Preheating of Biodiesel for the Improvement of the Performance Characteristics of Di Engine: A Review

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Abstract— As an alternative fuel for compression ignition engines, biodiesels are the principle renewable and carbon neutral sources. The causes of technical problems arising from the use of various biodiesel are the high Surface Tension and the high viscosity. In case of the CI engine, high Surface Tension and viscosity attains improper homogeneity in charge and fuel atomization .This reduces the overall efficiency of the engine. Transesterification, pyrolysis are the processes generally performed in order to reduce the viscosity of biodiesel but still it is higher to that of the diesel. Thus preheating is the technique to decrease viscosity of the biodiesel. The preheating of biodiesel at different temperature as at 60°C, 90°C, 120°C, 150°C reduces the viscosity and surface tension which enhances better fuel injection and there by better fuel atomization. To increase the fraction of biodiesel in blends, it is required to reduce the viscosity by preheating. Preheating of biodiesel can be made in recupretors by using the exhaust gases' special arrangement of recupretor and exhaust manifold are made for preheating. The preheating of biodiesel results in complete combustion of the biodiesel or fuel that results in decreased in amount of carbon dioxide ,carbon monoxide and particulate exhaust emission is also complete combustion of biodiesel and more cleaner exhaust can be obtained while elevated temperature of the fuel increases NOx emissions.

Keywords: WFO-Waste frying oil, COME-Cottonseed methyl ester, DF-Diesel Fuel.

1. INTRODUCTION

Industrial development and economy of any country mainly depends on its energy resources. Petroleum energy resources is one of those energy resources .The depletion diesel and their inherent environmental concerns has led to the pursuit of renewable biodiesel. Biomass sources, particularly biodiesel, have attracted much attention as an alternative energy source. They are renewable, non-toxic and can be produced locally from agriculture and plant resources. Their utilization is not associated with adverse effects on the environment because they emit less harmful emissions and green house gases [1]. Biodiesel, a form of biomass particularly produced from vegetables oils has recently been considered as the best candidate for a diesel fuel substitution. Biodiesel is a clean renewable fuel, simple to use, biodegradable, nontoxic, and essentially free of sulfur. It can be used in any compression ignition engine without the need for modification .Also usage of biodiesel will allow a balance to be sought between agriculture, economic development. Researchers have evaluated the use of sunflower, jetropha oil, rice bran oil, soyabean, cotton seed, rapeseed and orange oils as potential renewable fuel source.

The use of the biodiesel is being restricted due to variation of its injection, ignition and emission characteristics from that of the diesel. The direct use of vegetable oils is generally considered to be unsatisfactory and impractical for diesel engines. The high viscosity ,density of vegetable oil interferes with the injection process and leads to poor fuel atomization .This results in inefficient mixing of fuel with air contributes to incomplete combustion, carbonization of injector tip, poor cold engine start up ,misfire and ignition delay period. It is therefore unsuitable to use straight vegetable oils in diesel engines .To overcome these problems caused by the high viscosity of vegetable oils, a number of techniques have been used. These includes vegetable oil/diesel blends, preheating the vegetable oil, vegetable oil.

Lot of research works were conducted to examine the engine performance and exhaust emissions using preheated vegetable oils. Barsic et al.[7] have indicated that it is essentialto preheat the vegetable oil to 70–90^{0}C to resolve the fuel filter clogging problem. Ryanand his co-workers [8] have specified a fuel inlet temperature requirement of 140^{0}C for acceptable viscosity for using vegetable as fuel for both direct injection and indirect injection engines. It was reported that heating the vegetable oils to 140^0 C would (i) reduce the viscosity to near that of diesel at 40^0 C, (ii) increase the cetane rating, (iii) improve the spray characteristics by increasing the penetration rate accompanied by a decrease in cone angle. Bari et al. have showed that preheating of crude palm to 60^{0}C is essential to lower its viscosity, ensure smooth flow and to avoid fuel filter clogging. It was also indicated that the injection system was not affected even by heating to 100^{0}C.

