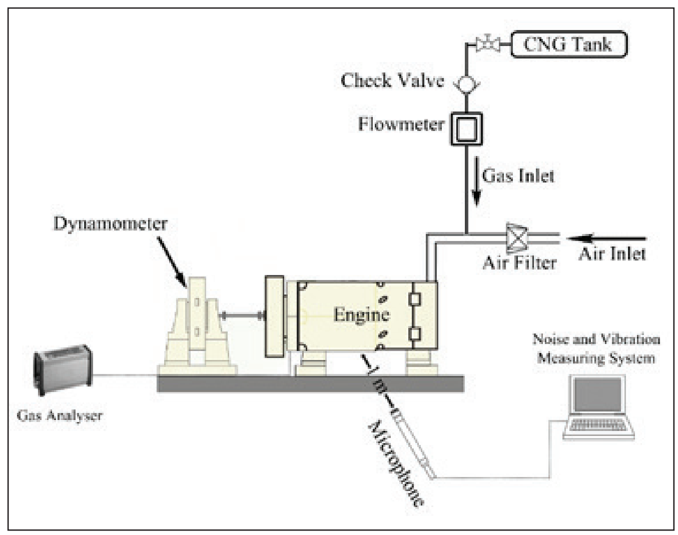

Figure 1. Experimental layout.

Table 2. Physical properties of test fuels.

Test Fuels	Density (kg/m³)	Cetane Number	Kinematic Viscosity at 40°C (mm²/s)	Gross Heating Value (kJ/kg)	Flash point (°C)
D100	837	59,3	2,7	45857	74,5
CoB20	847	55,4	3	42266	85,5
CoB40	856	52,1	3,2	41881	91,5
CoB100	887	42,2	4,2	37476	>140
EN590	820–845	Min 51	2,0–4,5	-	Min 55
EN 14214	860-900	Min 51	3,5 – 5,0	-	Min 120
NG (Bhasker and Porpatham 2017)	0,740	-	-	50000	540

(Ramadhas et al. 2006). However, flash point of biodiesel was measured as higher. This property indicates that transportation and storage of corn biodiesel are safer than low sulphur diesel fuel (Liaw 2018)(Gülüm and Bilgin 2015)(Varatharajan and Pushparani 2018).

Test engine was fueled with pure LSD (D100), 80% LSD - 20% corn biodiesel (CoB20); 60% LSD - 40% corn biodiesel (CoB40), by volume and each of them was tested with four different natural gas flow rate; without any NG flow, 5 L/min, 10 L/min, and 15 L/min, (NG0, NG5, NG10, and NG15, respectively) at five different engine speed (1200 rpm, 1500 rpm, 1800 rpm, 2100 rpm, and 2400 rpm) under no load condition in order to eliminate the effect of dynamometer loading mechanism.

Noise Emission

Figures. 2-6 show the SPL versus NG flow rate at various engine speed. The result of experiments which indicates average SPL without any NG addition found slightly lower than that of D100 with 0,2 dB(A), for CoB20; 0,4 dB(A), for CoB40. Similar trend were observed at the study of Çalık (2017). Decrement of SPL may be related with the decrement of engine vibration severity and the effect of ignition delay (Torregrosa et al. 2018)(Satsangi and Tiwari 2018). NG addition had also positive effect on noise emission. Compared to NG0, 0,2 dB(A), 0,4 dB(A), and 0,5 dB(A) improvement of SPL were measured with NG addition for NG5, NG10, and NG15, respectively. SPL of the engine was significantly increased by increasing engine

