PERFORMANCE STUDY OF 4-STROKE DIESEL ENGINE USING SOYBEAN OIL BLEND

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Abstract``
The rate of fossil fuel consumption is soaring with population growth but the fossil fuel reserves are finite in nature. It is only a matter of when they run out - not if. Every year, billions of tons of fossil fuel oil is consumed globally. So it is high time we contemplated over other alternative fuels. One such alternative is the use of Straight Vegetable Oil (SVO) or its blend in diesel engine if performance, emission and maintenance of an engine are comparable to diesel fuel. The main objective of this research was to evaluate the effectiveness of commercially available Soybean oil and diesel blends on the performance characteristics of *Kirloskar* single cylinder diesel engine. This study also sheds light on comparison and measurement of physical properties of diesel and test fuels i.e., the blends, and correlates them with the performance test result. It is concluded that the tested blends can be used safely and effectively in the diesel engine, at least in small blending ratios with normal Diesel fuel.

Keywords: SVO, Blend, Diesel Engine, Performance Characteristics

1. Introduction

A fuel is any material that is burnt to convert its chemical or nuclear energy to heat energy which can be further transformed into mechanical energy via a heat engine. One of the common types of heat engine is diesel engine in which diesel is employed as the fuel. Besides diesel, we can also employ alternative fuels such as alcohol, vegetable oils, etc. or their blends with diesel. Diesel engines with vegetable oils offer acceptable engine performance and emissions for short-term operation. Long-term operation results in operational and durability problems (Babu & Devaradjane, 2003). This reduced engine life is caused by the build-up of carbon deposits inside the engine (NREL, 2010). Aworanti (2012) concluded from their research that ternary blends of vegetable oils, diesel fuels and biodiesel can be used in diesel engines when the right proportion are blended to give the density and viscosity at which the diesel engine can function effectively.

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1.1. Diesel

Basically, any liquid fuel used in diesel engines is diesel. The injection of atomized diesel into the hot compressed inlet air causes the ignition of air-fuel mixture which ultimately powers the engines. Diesel engines are widely used because of their higher thermodynamic and fuel efficiencies. The important properties which are used to characterize diesel fuel include cetane number (or cetane index), fuel volatility, density, viscosity, cold behavior, and sulfur content. Diesel fuel specifications differ for various fuel grades and in different countries (Chevron, 1998).

The most common type of diesel fuel is a specific fractional distillate of petroleum fuel oil, but alternatives that are not derived from petroleum, such as biodiesel, biomass to liquid (BTL) or gas to liquid (GTL) diesel, are also being developed and adopted. To distinguish these types, petroleum-derived diesel is called petro-diesel. This fuel is employed in the major part of the transport and industrial sector and its demand is increasing.

1.2. Straight Vegetable Oil (SVO)

Vegetable oil can be used in diesel engines instead of diesel. When vegetable oil is used directly as a fuel, it is referred to as straight vegetable oil (SVO) or pure plant oil (PPO). The viscosity of vegetable oil is higher than that of diesel. This prevents complete combustion, which may damage the engine by causing a build-up of carbon. For higher efficiency, straight vegetable oil can also be blended with conventional diesel or processed into biodiesel or bio-liquids.

We can use various mixes, ranging from 10% SVO and 90% petro-diesel to 90% SVO and 10% petro-diesel.

There are many types of vegetable oil like Canola, Soybean, Peanut, Sunflower, Palm, Coconut oil, Jatropha, Curcas, Mahua, Neem, Karanj, Kusum, babassu, Rubber seed, Jojoba oil, etc.

1.3. Soybean oil

Soybean oil was chosen for this study mainly due to its wide availability as it is one of the most consumed cooking oils. Moreover, its price is cheaper compared to other vegetable oils.

Soybean oil is a vegetable oil extracted from the soybean seeds.

Composition:

Per 100 g, soybean oil has 16 g of saturated fat, 23 g of monounsaturated fat and 58 g of polyunsaturated fat(Poth, 2001).

The major unsaturated fatty acids in soybean oil triglycerides are the polyunsaturated alpha-linolenic acid (C-18:3), 7-10%, and linoleic acid (C-18:2), 51%; and the monounsaturated oleic acid (C-18:1), 23%.It also contains the saturated fatty acids stearic acid (C-18:0), 4%, and palmitic acid (C-16:0), 10%(Ivanov, Lević, & Sredanović, 2010).

