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Review on Admission of Preheated Vegetable Oil in C.I. Engine

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Abstract

Background/Objectives: This paper reviews the performance and emission characteristics of C.I. engine fueled with preheated vegetable oil. **Methods/Statistical Analysis:** Vegetable oils can be a good alternative source for fossil fuel. The engines available in the market are designed for petroleum diesel which found to be less efficient while using vegetable oil as fuel. The main problem in the usage of vegetable oils in C.I. engine is their high viscosity and low calorific value. The viscosity is reduced by methods such as transesterification, blending of vegetable oil with diesel, preheating the vegetable oil. Only few authors had done experiment with preheated vegetable oil in C.I. engine. **Findings:** From the result and output given by the authors the review is done. The results are favor for preheated vegetable oil than unheated vegetable oil. In all the cases BTE of preheated vegetable oil is higher than unheated vegetable oil. Most authors said that BSEC of preheated vegetable oil is almost equal to diesel and lesser than unheated vegetable oil. It was found that HC and CO emission for preheated vegetable oil is lesser than unheated vegetable oil, were NO_x is found to be higher for preheated vegetable oil. CO_2 emission while using preheated vegetable oil is higher than unheated vegetable oil and diesel. The usage of vegetable oil neutralizes CO_2 emission, so there will not be any new CO_2 emission into the atmosphere. Preheated vegetable oil is a promising alternate for mineral diesel. **Applications/Improvements:** Long term usage of preheated vegetable oil may affect the lubrication oil and fuel line so change in rescheduling of replacing the lubrication oil is needed. Pongamia oil, neem oil and jatropha oil are found to be reliable alternative fuels. Combined effect of preheated and blending of vegetable oil as an alternative fuel for diesel engine would give best result in performance and emission wise.

Keywords: C.I. Engine, Emission, Non-Edible Oil, Pongamia Oil, Preheated Vegetable Oil, Performance

1. Introduction

The energy crisis is becoming more and more acute. India is the fifth largest energy consumer in the world. India consumes about 4.4% of the world's energy consumption; it is equivalent to 524.2 million tons of oil. Oil has become the main item of import for India. India is a country with a huge population. So, obviously, the demand for energy is growing higher and higher. 80% of the oil in India is imported from other countries and it cost rupees 2.68 lakh crores during 2011–12 and the percentage of import of oil gets increased every year and the need for alternative fuel becomes imperative.

Vegetable oil is a good alternative fuel for diesel. India is an agro based country and it has all the potential to produce vegetable oil in huge quantities. The need for diesel is almost six times that of gasoline, so the vegetable oil would be a good alternative for diesel[1-5].

The previous studies used karanja oil as fuel in C.I. engine. This study stated that higher viscosity of karanja led to poor combustion and injector choking[6]. To avoid this problem viscosity has to be reduced. They found transesterification process as an expensive chemical process because of the usage of chemical catalyst and it involved heating process. Due to this reason they chose preheated vegetable oil as fuel for C.I. engine[7,8].

From the previous study it was found that the engine could be successfully operated using Pongamia oil as fuel. The peak efficiency was obtained at 80% load and it was found to be 24.65%. A slight higher vibration and

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knocking was seen while using Pongamia. Performance and emission characteristics, while using Pongamia, may be slightly inferior in direct admitting. By slight modifications of the fuel or the engine, Pongamia can be used for long term and the vibration and knocking can be reduced[9].

A lot of experiments and reviews have been done by other authors on the usage of biodiesel and direct admitting of vegetable oil in C.I. engine but only a few authors have done experiments in usage of preheated vegetable oil in C.I. engine. This paper reviews the performance and emission characteristics of preheated raw vegetable oil in C.I. engine.

2. Methods and Materials

2.1 Agro Property of Non-Edible Plants

Non-edible oil plants are mostly drought resistant and grow on a wide range of soils. India has a lot of unused land so that the non-edible oil yielding plants can be grown. The alternative oil chosen as a fuel should be easily available. A deep understanding of agro property is necessary in choosing non-edible oil plant. So some characteristics are tabulated in Table 1[10-15].

2.2 Physical and Thermal Properties of Non-Edible Oil

Knowledge of physical and thermal properties of vegetable oil is very important while using it as a substitute for diesel, so some of the characteristics are tabulated in Table 2[9-20]. From Table 2 it was found that the calorific value of raw vegetable oil is almost 10% less on volume basis than diesel. It is expected that there would be a loss in power and torque while usage of using vegetable oil in C.I. engine. Pour point of vegetable oil is higher than diesel, which makes it difficult to be used in the sub zero regions. Flash point of the vegetable oil is higher than diesel which makes it safer in transporting vegetable oil than diesel. Cetane number of vegetable oil is almost equal to that of diesel, which determines the smoother engine operation. A smooth operation with less vibration is expected during the usage of vegetable oil.