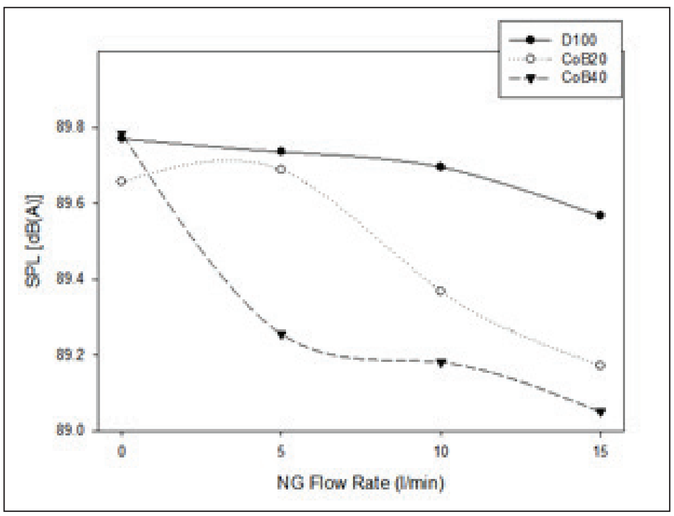

Figure 2. SPL versus NG flow rate at 1200 rpm.

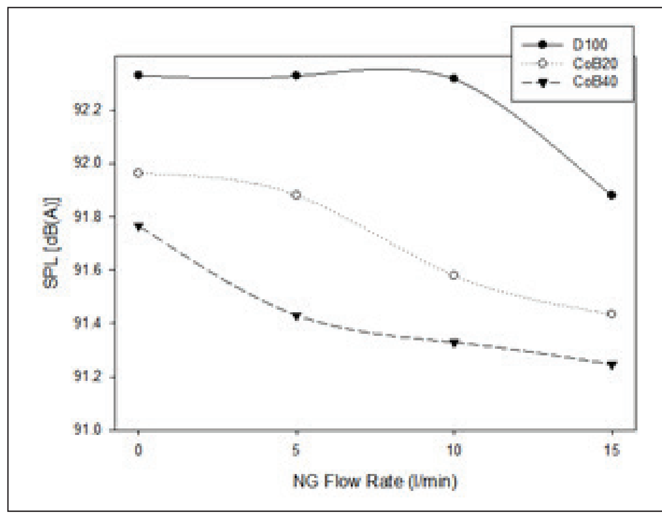

Figure 3. SPL versus NG flow rate at 1500 rpm.

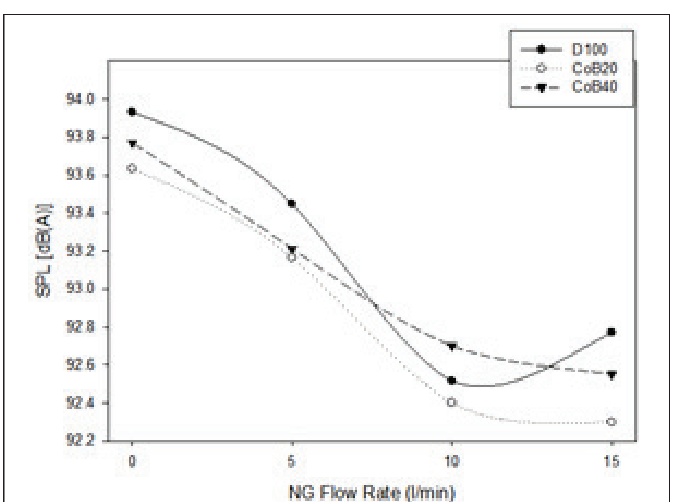

Figure 4. SPL versus NG flow rate at 1800 rpm.

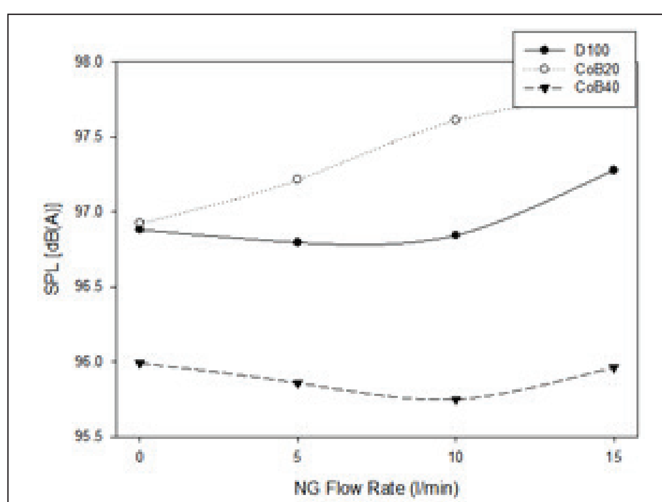

Figure 5. SPL versus NG flow rate at 2100 rpm.

speed. The least SPL occurred by the usage of CoB40 for the engine speed of 1200 rpm, 1500 rpm, 2100 rpm and 2400 rpm. At the engine speed of 1800 rpm, CoB20 caused to least SPL.