2. LITERATURE REVIEW

The use of the biodiesel is being restricted due to variation of its injection, ignition and emission characteristics from that of the diesel. The direct use of vegetable oils is generally considered to be unsatisfactory and impractical for diesel engines. The high viscosity, density of vegetable oil interferes with the injection process and leads to poor fuel atomization .During previous studies, biodiesel used with different blend of diesel. These blends without any prior processing found insufficient to decrease the viscosity of biodiesel. Therefore injection related problems were remained unsolved.

The studies were carried on transesterification process, which decreases effect on the viscosity of vegetable oil, biodiesel still has higher viscosity and density when compared with diesel fuel. The viscosity of fuels has important effects on fuel droplet formation, atomization, vaporization and fuel–air mixing process, thus influencing the exhaust emissions and performance parameters of the engine. The higher viscosity of biodiesel compared to diesel limits the use of complete biodiesel and biodiesel blends in the I.C. engine. It was found that the higher viscosity has effect on combustion and proper mixing of fuel with air in the combustion chamber. It avoids the proper atomization, fuel vaporization and ignition. Transesterification process reduced viscosity of biodiesel but still it was much higher compared to the diesel.

Investigations have shown that B20 blend has good performance and emission characteristics on CI engines. Thus it is preheated at different temperature as at 30°C, 60°C, 90°C, and 120°C. Further increase of biodiesel fraction in the blends will increase the viscosity and decrease performance. To increase the fraction of biodiesel in blends, it is required to reduce the viscosity by preheating. Preheating of biodiesel is the easy, less economical and efficient way for mentioned problem evaluation. The preheating of the vegetable oil improves the injection characteristics by decreasing the kinematic viscosity, surface tension and the density of biodiesel.

3. PREHEATING OF BIODIESEL

Preheating process involves heating of biodiesel before injecting it into combustion cylinder. Biodiesel can be preheated at different temperature of, 60°C, 90°C, 120°C, and 150°C. But the case study on preheating temperature have found that preheating temperature for biodiesel should be 90°C to meet above mentioned characteristic requirement. Heat exchangers can be used to preheat the biodiesel. Fig.1 shows a heat exchanger in which hot exhaust gases from engine are circulated around the fuel flowing tubes .These gases can increase the temperature of fuel flowing through tubes or heating coils can be used to preheat.