Viscosity of various vegetable oils at various temperatures is presented in Table 3[21-25]. From Table 3 it can be concluded that heating the vegetable oil up to 100°C reduces the viscosity and brings it closer to diesel, so that the problem in atomization while the raw vegetable oil is used at room temperature can be reduced.

3. Influence of Preheated Vegetable Oil in C.I. Engine

3.1 Performance and Emission Characteristics while using Preheated Pongamia Oil and Blends of Pongamia Oil-Diesel (Karanja Oil)

Previous study measured the performance and emission characteristics of karanja oil blends with diesel such as B100, B75, B50, B20, B10 and B0[20]. A single cylinder, water cooled, C.I. engine was used for test purpose. The same blends were used at elevated temperature and its output conditions were studied. Exhaust gas was used to heat the karanja oil blends. The performance and emission characteristics of the heated blend and the unheated were compared with the diesel. It was found that preheated B100 and its blends produced higher BTE than diesel. Preheating of the karanja oil and its blends reduced the viscosity which resulted in improved atomization property and karanja oil blends contain inbuilt oxygen so the combined effect caused the preheated blends of karanja oil to have higher BTE than diesel. The BTE of preheated karanja oil was about 30%. For blends of karanja oil up to 50% with unheated condition the BSFC was less than the diesel. Increasing the concentration of karanja oil

Table 1. Agro characteristics of non-edible oil yielding plants

Properties	Rain Fall (mm)	Temperature (°C)	Soil Preference	Height (m)	Seed Yield (Kg/ha/year)	Oil Content in Seed (%)
Pongamia Pinnata	500–2500	---	Wide Range	8–10	900-9000	30 to 40
Neem	750–1000	15–45	Deep Clay	20	120 to 200	33–45
Rubber	---	---	---	34	150	40–50
Mahua	550–1500	---	Deep Clay	18–20	---	30–40
Jatropha	480–2400	20–28	Any Type	3–5	100 to 800	43–59

Table 2. Physical and thermal characteristics of non-edible oil

Properties	Calorific Value MJ/Kg	Pour Point (⁰C)	Flash Point (⁰C)	Density Kg/m3	Cetane Number	Specific Gravity
Diesel	45	---	75	840	50	---
Rubber	37.2	---	198	---	---	0.91
Soapnut Oil	38.207	6.5	232	904	---	---
Poon Oil	39.65	-5	158	926	---	0.9264
Pongamia Pinnata	34	-3	263	938	46	0.913
Jojaba	---	-6	186	---	55	0.920
Honne	39.11	---	224	---	---	0.910
Polanga	39.25	---	221	---	---	0.896
Mahua	37.614	---	230	---	---	0.924
Jatropha	38.5	3 to 5	174	932.9	40	0.920
Cotton	39	---	210	---	---	0.912

Table 3. Viscosity of various vegetable oils at various temperatures

Fuel	Viscosity (cSt) at different temperatures						
	40ºC	50ºC	60ºC	70ºC	80ºC	90ºC	100ºC
Diesel	3.4	3.1	2.7	2.2	2	1.9	---
Jatropha oil	36.2	25	17.5	12.5	8.7	6.2	4.8
Cotton seed oil	32.7	23.3	16.8	9.3	6.2	5.3	---
Karanja oil	41.3	---	23.3	---	13.83	11.3	---
Rape seed oil	31.2	---	22	---	14.3	---	8.1
Waste fried oil	44.2	33.2	25.7	18.2	13.9	---	---
Palm oil	37	26	18.2	15	12	8	---
Cotton seed oil 80% + Diesel 20%	16.2	11.7	8.3	6.4	5.4	4.9	---
Cotton seed oil 60% + Diesel 40%	13.1	10.3	6.6	5.3	4.9	4.1	---
Cotton seed oil 40% + Diesel 60%	10	8	5.2	4.6	3.8	3.4	---
Cotton seed oil 20% + Diesel 80%	6.2	5.1	4.2	3.6	2.8	2.6	---
Rapeseed oil 50% + Diesel 50%	15.6	---	11.2	---	7.6	---	4
Rapeseed oil 20% + Diesel 80%	7.9	---	6.8	---	5.6	---	2.5

beyond 50% in the blend caused BSFC to become higher than diesel. It was because the density and the viscosity of the karanja oil being higher than the diesel, which led to reduction in the combustion quality and the increasing the percentage of karanja oil in the diesel reduced the calorific value of the blend.