Exhaust Emissions

CO emission formation mainly come out due to the incomplete combustion of fuel (Senthur Prabu et al. 2018). Figures 7-11 illustrate the CO emission values for test fuels at different engine operation speeds. The average CO emission for the entire speed range for CoB without any NG addition was found 4,05%, and 7,63% lower than that of D100 for CoB20, CoB40, respectively. Since extra oxygen molecules content of biodiesel, enhanced combustion would occur. Therefore, CO emission was decreased by using biodiesel blend in experiments (Sathish Kumar et al. 2018). Compared to NG0, CO emission ascends to 80,8% with NG15 addition into intake air as overall of all primary fuel. NG5 and NG10 have also increased the emission by 25,2% and 53,7%, respectively. Since intake atmosphere air replaced with NG, less complete combustion may occur with NG introduction to combustion chamber (Arat et al. 2016). Therefore, higher amount of CO emission occurred with NG addition.

CO_2 emission is also occurred by complete combustion of fuel (Sathish Kumar et al. 2018). Biodiesel blends increased CO_2 emissions 1,24%, 5,87%, for CoB fuels for 20%, 40%, volumetric ratio of biodiesel due to the extra oxygen content of biodiesel (Keskin et al. 2010).

On the other hand, introduction of NG into the cylinders, CO_2 emission decreased by 1,4%, 2,9%, and 4,3% with NG5,

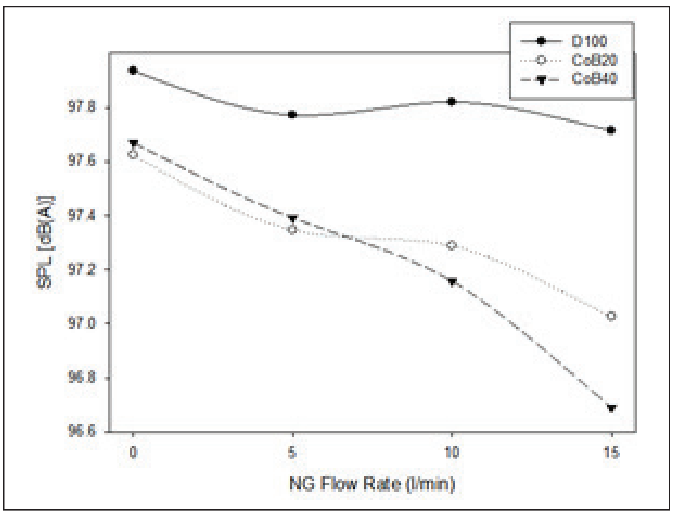

Figure 6. SPL versus NG flow rate at 2400 rpm.

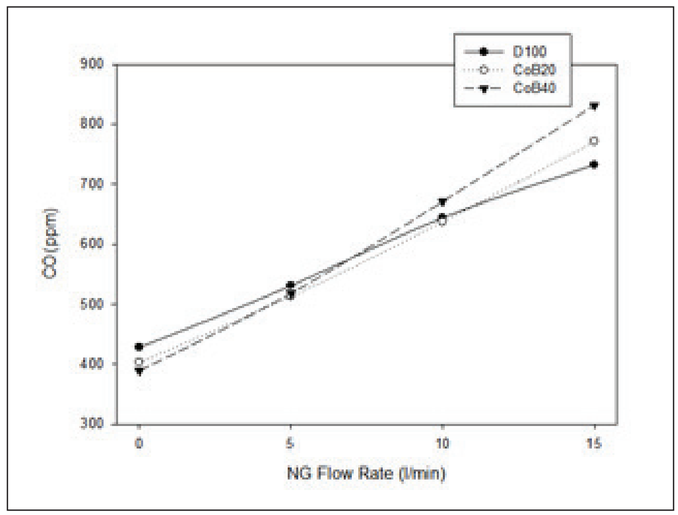

Figure 7. CO emission value at 1200 rpm.

