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THE EFFECT OF DIESEL-ALCOHOL BLENDS ON THE COLD-START COMBUSTION OF A COMPRESSION IGNITION ENGINE

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Abstract: The present work represents an experimental investigation of the effect of blending diesel fuel by alcohol on the cold-start combustion characteristics of the compression ignition engine. The studied characteristics are the CO_2, CO, and HC concentrations in the exhaust gases, in addition to the mixture Air/Fuel ratio, exhaust temperature, and engine noise levels. The experimental work has been carried out using a 4-stroke, single-cylinder compression ignition engine at different blending ratio values. These values are 0%, 10%, 20%, and 30% by volume of alcohol concentration with respect to the total mixture concentration. The engine has been tested under two rotational speeds (1800 and 2000 r.p.m). Two alcohols have been used in the experiments, these are ethanol and methanol. The obtained results showed that blending diesel fuel by alcohol has a positive effect on engine exhaust results during the cold-starting period. And that the results obtained from the ethanol blends are better than those obtained from the corresponding methanol blends. It is shown also that the 10% blending ratio for both ethanol and methanol blends is almost the optimum blending ratio, according to the results.

Keywords: *Compression Ignition, Engine, Cold-Start, Diesel-Alcohol Blend, Ethanol, Methanol*

تأثير مزيج وقود الديزل-الكحول على الإحتراق عند التشغيل البارد لمحرك الإتقاد بالضغط

الخلاصة: يمثل البحث الحالي دراسة عملية لتأثير خلط وقود الديزل بالكحول في خصائص الإشتعال البارد لمحرك الإتقاد بالضغط. الخصائص التي تمت دراستها هي تراكيز كل من ثاني اوكسيد الكاربون وأول اوكسيد الكاربون والهايدروكاربون غير المحترق، بالإضافة الى نسبة الوقد الى الهواء في الخليط المتفاعل ودرجة حرارة العادم ومستوى الضجيج الصادر من المحرك. تم إجراء الإختبارات العملية على محرك اتقاد بالضغط رباعي الشوط، أحادي الإسطوانة وبنسب خلط مختلفة. تراوحت نسب الخلط هذه بين 0%، 10%، 20%، و30% من كمية الكحول مقارنة بالحجم الكلي للخليط. تم اختبار المحرك تحت سرعتي دوران مختلفتين هما (1800 و 2000 دورة في الدقيقة). وكذلك تم فحص نوعين من الكحول هما (أثيل الكحول ومثيل الكحول). النتائج المستحصلة اظهرت أن إضافة الكحول الى وقود الديزل له تأثير ايجابي في تحسين خصائص العادم عند التشغيل البارد للمحرك. كما أن تحسين مواصفات نواتج الإحتراق عند خلط أثيل الكحول مع الديزل كان أكثر منه عند خلط مثيل الكحول مع الديزل. وكذلك أظهرت النتائج أن نسبة الخلط 10% تمثل الحالة الأنسب.

1. Introduction

The engine cold start period is the portion of engine working time during which the engine operates before the coolant temperature raises to a certain temperature, this temperature is about 250K [1]. This takes place when the engine is not working for a long time, in fact, more than eight hours [2]. The main problem with engine cold start is the relatively low temperature of the intake system. This causes lower evaporation rate

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of the fuel, leading to the accumulation of fuel in the different parts of the intake system in the form of liquid films. The subsequent evaporation of these liquid films results in fuel vapour effusion to the engine combustion chamber after the proper injection times. Therefore, the probability of unburned hydrocarbon HC emission from the engine increases during the cold starting periods [3–5]. Hence, two modes of the cold starting time interval are distinguished; firstly the cranking mode, in which fuel rich combustible mixtures are required in order to compensate for the shortage of fuel due to low evaporation rates [1]. Secondly, the engine warm-up mode, during which the engine temperature, and in turn, the coolant temperature increases above 250K. Investigations on engine cold-start and warm-up periods are widely conducted, especially for the last three decades, with exhaust emissions, fuel consumption, and engine performance being the main parameters under investigation. Al-Hasan [6] experimentally investigated the effect of atmospheric temperature on the exhaust emissions and fuel consumption during the engine warm-up period. He found that increasing the atmospheric temperature has a positive effect on the exhaust emissions and warm-up time of the tested engine. This is appeared in increasing the carbon dioxide (CO_2) concentration and decreasing those of the carbon monoxide (CO) and the unburned hydrocarbons (HC). Desantes et, al., [7] conducted a full description of the processes associated with engine ignition using in-cylinder high speed imaging. Laget, Pacaud and Perrin [8] also have used video imaging in addition to regular in-cylinder experimentation, and computational analysis for describing the diesel engine cold start at low compression ratio. The effect of low compression on the diesel engine cold start behavior was the main objective of the work conducted by MacMillan [9]. Bielaczyc, Szczotka, and Woodburn [10] pointed out a noticeable increase in the exhaust emissions and fuel consumption during the cold start period of several spark ignition engines. The same has been described by Yang, Lou, and Tang [11], and Chaichan, Maroon, and Abaas [12] during the early stages of diesel engine combustion. In addition to some numerical models [13–15]. Some offered alternative solutions to resolve the problems associated with engine cold start [3,4,16–18].