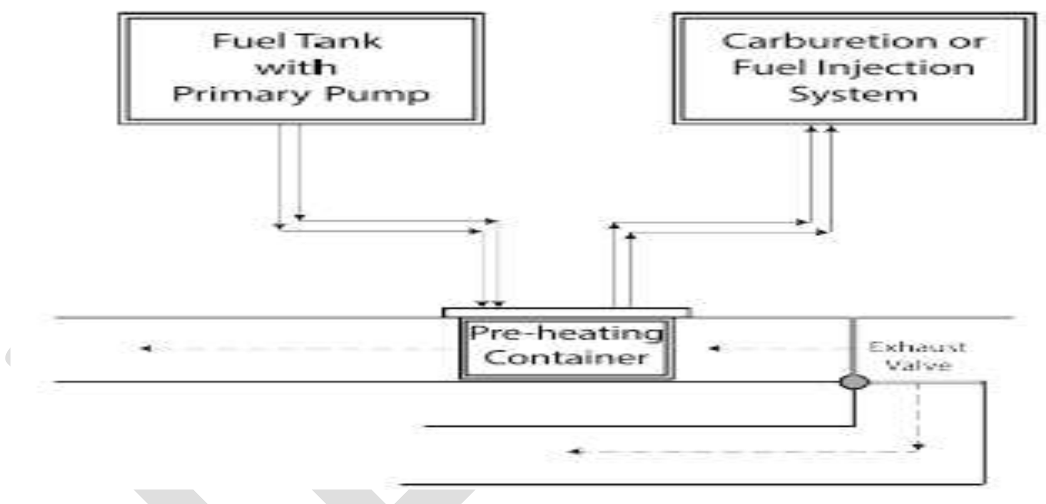

Fig.1 Preheating setup

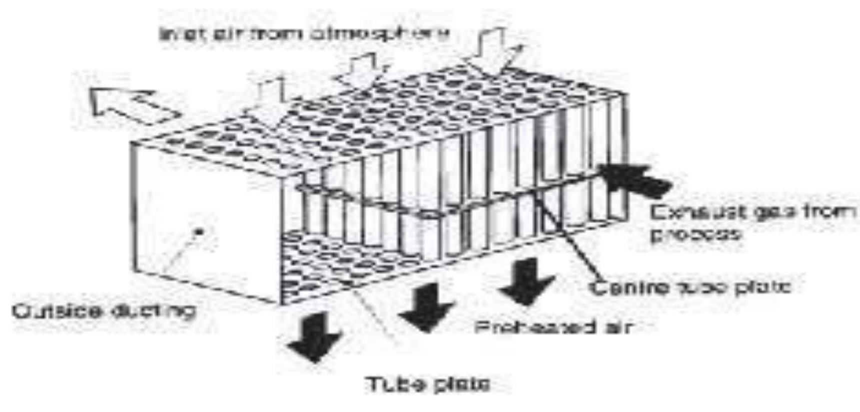

Fig.2 Recupretor for heat transfer

Fig. 1: Block Diagram of system setup consists of a fuel line that connects the already existing fuel tank to a pre-heating container. The container is designed to hold a volume depending in the size of the exhaust manifold. A recupretor consisting of copper tubes. These copper tubes carries fuel and hot exhaust gases through manifold are passed over these copper tubes. Thus heat is transferred to the fuel flowing inside the tubes. This container is placed within the manifold such that it receives heat directly from the exhaust gases. *A Fuel Line* The material used for the fuel line could be reinforced rubber flex pipe as it can withstand high pressures of up to 6Mpa and temperatures of around 250°C.

3.1 PRE-HEATING CONTAINER

The Preheating container should be made of a material that is a good heat conductor, able to withstand temperatures up to 1200°C [2] without undergoing any chemical change and any considerable change in physical properties. That is the material should have a

- Low specific heat capacity.
- Low Thermal expansion coefficient.
- Inert chemical property.
- The volume of the preheating chamber is assumed to be such that it fits snugly into the exhaust manifold.

3.2 EXHAUST MANIFOLD CHANGES

The exhaust manifold, in order to house the pre-heating container will have to undergo changes as well. The exhaust manifold is electronically operated [3] and its operation depends on the temperature in the pre-heating container. When required temperature is attained a valve cut of the supply of exhaust gases.

Fig. 3: Block diagram of fuel flow

3.3 FUEL PASSAGE DIVERSION

In our setup, from the fuel tank, the fuel is transported via the fuel line the fuel line is designed to handle high pressure of the fuel coming from the primary pump in the fuel tank. The line feeds the fuel into the pre-heating container.

3.4 HEATING MECHANISM

The fuel in the pre-heating chamber is heated using the exhaust gases. The flow of these exhaust gas is controlled with the help of an electronically controlled bypass valve. When the engine starts, the valve allows exhaust gases to come in contact with the pre-heating container. Once the required temperature is attainted, the valve automatically get switch off such that the exhaust gas supply get cut off in order to maintain constant temperature of fuel, when the temperature drops below the necessary value, the valve get switch on to restart heating process. this biodiesel with elevated temperature then flows through secondary fuel pipe made of the same material to the fuel injection mechanism, at this point the fuel is both pressurised and at an elevated temperature.

3.5 FUEL INJECTION

Once the fuel reaches the fuel injection system, the heated fuel is injected into the engine cylinder. Due to the high temperature, the droplet size and viscosity of the injected biodiesel is drastically reduced as compared to a conventional system. This has great consequences on combustion properties as stated ahead.

4. INJECTION, IGNITION AND EMISSION CHARACTERISTICS.

4.1 FUEL INJECTION

Fuel injection is process of injecting fuel at very high pressure (up to 200 Mpa) through a small orifice or multiple orifices in the injection nozzle into the combustion chamber that contains air that has been compressed to high pressure and temperature. This injection process is characterized by atomization. As atomized fuel droplets go through a process of heating and evaporation due to heat transfer from the hot cylinder. The evaporation process leads to a disappearance of the small droplets and rapid mixing of the vaporized fuel with the air resulting in the formation of a very fuel-rich mixture at the tip of the fuel jets. If the fuel jet penetrates too far, the fuel interacts with the wall, resulting in degraded mixing, low temperature combustion on the walls and high unburned hydrocarbon, NOx and smoke emissions. If the fuel vaporizes and mixes too close to the nozzle, the mixture will be overly rich, leading to high unburned hydrocarbons and smoke emissions. The fuel properties that have the greatest effect on injection include viscosity, density, and surface tension. Fuel injection is mainly characterized by atomization.