All preheated blends of karanja oil had significantly less BSEC than diesel. Irrespective of the blends with increase in the load CO increased for both preheated and unheated condition. Preheated blend produced significantly less CO than the unheated blends. The blends more than 20% of karanja oil in the diesel produced higher CO than diesel. The higher viscosity was stated to be the main reason for it. The higher viscosity reduced the availability of oxygen to the fuel and the vaporization got reduced, resulting in an increase in the CO emission in the fuel.

For both the heated and the unheated blends the HC emission was less at lower load but with increase in the load the blends of karanja oil produced higher HC than diesel. At higher load more fuel was injected into the cylinder, so the air fuel mixture reduced and consequently so the HC was higher at higher load than at lower load. Irrespective of the blends of karanja oil subject to the condition (heating and without heating), the NO_x reduced with the increase in load. The NO emissions for karanja oil blends were less than diesel because the fuel droplet size of the karanja oil blends was greater when compared with diesel. Larger fuel droplet size led to longer combustion duration which reduced the peak temperature; so NO less for karanja oil blends than diesel. The longer duration of the karanja oil blends was the reason for the higher EGT than the diesel. The higher viscosity and the lower volatility of karanja oil blends led to higher smoke than diesel.

Researchers conducted an experiment using single cylinder, diesel engine[21]. The fuel used for experimental study was karanja oil and its blends with diesel. Different blend ratios were used and the author chose a ratio of karanja oil 40% and diesel 60% for his study. Different injection timings of 23º, 21º, 19º, 17º and 15º BTDC were used and it was found that injection 19º before BTDC had the best BTE for the blend of karanja oil 40% and diesel 60%.

Reduction of viscosity of pure karanja oil to the level of diesel using heat exchangers and the exhaust could not be achieved by the authors; so to reduce the viscosity of the fuel a combined method of blending and preheating was done. So it was found that heating to the temperature of 55 to 60ºC the blend of karanja oil 40%-diesel 60% reduced the viscosity to the level of diesel at room temperature. So the blend ratio of B40 was used for this whole experiment under the preheated condition of 55-60°C. The optimum load point for the blend of B40 was achieved around 80 to 85% of the load. It was found that the injection timing of 19° BTDC was optimum. Injection timing of 19° BTDC produced the lowest BSFC of 0.2691 kg/kWh, the lowest smoke density and the highest BTE of 28.89% while fueled with B40. The injection timing of 19° BTDC was found to be the optimum for the blend of K40 for the injection pressure of 200 bars.

3.2 Performance and Emission Characteristics while using Preheated Jatropha Oil and Blends of Jatropha Oil- Diesel

Performance had done an experiment with single cylinder, water cooled, Diesel engine fueled with blends of jatropha oil and its blends with diesel[22]. To reduce the viscosity of jatropha oil two methods were followed: the first method was the blending of jatropha oil with diesel and the second was heating the jatropha oil.

Pour point of jatropha is about 4°C while the diesel has about −5°C. The higher pour point of jatropha oil makes it unsuitable for usage in colder regions. The viscosity of jatropha oil at 40°C is about 35 cSt, but at 100°C it drastically reduces to 6 cSt. Blends of 30% jatropha oil-70% diesel and 20% jatropha oil-80% diesel have a viscosity of 5.35 and 4.19 cSt at 40°C which satisfy the ASTM limits.

To find the optimum injecting pressure, the engine was is operated at different injection pressures of 180 bar, 200 bar, 220 bar and 240 bar and it was found that the injection pressure of 200 bar produced maximum efficiency of 30.71%, so for the whole experiment the engine was operated under the condition of 200 bar. The BSFC for jatropha oil and its blends was higher than diesel because the calorific value of jatropha oil is less than diesel. The preheated blends of jatropha oil produced a slightly lower efficiency compared with diesel but the unheated jatropha oil produced a less BTE than diesel and heated jatropha oil. The atomizing property for the heated jatropha oil was improved so the thermal efficiency was better than the unheated jatropha oil. The heated jatropha oil produced less CO when compared with unheated jatropha oil. Diesel fuel produced less HC when compared with heated and unheated jatropha oil. The CO_2, CO and HC emissions for heated jatropha oil were closer to diesel.