Alcohols on the other hand, are being attractive alternate fuels because they can be obtained from a number of sources, both natural and artificial [19]. Hence, with the shortage of the fossil fuel resources, Alcohols represent a good alternative to the classical fuels since it offers both sustainability and lower effects on the environment. Alcohols are being used as fuel blending compounds to improve fuel quality. The addition of small amounts of alcohols, with carbon number greater than one, improves the fuel blend water, tolerance, material compatibility and volatility characteristics. Increasing the alcohol content, increases oxygen content up to a certain concentration and improves the blends knock resistance [20]. Alcohol burns with lower flame temperature and luminosity owing to the decrease of spark temperature inside the cylinder so that the heat loss and NO_x emissions are lowered. Alcohol has high latent heat of vaporization, the latent heat cools the intake air and hence increases the density and volumetric efficiency, however, the oxygen content in alcohol reduces the heating value more than the classical fuel does [21]. Alcohol-blended fuel is going to be more widely used due to the environmental problems concerned with petroleum fuels.

Therefore, the process of blending fuel by alcohol was the basis of a vast number of studies all over the world. Guerrieri and co-workers tested gasoline and gasoline-ethanol blends on six in–use vehicles to determine the effect of ethanol content on emissions and fuel economy [22]. Wang and co-workers compared the exhaust emission from in-use heavy trucks fueled with a biodiesel blend [23]. Hsieh and co-workers investigated the engine performance and emissions of a spark ignition engine using an ethanol-gasoline blends fuel in the ratios of 5%,10%, 20%, and 30% [24]. Yasar experimentally investigated the effect of methanol and butanol addition to gasoline on exhaust emissions and noise level [25].

From all the above, the cold-start and warm-up processes and the associated performance and combustion issues are of great interest to the combustion community especially in the case of the compression ignition engines. On the other hand, blending diesel by alcohols represents one of the solutions offered globally to overcome or minimize the environmental effects of the diesel exhaust products. Hence, exploring the effect of these blends on the engine performance and exhaust emissions during the cold-start and warm-up periods is essential. However, a theoretical description of the exhaust emissions during the cold-start period for engines supplied with alcohol-blended diesel fuel is a relatively complicated problem. This is because the mode of fuel combustion during the cold-start period is not well addressed (whether it is fuel lean or fuel rich combustion). Therefore, the present work offers experimental results of the exhaust emissions in addition to the exhaust temperature and noise levels during the cold-start combustion of the compression ignition engine when it is fed by alcohol-blended diesel fuel.

3. Experimental Work

Figure 1 shows the schematic drawing of the experimental setup. An economic, single-cylinder, four-stroke, air-cooled compression ignition engine has been used for all the experiments. The bore, stroke, and compression ratio of the engine are 8.2 cm, 6.8 cm, and 16 respectively. The engine is connected to a TecQuipment TD114 lab Instruments Unit. This unit is an integration of a hydraulic dynamometer for measuring the engine torque, a tachometer for measuring the engine rotational speed, and a chrome/alumel thermocouple that is connected to the engine exhaust system for measuring the exhaust temperature. All these parameters are displayed and controlled by the control board of the unit that is shown in Figure 1.

The exhaust gas analysis is carried out using a Flux 2000 gas analyzer that is an infrared-microprocessor-based photometer designed to measure the CO, CO_2, HC, O_2, and Air/Fuel ratio by collecting a gas sample from the engine exhaust system. Additionally, a sound level meter is used for measuring the variation in sound levels –in db – during the engine cold start and warm-up. All the experiments have been performed in the combustion lab in the mechanical engineering department / Al-Mustansiryah University.