4.1.1 Kinematic Viscosity

Viscosity is a measure of the internal fluid friction of fuel to flow, which opposes any dynamic change in the fluid motion. Viscosity, a measure of the fuel's resistance to flow, impacts the fuel spray characteristics through flow resistance inside the injection system and in the nozzle holes. Higher viscosity generally results in reduced flow rates for equal injection pressure and degraded atomization. Fuels with high viscosity tend to form larger droplets on injection which can cause poor combustion, increased exhaust smoke and emissions. Fuels with low viscosity may not able to supply sufficient fuel to fill the pumping chamber, and again this effect will be a loss in engine power.

Murat Karabektas [16] reported that the specific gravity and kinematic viscosity of the cottonseed oil Methyl Ester (COME) gradually decrease with the increase in the preheating temperature. It is seen that the kinematic viscosity is 6.54 cSt at 30^0C and decreases gradually to 1.26 cSt at 120^0C. Additionally, the specific gravity decreases from 0.882 at 30^0C to 0.851 at 120^0C.

	DIESEL	**JATROPA OIL**	**COTTON SEED OIL**	**RICE BRAN OIL**
1.Kinematic viscosity (cSt)	**2.25**	**Without Preheat 35.9**	**Without Preheat 5.49**	**Without Preheat 5.49**
		After Preheat At 120^0 C 5.82	**After Preheat At 120^0 C 1.26**	**After Preheat At 120^0C 1.26**
2.Cetane number	**48**	**52**	**- - - - -**	**56.2**
3.Densitygm/cc	**0.82**	**0.88**	**0.82**	**0.78**

Table 4.1 Properties of various oils

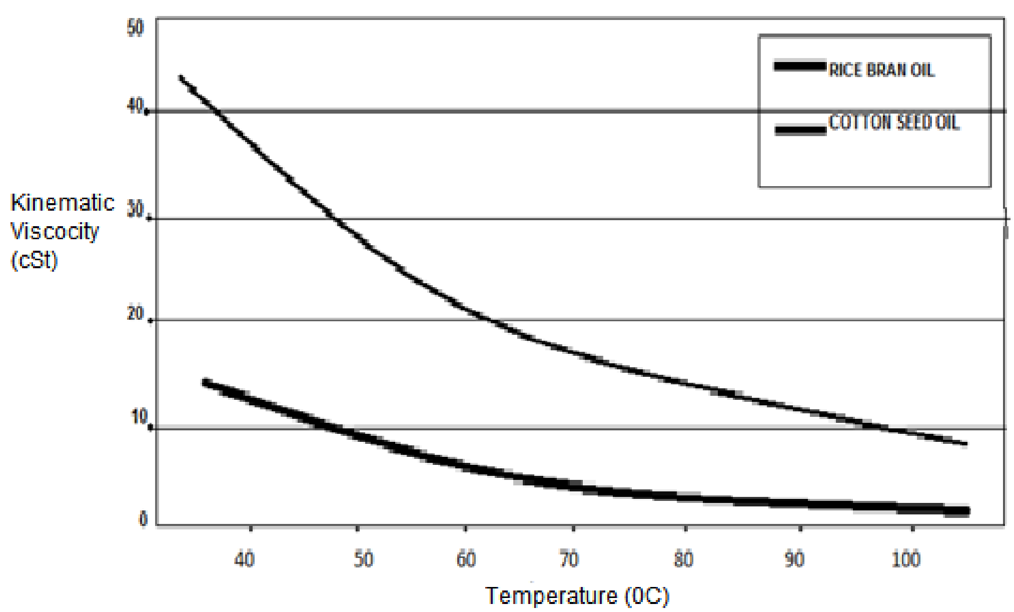

Fig. 4.2 Viscosity Vs Temperature for rice bran oil and cotton seed oil [6]

4.1.2 Density

Increased density tends to degrade atomization rates. Fuel density has importance in diesel engine performance as it affects pump and pipeline design. However, most importantly, they have a significant effect on the atomization quality of the spray injectors, with subsequent impacts on the efficiency of the combustion and emissions. All diesel injection systems meter the fuel on a volume basis, so that fuel density affects the mass of fuel injected. Increased density beyond specification results in higher than designed fuel injection rates due to the direct relationship between mass, volume and density.