The performance, combustion and emission characteristics of a three cylinder, indirect injection with glow plug chamber, water cooled engine fueled with jatropha oil and karanja oil were also analysed[23]. Their results were compared with neat diesel. The heat from the engine water jackets was used to preheat the vegetable oil. The researchers reported that the lower heating values of the vegetable oils were less about 11% than diesel. The flash point and the viscosity of vegetable oil were much higher than those of diesel. The viscosity of the oil could be reduced up to 90% by heating it to 90°C. In this experiment the viscosity of the vegetable oil was reduced up to 70% of its original value by heating up to 60°C but the viscosity still remained higher by almost 10 times that of diesel. It was found that BSFC was higher by 16% on volume basis for vegetable oils than diesel. At higher load the BTE of the preheated oils was almost equal to that of diesel. With the increase in the load the CO emission increased, because at higher load the quantity of fuel injected was is higher but the intake air remained constant; so the availability of oxygen decreased and it led to an increase in CO. Since the BSFC of the vegetable oils was higher than diesel, the CO emission was is higher for vegetable oil than diesel. The oxygen content in the jatropha oil is lower than in karanja so the CO is higher for jatropha oil. Due to the presence of oxygen content in the vegetable oil, CO_2 emission for vegetable oil is higher than diesel. Due to the higher combustion temperature of the vegetable oil, NO_x emission for the vegetable oils is higher than diesel by 7%. A small amount of coke formation was observed by the authors on the piston and cylinder head after 50hours of operation with heated vegetable oil while the corrosion of injectors and the clogging of fuel filters were negative.

Another authors[24] analyzed the combustion and performance characteristics of a single cylinder, naturally aspirated, direct injection diesel engine fueled with preheated jatropha oil. The oil was preheated by using the exhaust gas from the engine.

It was found that the EGT increased with increase in load. At 80% of the load the EGT before and after recovery of heat was 310°C and 226°C respectively. The performance and emission characteristics were studied at three modes of fuel. The first one was with pure diesel at normal temperature; the second one was jatropha oil without heating condition and the third one was jatropha oil in heated condition of around 70°C. At full engine load condition the corresponding BSFCs for diesel, jatropha oil without heating and jatropha oil with preheated were 286.88, 319.48 and 328.06 g/kWh, respectively. Higher density and lower calorific value of the vegetable oil could be the reason for the higher BSFC of vegetable oil than diesel. Maximum BTE was obtained at full engine load condition. The BTE for diesel, jatropha oil without heating and jatropha oil with preheating were 29.88%, 29.15% and 28.33% respectively. Lower calorific value and higher fuel consumption was reported as the reason for less BTE of jatropha oil than diesel. Jatropha oil produced higher EGT than the diesel. With the increase in the load the occurrence of the peak heat release rate advances. With increase in the load the ignition delay decreased. The ignition delay decreased for the preheated oil more than the oil without heated condition, and diesel was is mentioned as the fuel with lower ignition delay. Viscosity was stated to be the reason. Better atomization took place for preheated jatropha oil and it produced less CO than the jatropha oil without heated condition. The automation property was improved for the preheated jatropha oil so it led to better combustion and reduction of HC for preheated jatropha oil; it was less than the jatropha oil without heating. The maximum NO_x was obtained at full engine load condition. The NO_x for diesel, jatropha oil without heating and jatropha oil with preheating were1827, 1302 and 1084 ppm respectively.

Some studies were conducted an experiment with single cylinder, air cooled C.I. Engine at constant rpm of 1500, at a rated brake power of 5.9 kW and with a compression ratio of 17.5:1[25]. Performance and emission characteristics of the engine were tested using jatropha oil as fuel. The jatropha oil was preheated to different temperatures of 40, 60, 80 and 100°C and its performance and emission characteristics were compared with those of diesel, with its being admitted at normal temperature.

Preheated and unheated oils had less BTE than diesel. With increase in the temperature of jatropha oil the BTE increased. Jatropha oil admitted at a temperature of 100°C showed BTE closer to diesel. The high viscosity and the lower calorific value were stated to be the reason for the less BTE of jatropha oil than diesel. The higher density and lower calorific value of unheated jatropha oil led leads to higher BSEC than diesel. Jatropha oil heated to 100°C produced SEC almost equal to that of diesel. The reduction of viscosity of the preheated jatropha oil led to better atomization of fuel and better combustion resulting in lower BSEC.

With increase in load for both diesel and jatropha oil heated and unheated condition the EGT increased. Increase in the inlet temperature of jatropha oil produced higher EGT than the jatropha oil at a lower temperature. The EGT of diesel, unheated jatropha oil and jatropha oil heated to 100°C were 359°C, 345°C and 389°C respectively.