Two types of alcohols are used in the present work, namely ethyl alcohol and methyl alcohol. These alcohols are mixed with diesel fuel in three proportions (10%, 20%, and

30% of alcohol by volume compared to the overall mixture volume. These proportions are termed up as the blending ratio in the present work. The blending process is applied using a metered glass. The base fuel (diesel fuel) is added to glass first; then, the alcohol (whether ethanol or methanol) is added gradually. The contents are then mixed together by rapid shaking of the glass until a uniform mixture colorless mixture is obtained. This mixture is then added to the fuel tank attached to the engine (which is already empty). Three types of fuel have been used in the experimental work, these fuels are; pure diesel, ethanol-blended diesel, and methanol-blended diesel, at different blending ratios (0%, 10%, 20%, and 30% of alcohol concentration with respect to the overall mixture concentration. The engine has been tested under two rotational speeds (1800 and 2000 rpm). The selected testing times were (0, 5, 10, 15, and 20 minutes after the initial start-up of the engine).

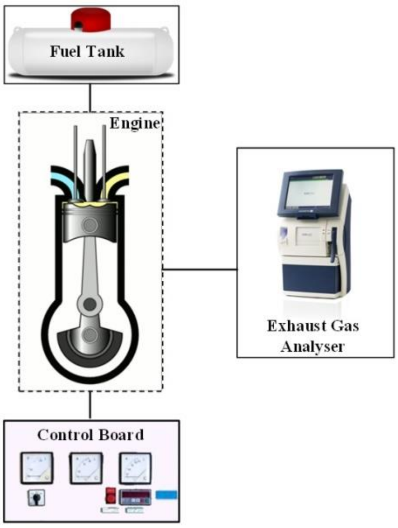

Figure 1: Schematic diagram of the experimental setup.

4. Results and Discussion

The data obtained by the experiments described in section (3) have been curve fitted and then used to construct some graphs that are shown in the coming figures. These figures outline the effect of both blending ratio and warm-up time on the main characteristic parameters of engine performance and exhaust emissions.

Figure 2 shows the variation of carbon dioxide (CO_2), carbon monoxide (CO), and the unburned hydrocarbons (HC) with engine warm-up time for different diesel-ethanol blending ratios. From this figure, it can be seen that at the early time of operation (the first 5 minutes) the CO and HC concentrations show higher values compared to their behaviors in later times. This is exactly the opposite in the case of CO_2 concentration. The behaviors of the three parameters are in agreement with the published literature mentioned and discussed in the introductory section of the present work. It is shown also that the values of each parameter are varied with varying alcohol blending ratio (from 0% to 10%, 20%, and 30%) which infers that fuel blending is also affected during

The engine early start-up times. This fact takes place for all the three emissions parameters.

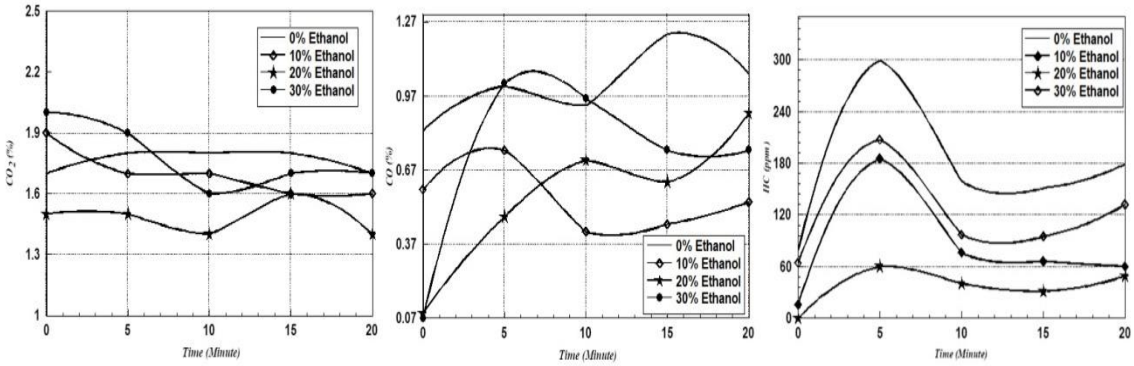

Figure 2: Variation of CO_2, CO, and HC concentrations in the exhaust with the warm-up time for 2000 rpm engine speed and ethanol-blended diesel.