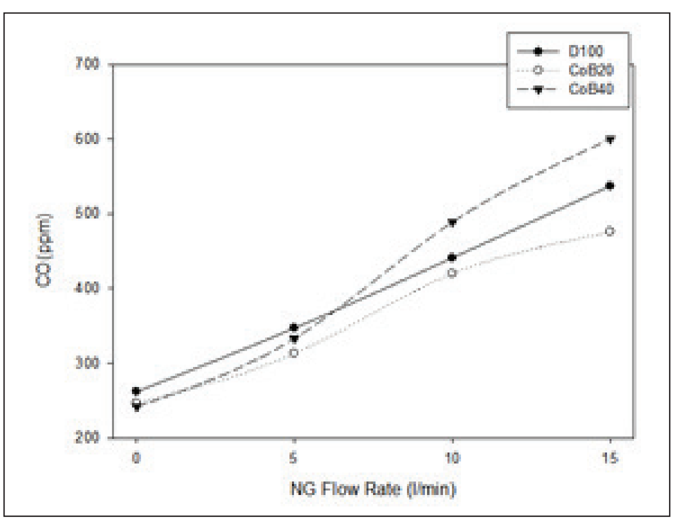

Figure 8. CO emission value at 1500 rpm.

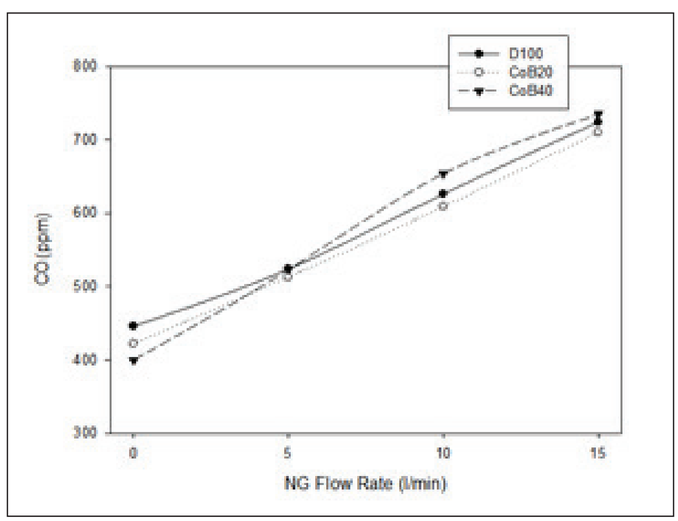

Figure 9. CO emission value at 1800 rpm.

NG10, and NG15 introduction, respectively. This result may be caused by the low hydrogen to carbon ratio of methane which is the major component of NG (Akar et al. 2018). Values of CO_2 emission was presented in Figures 12-16.

NO_x emissions which are the most detrimental pollutant at the combustion stage, primarily effected by higher combustion temperature, longer combustion duration inside the combustion chamber and ample local oxygen (Senthur Prabu et al. 2018)(Arat et al. 2016). Thus, in experiments, addition of 20% and 40% of biodiesel volumetric ratio into LSD fuel increased NO_x emissions 4,08%, 18,00%, respectively due to higher oxygen content of biodiesel (Calder et al. 2018).

Cooling effect of NG into the cylinder leads to decrease in peak temperature. This decrement leads to decrease of NO_x emissions as well (Cheenkachorn et al.2013). Therefore, NO_x emissions also reduced with NG introduction. Compared to NG0; NG5, NG10, and NG15 diminished the value of NO_x by 16,2%, 26,6%, and 33,0%, respectively due to the cooling effect of NG injection into the cylinders. Figures 17-21 show the result of NO_x emissions.