The increase in the inlet temperature of the jatropha oil increased NO_x emission. The NO_x emission of diesel, unheated jatropha oil and jatropha oil heated to 100°C were 2046 ppm, 1813 ppm and 2696 ppm respectively. Preheated jatropha oil produced higher combustion temperature than the unheated oil so the NO_x production was higher for the heated oil. Unheated jatropha oil produced higher CO than diesel and preheated jatropha oil. The higher viscosity of unheated jatropha oil reduced the atomization which in turn reduced the proper mixing of oxygen with the fuel which eventually led to higher CO emission for unheated jatropha oil than the diesel and preheated jatropha oil.

CO_2 emission for diesel was less than jatropha oil heated and non heated oil. The presence of higher oxygen content and lower carbon content in the vegetable oil was stated to be the reason for the less CO_2 emission for vegetable oil than diesel. The increase in the inlet temperature of the jatropha oil produced higher CO_2 emission than the jatropha oil with lower temperature.

Jatropha oil without heating produced the highest amount of HC. Increasing the inlet temperature of the jatropha oil reduced the HC emission but only at the inlet temperature of 100°C for the jatropha oil the production of HC was less than diesel. At lower and medium load the smoke opacity for jatropha oil heated and unheated were higher than for diesel; with full load condition diesel produced maximum smoke than the other fuels. This was due to the higher oxygen content in the jatropha oil. Increase in the temperature of the jatropha oil reduced the smoke opacity.

3.3 Performance and Emission Characteristics while using Preheated Soybean Oil and Blends of Soybean Oil- Diesel

Experiments were conducted using a single diesel engine and different blends of soybean oil-Diesel being used as fuel[26]. With the blends being heated and the angle of injection of the fuel being changed, the performance and emission characteristics were analyzed. The blend of Soy vegetable oil 70%-diesel 30%, 100% soy vegetable oil and 100% diesel were used as fuel. The blends used were admitted at different temperatures of 30°C and 60°C. The preheated blends produced higher torque than the blends without preheating. The blend of 70% soy oil without preheated condition had higher torque by 2.1% than diesel whereas the preheated blend of 60° C had a higher torque of 4.1% than diesel. Due to the less partial vapor pressure of the diesel the increasing the temperature of the diesel from 30°C to 60°C reduced torque. Changing the injection angle from 17° to 19° increased the torque by 6.1% and 5.9% for diesel and blend of soy vegetable oil respectively. Increase in temperature of the blends and diesel reduced the power of the engine.

3.4 Performance and Emission Characteristics while using Preheated Cotton Seed Oil and Blends of Cotton Seed Oil-Diesel

Experiments were conducted using single cylinder C.I. engine to optimize the blend ratio of cotton seed oil with diesel and the inlet temperature of the fuel[27]. The viscosity values for the blend ratio of 80% of cotton seed oil-20% diesel and 60% of cotton seed oil-40% diesel at the temperature of 70°Cwere 6.4 and 5.3 cSt respectively, which were close to the viscosity of diesel 4.59 cSt at 30°C. So the above blend ratios with the preheated temperature of 70°C were used by the authors as the test samples. The performance and emission characteristics were compared with those of diesel at normal temperature.

Blend ratio of 80% of cotton seed oil-20% diesel produced a BTE of 28% and 30% for unheated and heated blends respectively. With increase in the percentage of cotton seed oil in the blend the BTE decreased. It was because of the reduction in viscosity caused by heating and the blending of the fuel that eventually led to better atomization. The volumetric efficiency of preheated oil was higher than the unheated oil. It was because the exhaust gas temperature for the blends without heating was higher when compared with heated blends. The higher exhaust reduced the volumetric efficiency. The volumetric efficiency for heated and unheated cotton seed oil was 83% and 82.3% respectively. For all the blends under both heated and unheated conditions with the increase in load the smoke increased. The smoke level of preheated cotton seed oil was 3.6 BSU, whereas for the cotton seed oil without preheated condition it was 3.9 BSU. Cotton seed oil and its blends under both conditions of heating and unheating, produced higher CO and HC than diesel. But the heated oil and its blends produced less HC and CO than the respective unheated oil and their blends. The reduced viscosity of heated oil and its blend was the reason for the less emission. The combustion delay was higher for the cotton seed oil than for diesel.