4.1.3 Surface tension

Surface tension or the tendency of the fuel to adhere to itself at the fuel-air interface, affects the tendency of the fuel to form drops at the jet-air interface. The surface tension of the liquid is a property that allows it to resist an external force. The relatively high surface tension of bio-oil presumably results from the high amount of water which has a high surface tension due to its strong hydrogen bonding. For bio-oils, surface tension values of 28–40 MN/m at room temperature have been measured. Greater surface tension causes more shearing between fuel molecules and thus poor atomization will occur.

4.1.4 Atomization

The high-pressure injection process results in a breakup of the fuel injection jets into small droplets due to the shear forces induced between the high velocity jets and the relatively air in the combustion chamber. This process is known as atomization. In this process fuel is split up into small droplets for spray atomization is typically characterized by the ratio of fluid volume to surface area in a given spray. Atomization includes spray properties affected like droplet size, degree of mixing, penetration and evaporation. The change in any of these properties might be lead to different relative duration of premixed and diffusive combustion regimes.

The droplet distribution (also called "dispersion") is a parameter which describes the distribution of the droplets in a spray volume. It mainly depends on the characteristics of the properties of the fuel being injected .Fuel properties such as density, viscosity and surface tension. But in case of biodiesels these fuel properties are found to be higher than that of the diesel. This affects the atomization of biodiesel .Thus preheating of biodiesel at about 90°C decreases the viscosity nearer to diesel and thereby improves atomization.

A well-formed droplet distribution (atomization) promotes fuel evaporation, flame stability, and improves fuel combustion and reduces emissions. Droplets Should be small in order to ensure complete carbon burnout and proper flame Shape and length in existing burners, while large spray droplets may cause incomplete Combustion, soot (smoke) formation etc.

4.1.5 Cloud Point

The key flow property for winter fuel specification is a cloud point. Cloud point is the temperature at which wax (crystal) formation of the fuel particles might begin. Below the cloud point, these crystals might plug filters or drop to the bottom of a storage tank. Cloud point is the most widely used and most conservative estimate of the low temperature operability limit. However, fuels can usually be pumped at temperatures below the cloud point. It is measured as the temperature of first formation of wax (crystal) as the fuel is cooled. Cloud point is a measure of the fuel gelling point at which the fuel can no longer pumped.

The cloud point of biodiesel creates ignition problem called' ignition delay' in winter season and in cold countries. Preheating of biodiesel will melt the waxy crystals formed during cold season or in the cold countries and will decrease the ignition delay time .Thus it minimizes the excess delay time taken by the fuel and thereby improves the ignition characteristic associated with biodiesel.

5. EXPERIMENTAL WORK OVER PREHEATED BIODIESELS

Dhinagar et al [13] tested neem oil, rice bran oil and karanji oil on a low heat rejection engine. An electric heater was used to heat the oil. The exhaust gas was also utilized for heating the oil. Without heating, 1–4% lower efficiency was reported compared to that of diesel. However, with heating, the efficiency was improved. Silvico et al [12] used heated palm oil as the fuel in a diesel generator. Studies revealed that exhaust gas temperature and specific fuel consumption were increased with an increase in charge percentage. The carbon monoxide emission was increased with the increase of load. Unburned HC emissions were lower at higher loads, but tended to increase at higher loads. This was due to a lack of oxygen resulting from the operation at higher equivalence ratios. Palm oil NOx emissions were lower as compared to the diesel fuel. They also reported that a diesel generator can be adapted to run with heated palm oil and would give better performance.

Masjuki et al [10] used preheated palm oil to run a compression ignition engine. Preheating reduced the viscosity of fuel and hence better spray and atomization characteristics were obtained. Torque, brake power, specific fuel consumption, exhaust emission and brake thermal efficiency were found to be comparable to that of diesel.