4. Conclusion

In this study, influence of biodiesel which produced from corn oil and NG addition into intake air on noise and exhaust emission of a diesel was investigated. The biodiesel with NG addition has the potential for replacing LSD fuel to fuel the diesel engines in the view point of noise and exhaust emissions.

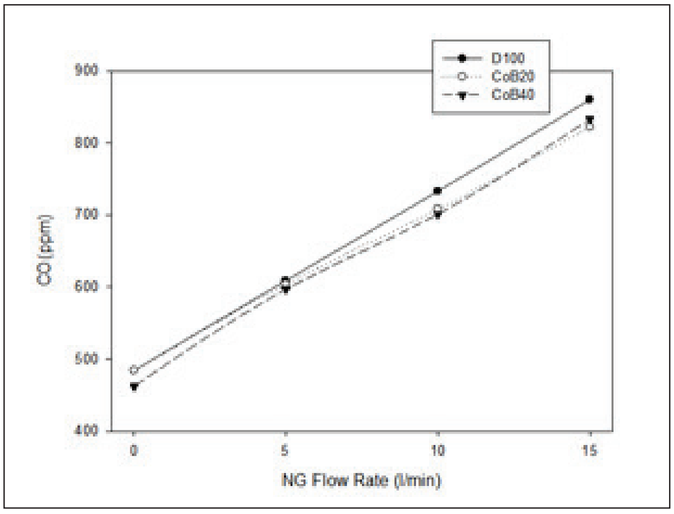

Figure 10. CO emission value at 2100 rpm.

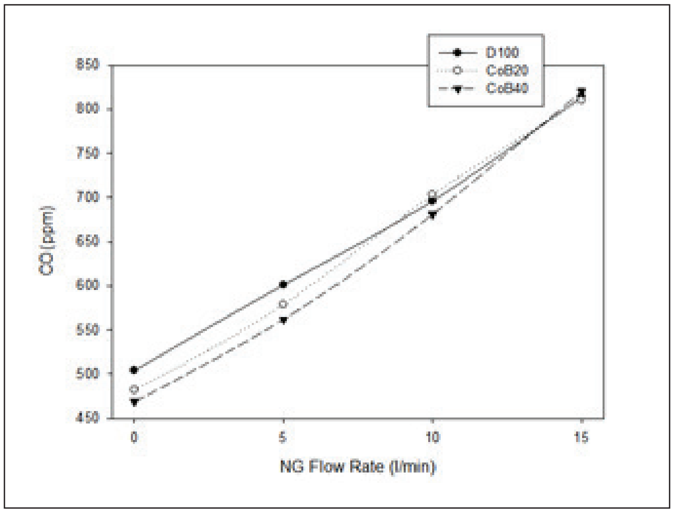

Figure 11. CO emission value at 2400 rpm.

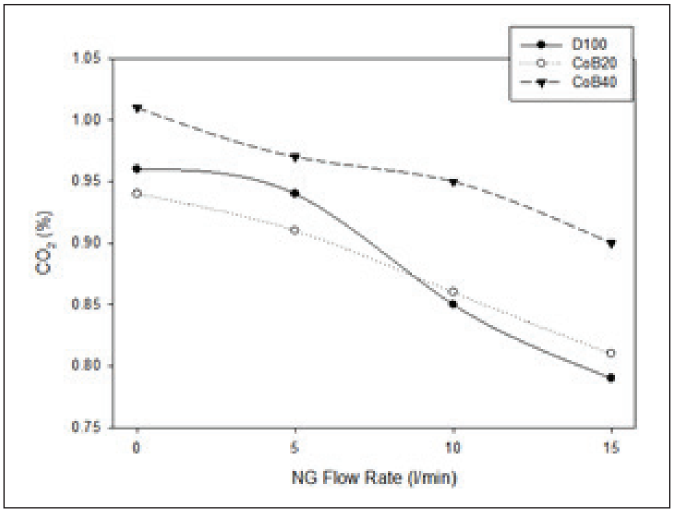

Figure 12. CO_2 emission value at 1200 rpm.