3.5 Performance and Emission Characteristics while using Preheated Rapeseed Oil and Blends of Rapeseed Oil-Diesel

Research was carried out in single cylinder, four stroke, naturally aspirated, direct injection, variable speed engine. Blends of rapeseed oil and diesel were heated to 100°C[28]. The preheating of oil resulted in the reduction of viscosity of rape seed oil blends, smooth flow of blends and non-occurrence of fuel clogging. The blends of rape seed oil without preheating have certain disadvantages such as poor atomization and delay in the start of combustion. Normally vegetable oils have high viscosity, high density, and poor volatility and these properties lead to problem in pumping, atomization and poor combustion. Transesterification is a good method to reduce viscosity but it reduces the heating value of Rape seed oil, so it increases BSFC. The authors had heated the rape seed oil to 100°C and reported it as the optimum temperature and that heating beyond the temperature led to reduce the spray characteristics.

The blends of preheated rapeseed oil produced higher torque than the diesel. Brake power for rapeseed oil blends was less than diesel because preheating of rape seed oil resulted in leakage in pump and lower heating value of rape seed oil-Diesel blends. The calorific value of the blends of rape seed oil is lower than that of diesel but at the same time, the lubricity of the rape seed oil is higher than that of diesel. This leads to maintain the power for rape seed oil blends. BSFC for preheated blends at all loads was less than blends without heating, because for preheated blends the atomization was better and they got a better chance to involve in the combustion. Preheated diesel fuel had the lowest BSFC than the other blends with and without preheating and it was because of the lower viscosity and higher calorific value of diesel. The poor volatility of the rape seed oil blends led to their burning during the late combustion phase, so the exhaust temperature of rape seed oil blends could become higher than that of diesel. NO_x was higher at 2000 rpm instead of at 2500 rpm. This was because at 2500 rpm the time for combustion was less; so it led to less NO_x at 2500 rpm. NO_x increased for preheated fuel. NO_x decreased with increase in the blends of oil because the peak temperature for the blends decreased. CO was higher for unheated blends because of poor atomization leading to local rich mixture resulting in more CO formation. Smoke was less for preheated blends than for diesel but the unheated blends produced higher smoke than diesel because the blends of unheated rape seed oil were of higher viscosity and poor volatility than the heated blends.

3.6 Performance and Emission Characteristics while using Preheated Peanut Oil, Canola Oil and Sunflower Oil

Some tests were conducted using two engines with different specifications[29]. Performance and emission characteristics of peanut oil, canola oil and sunflower oil were analyzed using the engines. The oils were used at two conditions; the first one was at normal room temperature of 25°C and the second condition was at an elevated temperature of 90°C. The specifications of the two engines used were Yanmar Diesel engine, with maximum output of 5.5 kW, air cooled, with one cylinder, 406 cc, direct injection and the C.R. 20:1 while those of the second engine were Kubota Diesel engine, with maximum output of 6.5 kW, liquid cool, 479 cc, two cylinders, indirect injection and C.R. 23.5:1. Diesel was used as the base fuel to compare the characteristics of the engines. Peanut oil with and without preheating had higher BTE than diesel and the other oils.

Kubota engine had higher BTE than the Yanmar engine. All the preheated vegetable oils showed higher BTE than diesel for both the engines. This indicated the spray characteristics and the improvement in atomization in the preheated vegetable oil. Higher CO emission was seen for vegetable oil than diesel. At lower load the EGT for diesel is slightly less than vegetable oil, but with increase in the load the EGT for vegetable oil increased than for diesel. Kubota engine produced higher EGT than Yanmar engine .The temperature difference between the vegetable oil and diesel was higher for Kubota engine and it was because the C.R. for Kubota engine was higher and so it led to reduction in ignition delay when compared with the engine with lower C.R. The vegetable oil produced less UBHC than diesel. With the increase in load the NO increased for all the oils and for both the engines. Kubota engine produced two to three times the emission of NO by Yanmar engine. Due to the presence of oxygen content in the vegetable oil the NO emission for vegetable oil was higher than diesel. The vegetable oil with heating and without heating produced almost equal NO in both the engines.

Some studies were performed using four cylinder C.I engine, indirect injection with injection pressure of 130 Bar and sunflower oil preheated to 75°C being admitted as fuel for the engine and the performance, emission, combustion characteristics were analyzed and compared with mineral diesel fuel[30]. The brake torque for preheated sunflower was 1.36% less than diesel. The BSFC, when preheated sunflower oil was used, increased by 5% when compared with diesel. At 200 rpm the engine produced the highest BTE for both the fuels whereas the BTE of preheated sunflower oil and diesel were 30.8% and 30.4% respectively. The higher BTE of the preheated sunflower oil was due to the better combustion property than diesel. Due to the higher viscosity and lower volatility of preheated sunflower oil there was slight decrease in the maximum cylinder pressure for the preheated sunflower oil. The higher speed increased turbulence, atomization of the fuel and BSFC so the maximum cylinder pressure was obtained at 3000 rpm.