Figure 3 shows the variation of the Air/Fuel ratio, exhaust temperature, and engine noise with engine warm-up time for different diesel-ethanol blends. From this figure, it is shown that at the early time of operation (the first 10 minutes) the behavior of all parameters seems to be arbitrary, then it seems to stabilize at the operating condition after that time. It is shown also that the values of each parameter are varied with varying alcohol blending ratio (from 0% to 10%, 20%, and 30%) which means that fuel-blending is also affected at the early starting time. This fact takes place for all the parameters except exhaust temperature, where varying blending ratio has no effect on exhaust temperature, because the thermo-physical properties of alcohol fuel are almost close to those of the fuels used in internal combustion engines.

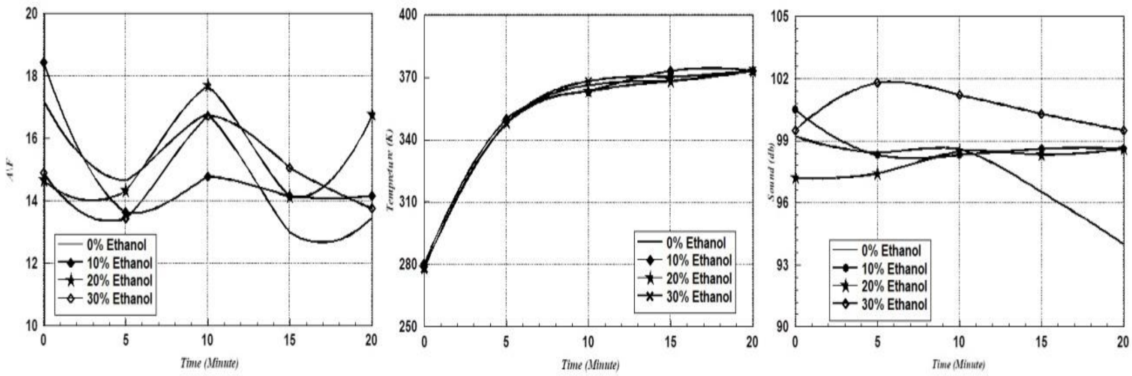

Figure 3: Variation of Air/Fuel ratio, exhaust temperature, and engine noise level with the warm-up time for 2000 rpm engine speed and ethanol-blended diesel.

Furthermore, from both Figure 2 and Figure 3, blending the diesel fuel by ethanol is shown to decrease the CO and HC concentrations of the exhaust emissions during engine cold-start and warm-up periods i.e. increasing combustion efficiency, but at the same time engine noise levels are found to be greater than its level when using pure diesel. Therefore, it could be concluded that blending diesel by ethanol has a positive effect on combustion efficiency and adverse effect on engine noise.

Figure 4 shows the effect of varying engine speed on the CO_2, CO, and HC concentrations in the exhaust gases from the CI engine during cold-start and warm-up operation when the engine is fueled by 10% ethanol-blended light diesel. From this figures, it is shown that increasing engine speed increases both CO_2 and HC concentrations and decreases the CO concentration with respect to the engine warm-up time. This is because of the increased fuel flow rate when increasing engine speed which means that the cylinder receives a fuel-rich mixture, and, therefore, the mass burning rate is increased, which leads to increasing exhaust emissions and temperature.