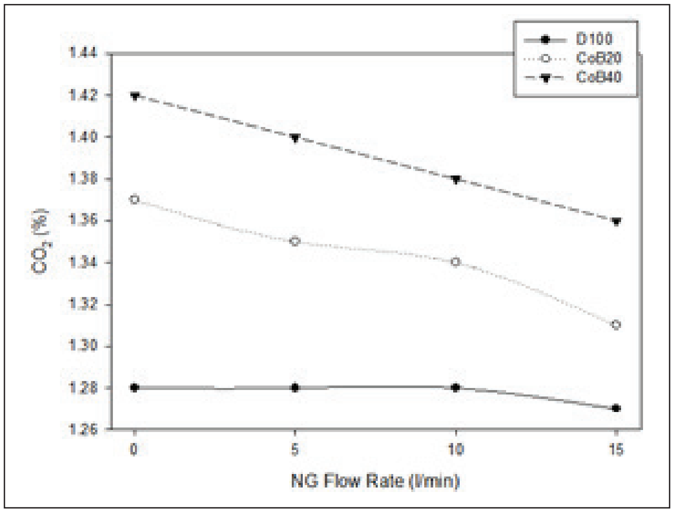

Figure 13. CO_2 emission value at 1500 rpm.

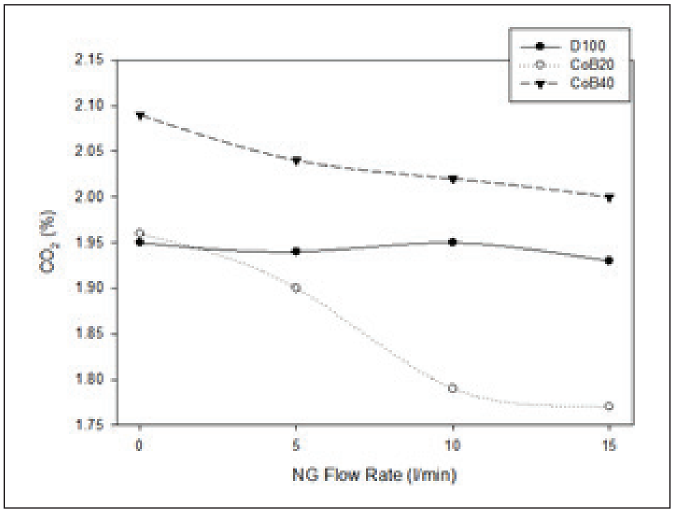

Figure 14. CO_2 emission value at 1800 rpm.

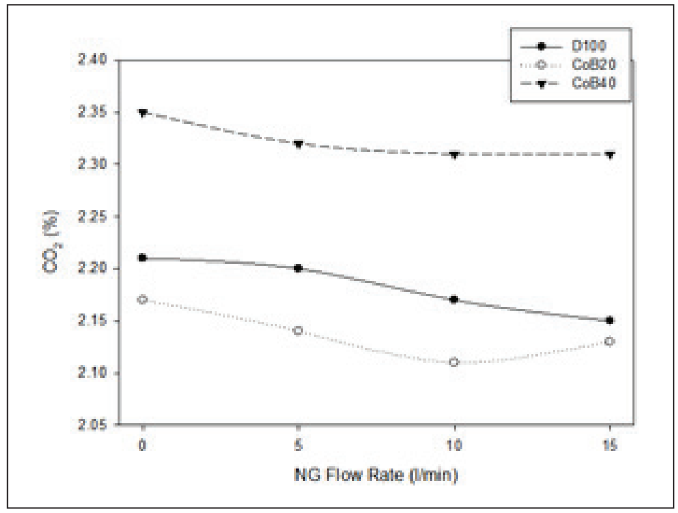

Figure 15. CO_2 emission value at 2100 rpm.