The fuel line pressure increased with increase in pressure so the starting of the injection advanced rather than at the lower speed. The higher viscosity and density of the preheated sunflower oil caused the fuel injection advance which was not the case with diesel. The Ignition delay for the preheated sunflower was higher than diesel. It was because of the higher viscosity and poor volatility that led to the injection of higher quantity of injection of fuel into the cylinder. The expansion stroke for both the fuels remained almost similar and this led to better combustion for the preheated sunflower oil and higher BTE.

At 1000 rpm and 2000 rpm the CO emission for preheated sunflower oil was higher than for diesel but when the speed was increased to 3000 rpm; the CO emission for the sunflower oil was less than for diesel by 6%. With the increase in the engine speed the atomization property of the preheated sunflower improved so the CO emission less for CO than for diesel. At all speeds the UBHC for preheated sunflower oil was less than for diesel. At 1000 and 3000rpm UBHC for preheated sunflower was less by 37% and 27% respectively. The higher temperature of the preheated sunflower oil and the presence of oxygen in it led to less UBHC than diesel. The indirect injection reduced UBHC more than the direct injection engine. With the increase in engine speed more fuel was burnt in the premixing phase which led to the reduction of UBHC at higher speed than at lower speed. The less sulfur and higher oxygen content in the preheated sunflower oil led to the production of less smoke opacity than diesel in all the load conditions.

3.7 Performance and Emission Characteristics while using Preheated Waste Fried Oil

The performance and emission characteristics of a single cylinder, diesel engine with injection pressure of 190 bars were tested [31]. Waste fried oil which was obtained from sunflower oil was used as the fuel for the engine. The oil was admitted at different temperatures of 30°C, 75°C, and 135°C and the performance and emission characteristics were compared with those of diesel which was admitted at room temperature. The biodiesel production has some disadvantage such as usage of methanol being a flammable process during production, sodium hydroxide potassium hydroxide being not environmental friendly. The calorific value of the waste fried oil is was less by 14% than the diesel. Diesel has the lowest BSFC. With increase in the temperature of the oil the BSFC decreased. The BSEC for waste fried oil without heating was 28% higher than for diesel. With the heating of the oil the BSFC decreased more than the unheated oil because the spray characteristics are improved due to reduction in viscosity.

The maximum BTE values for waste fried oil admitted at 75°C, 135°C, and 30° were 25.26, 25.79, and 21.6% while diesel produced the highest BTE of 30%. Poor volatility, higher density and higher viscosity were cited as the reasons for the less BTE of the oil. The EGT for the oil without heating was higher than for the oil with heating and diesel because the combustion for the oil without heating took place at the later phase. With the increase in the engine load the combustion temperature increased and the results were higher in NO_x. The NO_x for the oil with heated condition of 135°C produced 25% higher than the oil without heating. The lower peak combustion temperature for the vegetable oil with preheating was cited as the reason for the less EGT than the oil with heated condition. With increase in load the CO emission increased. The oil without heating produced the maximum CO of 0.77% and the diesel produced 0.22%. Increasing the inlet temperature of the oil reduced the CO. It was because of the reduction in viscosity and the improvement in spray characteristics.

The higher viscosity of the vegetable oil led leads to less flower characteristics. The jet Reynolds number for vegetable oil is 7500 and for diesel it is 55000. This shows lesser flow characteristics of vegetable oil than diesel. These factors led to higher smoke emission for the unheated oil than for diesel. The smoke emission for the heated fuel was less than diesel.

3.8 Performance and Emission Characteristics while using Preheated Animal Fat Oil

Experiment in a single cylinder C.I engine, with injection pressure of 250bar, air cooled engine with a rated power of 2.8kW at 1500rpm was conducted [32]. Animal fat was used a fuel and it was admitted at different temperatures of 30, 40,50,50,60, and 70°C. Combustion, performance and emission characteristics were analyzed and were compared with those of mineral diesel oil. The peak pressures for the animal fats were less than for diesel. The maximum cylinder pressures for diesel and animal fat at 30°C were 94.5bar and 84.2bar respectively. With increase in the inlet temperature of the animal fat the peak pressure increased and the animal fat with the temperature of 70°C produced a peak pressure of 92.5bar. The reason for less peak pressure for the animal fat oil was due to the higher viscosity and lower volatility which led to higher ignition delay and that in turn reduced the quantity of the fuel taking part in the uncontrolled combustion phase which was the main influence for the peak pressure produced in the combustion chamber.