6. EMISSION

Diesel engines are assumed as a good alternative to gasoline engines because they produce lower amount of emissions. On the other hand, higher emissions of oxides of nitrogen (NOx) and particulate matter (PM) have been noticed as major problems. Although, major constituents of diesel exhaust include carbon dioxide (CO2), water vapor (H_2O), nitrogen (N_2), and oxygen (O_2); carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NOx), and particulate matter (PM) are present in smaller but environmentally significant quantities. In modern diesel engines, first four species normally consist of more than 99% exhaust, while last four (the harmful pollutants) account for less than 1% exhaust. NOx comprise of nitric oxide (NO) and nitrogen dioxide (NO_2) and both are considered to be deleterious to humans as well as environmental health. NO_2 is considered to be more toxic than NO. It affects human health directly and is precursor to ozone formation, which is mainly responsible for smog formation.

6.1 CO EMISSION

The increasing trend of CO emissions is due to increase in volumetric fuel consumption and knock with the engine power output. The formation of CO emission mainly depends upon the physical and chemical properties of the fuel used. It is observed that, the CO emission of biodiesel is less than that of diesel fuel. The decrease in CO emission for biodiesel is attributed to the high cetane number and the presence of oxygen in the molecular structure of the biodiesel. Also, the CO emission levels are further reduced for preheated biodiesel and the reason is attributed to its reduced viscosity, density, and increase in rate of evaporation due to preheating. The decreasing CO emission is more when preheating temperature is increased from 75°C to 90°C.

M. Pugazhvadivu et al [11] found the maximum CO emission was 0.22% and 0.77% with diesel and Waste frying oil WFO (without preheating) respectively. The CO emission was decreased with preheating due to the improvement in spray characteristics and better air-fuel mixing. The maximum CO emission was 0.58% and 0.48%, respectively, with WFO (750^0C) and WFO (135^0C), respectively.

Hanbey Hazar et al [15] found that CO emission was decreased for all test fuels with preheating due to the improvement in spray characteristics and better air–fuel mixing. When rapeseed oil preheated, CO emissions were decreased by 20.59%, 16.67% and 25.86% for DF, B20 and B50, respectively.

Murat Karabektas et al [16] reported that the CO emissions arisen from incomplete combustion is decreased by applying preheating to the fuel. CO emissions obtained with COME operations were on averages of 14.40–45.66% lower than those with diesel fuel operations.

6.2 CO_2 EMISSIONS

The increasing trend of CO_2 emissions is due to increase in volumetric fuel consumption. It is observed that, the CO_2 emission of biodiesel is less than that of diesel fuel. This is attributed to the presence of oxygen and high cetane number of biodiesel. However, the CO_2 emission levels are lowered preheated and the reason is attributed to more fuel consumption caused by high temperature and improved combustion.

6.3 NOX EMISSIONS

The NOx emissions against increasing preheating temperature of biodiesel blends are plotted in the Fig.6. Results show that blends 20, 40 at preheating temperature 60°C, 75°C, 90°C the increased NOx emission. This shows that the formation of NOx is very sensitive to temperature and it increases with increase in the preheating temperature of biodiesel. This is because preheated fuel premixes more rapidly with oxygen molecules present in air. Resulting in the formation of increased NOx emissions. NOx emission is more when preheating temperature is increased from 75°C to 90°C This is the disadvantage of preheating biodiesel which can further be reduced using EGR technique.