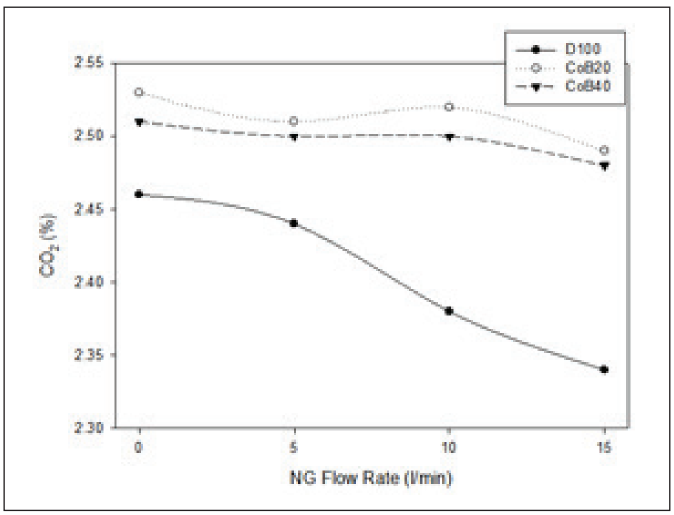

Figure 16. CO_2 emission value at 2400 rpm.

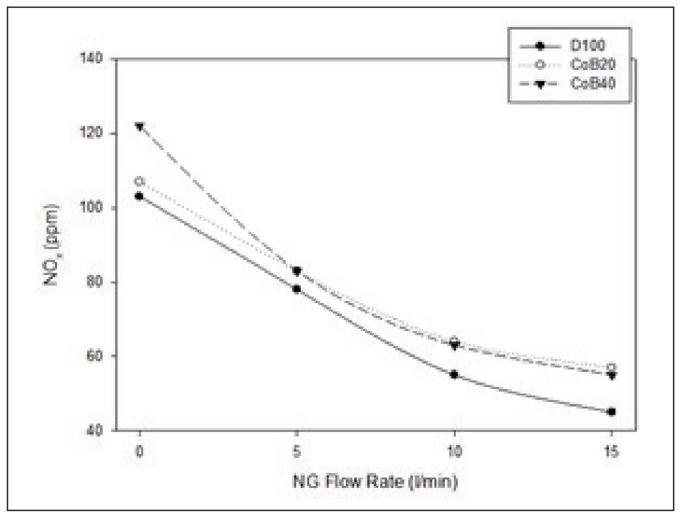

Figure 17. NOx emissions value at 1200 rpm.

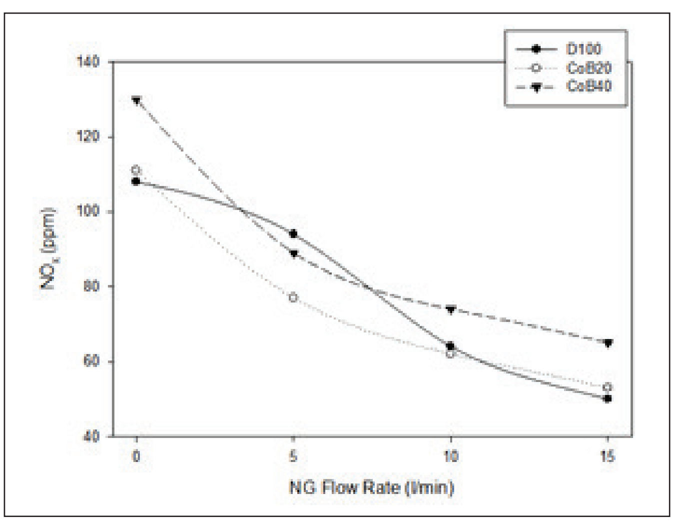

Figure 18. NOx emissions value at 1500 rpm.