The exhaust temperature of animal fat at different temperatures was higher than that of diesel and this would have resulted in the higher temperature of the retained gas inside the cylinder. Because of the higher temperature of the retained gas in the cylinder, the volumetric efficiency for the heated vegetable oils was lower than for diesel. Diesel has the EGT of470°C compared with animal fat oil at various temperatures. With increase in the animal fat temperature the EGT increased; the EGTs of animal fat at 30°C and 70°C were570°C and 620°C respectively.

The fixed carbon present in the animal fat was 72% whereas diesel had about 87%; this resulted in less smoke emission for the animal fat for all the temperatures of admission. With increase in the inlet temperature of the animal fat the HC emission decreased. The animal fat at normal temperature produced higher HC than diesel. Higher Viscosity and poor volatility of the animal fat led to higher HC than diesel. The higher viscosity and lower volumetric efficiency of animal fat admitted temperature led to richer pockets of animal fat with less oxygen in the combustion chamber, so the CO production was higher than diesel. With increase in the temperature of the admitted animal fat the CO emission decreased and it was less than diesel above 50°C.The NO production was less for animal fat than diesel. The mixing of fuel with the air was less for animal fat than for diesel; this was the reason for less NO for animal fat.

3.9 Performance and Emission Characteristics while using Preheated Palm Oil

Performance, emission and friction characteristics of a single cylinder, air cooled, and diesel engine with rated power of 4.4kW at 3600 rpm was analyzed[33]. Crude palm oil was used as fuel and it was admitted at different temperatures. The temperature does not affect friction. Diesel and palm oil have almost the same friction level at different temperatures. It was stated that admitting of palm oil at elevated temperature did does not improve the performance characteristics. The palm oil started to solidify below 60°C and bubbling started to occur above 97°C; this led to instability of engine and increased in vibration. Due to the above reasons the engine was operated with a fuel inlet temperature of 80°C for further investigation of the engine.

The preheating of palm oil led to the cracking of the double bond carbon chain and so the property of raw palm oil was changed to a light, volatile fuel. The peak pressure while using preheated palm oil was higher than diesel by 6% and the ignition delay was reduced by 2.5° crank angle than in the case of diesel. The shorter combustion delay of the preheated palm led to less heat release rate and less knock. The vegetable oils are made of heavy molecules so the combustion duration is higher than diesel. Preheated palm oil produced higher CO and NO than diesel by 9.2 and 29.3% respectively. The higher combustion temperature and inbuilt oxygen in the preheated palm oil led to higher NO than the diesel.

4. Conclusion

The demand for energy increases every day, so the need for alternative energy source is great. Vegetable oil is a promising alternative energy resource which has its own advantages and disadvantages. Many authors have stated that higher viscosity of vegetable oil is the main problem in using it in the C.I. engine. To reduce the viscosity some authors followed preheating method. The experiment results were reviewed above and some of the conclusions are given below:

- Preheated vegetable oil is a promising alternative fuel for petroleum diesel.
- Long term usage of vegetable oil may lead to change in the schedule of replacing the lubrication oil and cleaning the oil filter and pump.
- Since the lubricating oil in the market is designed for petroleum diesel, the physical and chemical characteristics of lubrication oil can be modified by using additives according to vegetable oil usage.
- Even though the viscosity of preheated vegetable oil is higher than that of diesel, the BTE is almost equal to that of diesel.
- Heating palm oil beyond 97°C causes bubbling of fuel which leads to more vibration and instability of engine. Bubbling effect may occur for any oil at certain temperature and so optimum heating temperature has to be found.
- In most cases NO_x produced for preheated oil is higher than for diesel.
- Optimized injection timing and injection pressure for certain oil at certain preheated temperature is necessary for maximum BTE.
- Most authors reported that the combustion duration was higher for preheated vegetable oil than for diesel.
- Preheated vegetable oil can be used in the C.I engine with slight modification of the engine.
- Pongamia oil, neem oil and jatropha oil are found to be reliable alternative fuels.

Nomenclature

BSFC - Brake Specific Fuel Consumption
BTE - Brake Thermal Efficiency
NO_x - Nitrogen Oxides
CO - Carbon Monoxide
CO_2 - Carbon dioxide
HC - Hydrocarbons
C.I. - Compression Ignition
C.R. - Compression Ratio
I.P. - Injection Pressure
Bxx - xx (numbers) indicates the percentage of vegetable oil in the blend with diesel (Volume Basis)

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