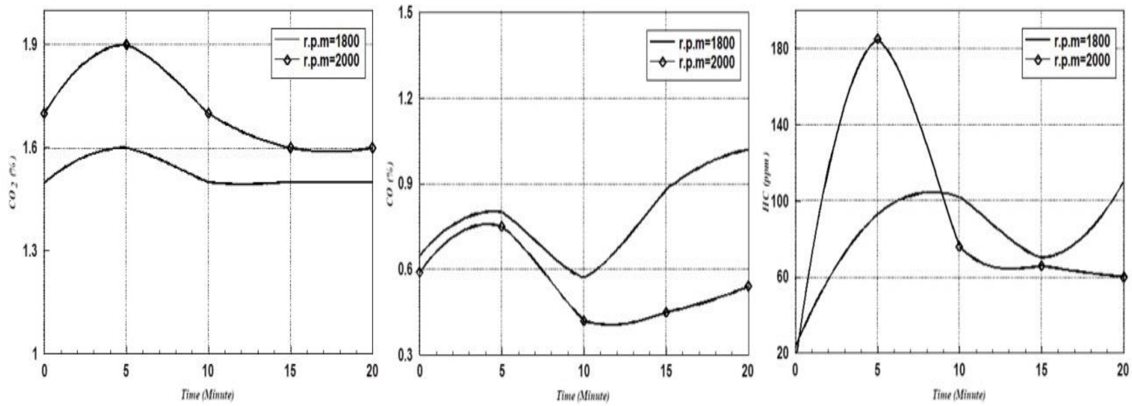

Figure 4: Variation of CO_2, CO, and HC concentrations in the exhaust with the warm-up time for 1800 rpm and 2000 rpm engine speed and (10%) ethanol-blended diesel.

While CO is decreased due to increasing CO_2 which means improving the combustion efficiency since the engine is working at its average operating speed (2000 r.p.m). The same is shown in Figure 5 that represents the effect of varying engine speed on the Air/Fuel ratio, exhaust temperature, and engine noise for the CI engine at cold-start and warm-up operation when the engine is fueled by 10% ethanol-blended light diesel. Where increasing the engine speed led to the increase in engine noise and exhaust temperature.

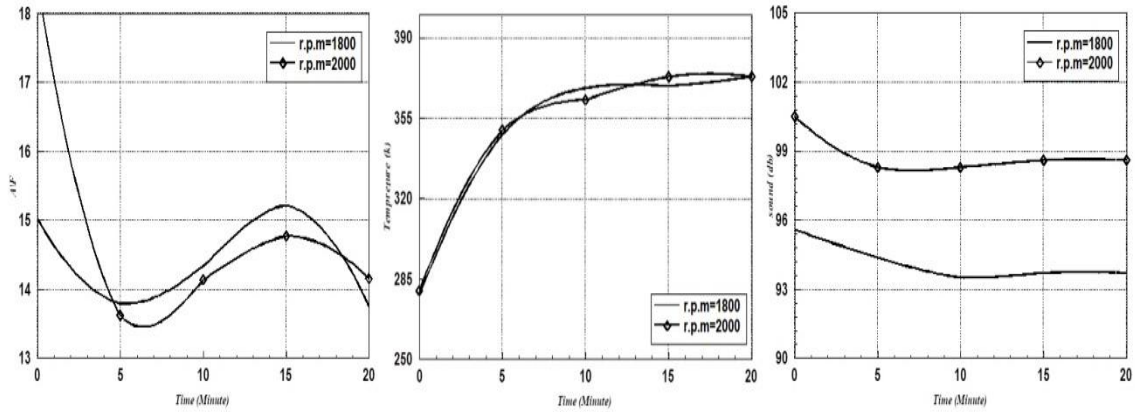

Figure 5: Variation of Air/Fuel ratio, exhaust temperature, and engine noise level with the warm-up time for 1800 rpm and 2000 rpm engine speed and 10% ethanol-blended diesel.

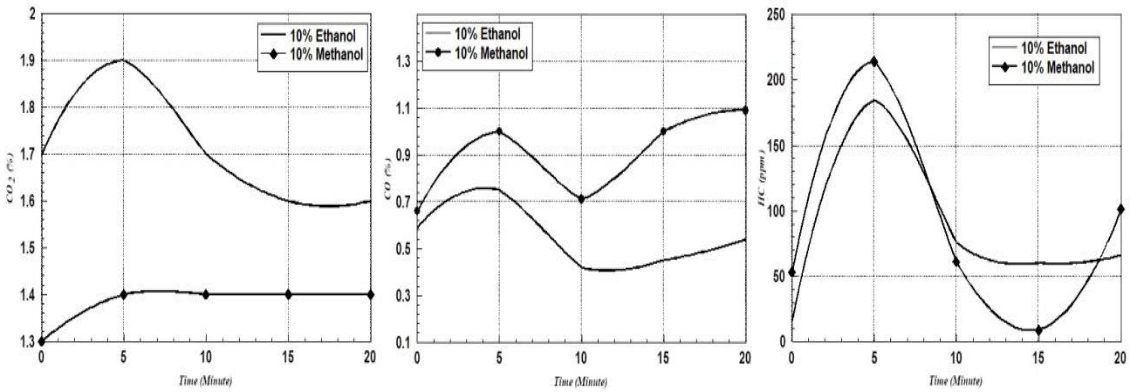

Figure 6: Comparison between blending diesel by ethanol and methanol on the CO_2, CO, and HC concentrations in the exhaust during the engine cold start period.