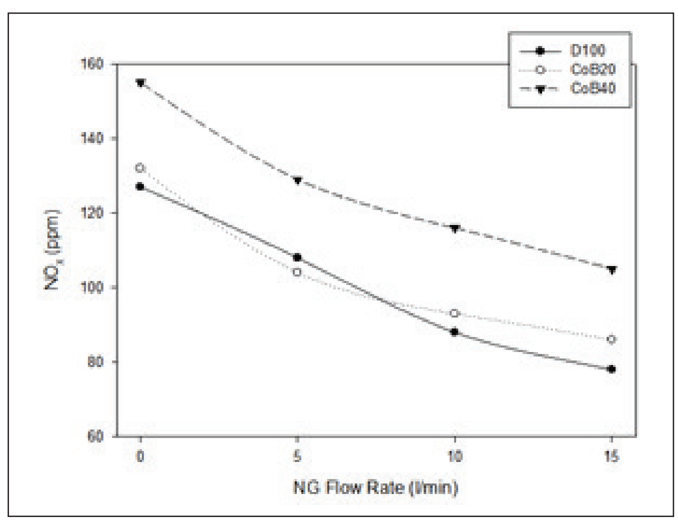

Figure 19. NOx emissions value at 1800 rpm.

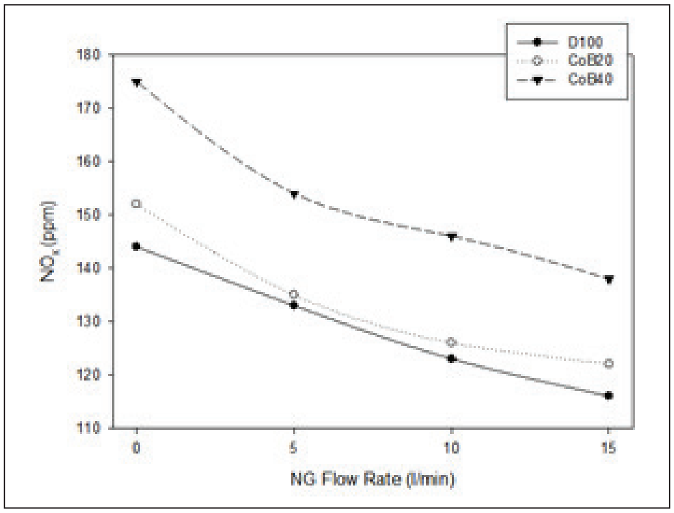

Figure 20. NOx emissions value at 2100 rpm.

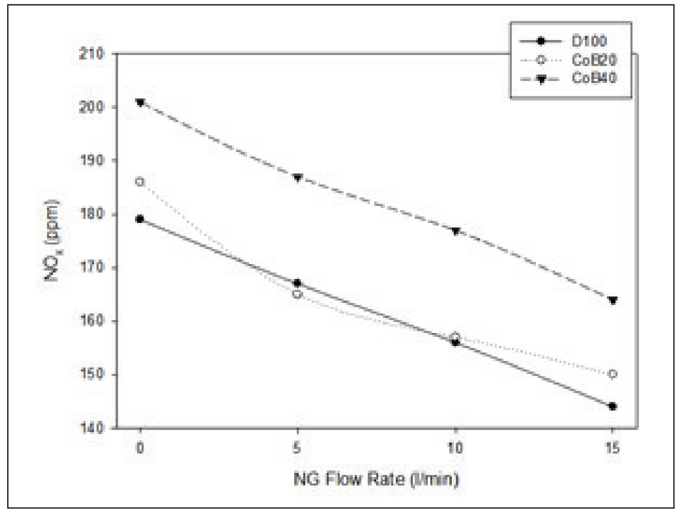

Figure 21. NOx emissions value at 2400 rpm.

Based on the experimental results throughout this study, the following results can be summarized:

- Compared to LSD; 0,2 dB[A], and 0,4 dB[A] decrement of SPL was measured with CoB20, and CoB40, respectively. NG addition lowered the noise emission further as 0,2 dB(A), 0,4 dB(A), 0,5 dB(A) for NG5, NG10, and NG15, respectively when the engine was fuelled with pure low sulphur diesel and biodiesel blends.
- CO exhaust emission improved with the usage of CoB20 and CoB40. However, introduction of NG5, NG10, and NG15 increased the emission by 25,2%, 53,7%, and 80,8%, respectively.
- Increment of CO_2 and NO_x exhaust emissions was observed with the usage of biodiesel blend. However, it was concluded that NG has the potential to compensate the increment of CO_2 emission

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