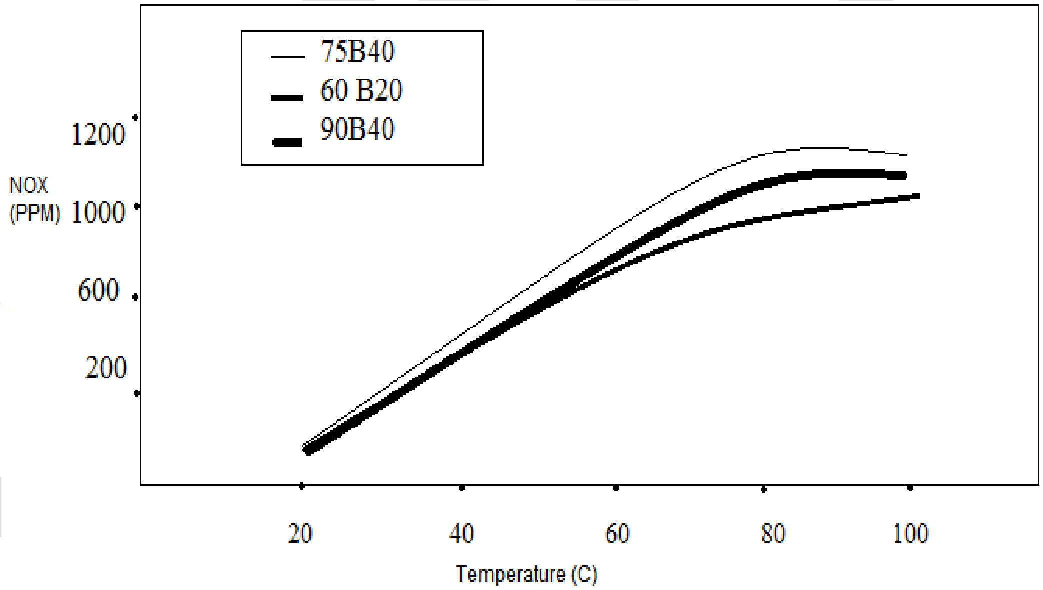

Fig.6 Preheated biodiesel temperature (^{0}C)

Hanbey Hazar et al [15] found that NOx emission increases with the increase in the fuel inlet temperature preheated rapeseed oil (RRO). The average NOx emission was increased by 19%, 18% and 15% using DF, O20 and O50, respectively. The increase in NOx with preheating emission may be attributed to the increase in the combustion gas temperature with an increase in fuel inlet temperature.

It is seen that the maximum NOx emission was 44% lower for Waste frying oil WFO (without preheating) compared to diesel. It was found that the NOx emission was increased with the increase in the fuel inlet temperature. The maximum NOx emission was increased by 23% and 25% using WFO (75^0C) and WFO (135^0C) respectively compared to WFO (without preheating). The increase in NOx with preheating emission may be attributed to the increase in the combustion gas temperature with an increase in fuel inlet temperature However the NOx emissions were 26% and 28% lower, respectively, using WFO (75°C) and WFO (135°C) compared with that of diesel.

6.4 SMOKE EMISSION

M. Pugazhvadivu reported that the smoke emission for WFO (without preheating) was significantly higher than diesel. This may be due to the higher viscosity and poor volatility of WFO compared to diesel. Combustion characteristics by preheating [10–14]. The smoke emission was reduced by 10% and 24%, respectively, using WFO (75^{0}C) and WFO (135^{0}C) compared to WFO (without preheating). The maximum reduction in smoke emission was observed using WFO (135^{0}C).

Hazar reported that the lowest smoke densities were obtained with preheated 50^{0}C and 20^{0}C. The average smoke densities were decreased by 9.4%, 20.1% and 26.3% for DF, 20^{0}C and 50^{0}C, respectively. This may be due to the reduction in viscosity and subsequent improvement in spray injection.

7. CONCLUSION

Various biodiesels like rapeseed oil,waste fryinf oil (WFI),rise bran oil,COTTONSEED METHYL ESTER (COME) can be used in CI engines without making any changes in engine.The major technical problem of higher viscosity, density can be effectively eliminated by heating biodiesel before injecting it into combustion chamber. Biodiesel thus with decreased viscosity can be successfully used with following improved ignition and emission characteristics:-

1. Preheating of biodiesel effectively decreases the kinematic viscosity, density and surface tension properties which dominantly improves injection of biodiesel by contributing to better fuel atomization at the elevated temperature of the biodiesel.
2. Moreover preheating reduces the ignition problem by decreasing the ignition delay time during cold start of engine in cold countries.
3. Preheating contributes to reduction in CO ,CO2 emissions of biodiesel than that of the pure diesel and unpreheated biodiesel while the NOx emission increases with increase in preheating temperature due to increase in combustion temperature.

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