Figure 6 shows a the effect of alcohol type on the concentrations of the CO_2, CO, and HC respectively in the exhaust from the CI engine during cold start when the blending ratio is 10% alcohol by volume. From the figure, it is shown that ethanol properly gives results better than those corresponding results of methanol, since CO, and HC in the case of ethanol are lower than those corresponding values in the case of methanol. This is shown also in the case of exhaust temperature and engine noise shown in Figure 7. Therefore, it could be concluded that blending diesel by alcohol (either ethanol or methanol) will improve combustion efficiency during engine cold-starting time of a compression ignition engine. It is noticed also, that ethanol addition has better exhaust characteristics than methanol addition, due to the low CO and HC emissions of ethanol-blended diesel compared with those of the methanol-blended diesel, but methanol has better noise decrease ability than ethanol.

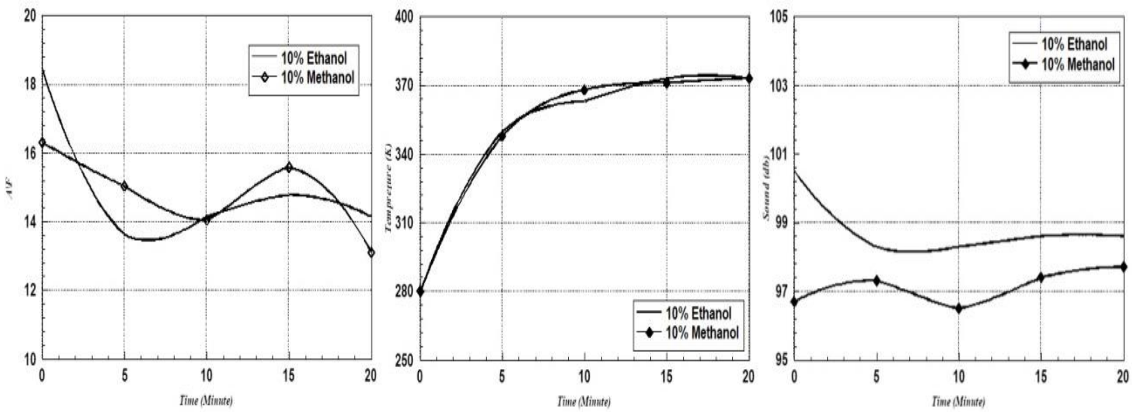

Figure 7: Comparison between blending diesel by ethanol and methanol on the Air/Fuel ratio, exhaust temperature, and engine noise level during the engine cold start period.

5. Conclusions

In the present work, an experimental investigation of the effect of blending the diesel fuel by ethanol and methanol in different proportions on the cold start characteristics of the compression ignition engine has been performed. The following points represent the main conclusions:

1. At the early time of operation the CO and HC concentrations show higher values compared to their behaviors in later times. This is exactly the opposite in the case of CO_2 concentration. The behaviors of the three parameters are in agreement with the published literature.
2. The values of CO, CO_2, and HC concentration during the cold-start period when the engine is fueled with the alcohol-blended diesel are responsive to the change in blending ratio.
3. The exhaust temperature is shown to be irresponsive to the change in blending ratio. This is because the thermo-physical properties of alcohol fuel are almost close to those of the fuels used in internal combustion engines.
4. A slightly arbitrary behavior in the trend of all the studied parameter is shown to occur in the early time of engine operation (the first 10 minutes).
5. Blending the diesel fuel by ethanol is shown to decrease the CO and HC concentrations of the exhaust emissions during engine cold-start and warm-up periods i.e. increasing combustion efficiency, but at the same time engine noise levels are found to be greater than its level when using pure diesel. Therefore, it could be concluded that blending diesel by ethanol has a positive effect on combustion efficiency and adverse effect on engine noise.
6. The ethanol properly gives results better than those corresponding results of methanol.
7. Blending diesel by alcohol (either ethanol or methanol) will improve combustion efficiency during engine cold-starting time of a compression ignition engine.
8. Ethanol addition has better exhaust characteristics than methanol addition, due to the low CO and HC emissions of ethanol-blended diesel compared with those of the methanol-blended diesel, but methanol has better noise decrease ability than ethanol.

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