1.4. Flash Point and Fire point

Flash point is determined by heating the fuel in a small enclosed chamber until the vapors ignite when a small flame is passed over the surface of the liquid. The temperature of the fuel at this point is the flash point. The flash point of a diesel fuel has no relation to its performance in an engine nor to its auto-ignition qualities. It helps to check the presence of suspected contaminants.It is much higher for SVO blends than for diesel fuel.

The fire point of a fuel is the lowest temperature at which the vapor of that fuel will continue to burn for at least 5 seconds after ignition by an open flame.

1.5. Viscosity

Viscosity is defined as the property of fluid by the virtue of which it opposes its own flow. Vegetable oil is much more viscous (thicker) than either petro-diesel or biodiesel. The purpose of mixing or blending straight vegetable oil (SVO) with other fuels and solvents is to lower the viscosity to make it thinner, so that it flows more freely through the fuel system into the combustion chamber after atomization.

1.6. Performance Characteristics

The brake specific fuel consumption, brake thermal efficiency and volumetric efficiency parameters are discussed in performance characteristics.

1.7. Brake power

An IC engine is used to produce mechanical power by combustion of fuel. Power is referred to as the rate at which work is done. Power is expressed as the product of force and linear velocity or product of torque and angular velocity. In order to measure power one needs to measure torque or force and speed. The force or torque is measured by Dynamometer and speed by Tachometer. The power developed by an engine and measured at the output shaft is called the brake power (BP). It is given by:

$$BP = \frac{2\pi NT}{60} \quad (1)$$

where, T is the torque, in Newton meter (N.m),

N is the rotational speed, in rpm (revolutions per minute)

BP is the brake power, in Watts.

1.7.1. Brake Thermal Efficiency

It is the ratio of output to that of energy input in the form of fuel. It gives the efficiency with which the chemical energy of fuel is converted into mechanical work. It shows that all chemical energy of fuel is not converted into heat energy. Brake thermal efficiency also varies with torque.

1.7.2. Volumetric Efficiency

It is the ratio of the actual volume of the charge drawn in during the suction stroke to the swept volume of the piston. It also denotes the ratio of air volume drawn into the cylinder to the cylinder's swept volume(Ferguson & Kirkpatrick, 2016). The amount of air taken inside the cylinder is dependent on the volumetric efficiency of an engine and hence puts a limit on the amount of fuel which can be efficiently burned and the power output. The value of volumetric efficiency of a normal engine lies between 70 to 80 percent for normal engines(Rajput, 2014).

1.7.3. Brake Specific Fuel Consumption

BSFC is a parameter that reflects the efficiency of a combustion engine which burns fuel and produces rotational power at the shaft or crankshaft. It is the rate of the fuel consumption divided by the power produced i.e., BSFC is the amount of fuel consumed in one hour to produce one kilowatt brake power. Brake specific fuel consumption is the ratio of fuel consumption in kg/hr to the brake power (kW). So its unit is kg/(hr-kW). It is typically used for comparing the efficiency of internal combustion engines with a shaft output.

Any engine will have different BSFC values at different speeds and loads.

2. Experimental Setup

Before the conduction of tests, five blends of soybean oil and diesel were prepared, namely B10, B20, B25, B30 and B40 where the number represents the percent of soybean oil in the blend. The diesel fuel used was high speed diesel (HSD) obtained from a local gas station.

In the present study, three tests were conducted. In the first test, the efficiencies of various blends were measured on the diesel engine by varying brake load and speed in a 4-Stroke variable compression ratio single cylinder diesel engine which was computer-based. It has an auxiliary water cooled head coupled to an eddy current dynamometer with the use of star coupling, mounted on a sturdy MS channel base. The engine compression ratio is varied by using a screw rod assembly, which activates the auxiliary pistons. The screw rod assembly is provided with calibrated scales to precisely position the auxiliary pistons for different compression ratios. On the top of the engine two oil cups are provided for lubrication of rocker arm and auxiliary mechanisms. A small amount of exhaust smoke is bypassed from the main exhaust to the oil governing system within engine for lubrication of rocker pin. An exhaust fan provided on the top side of the engine removes the small amount of exhaust gas after functioning. The engine should be started in the compression ratio from 15 to 17. The compression ratio can be varied while the engine is in running condition. The smoke conditions may change continuously with respect to compression ratio. Adjusting the governor nut can set the speed of the engine.

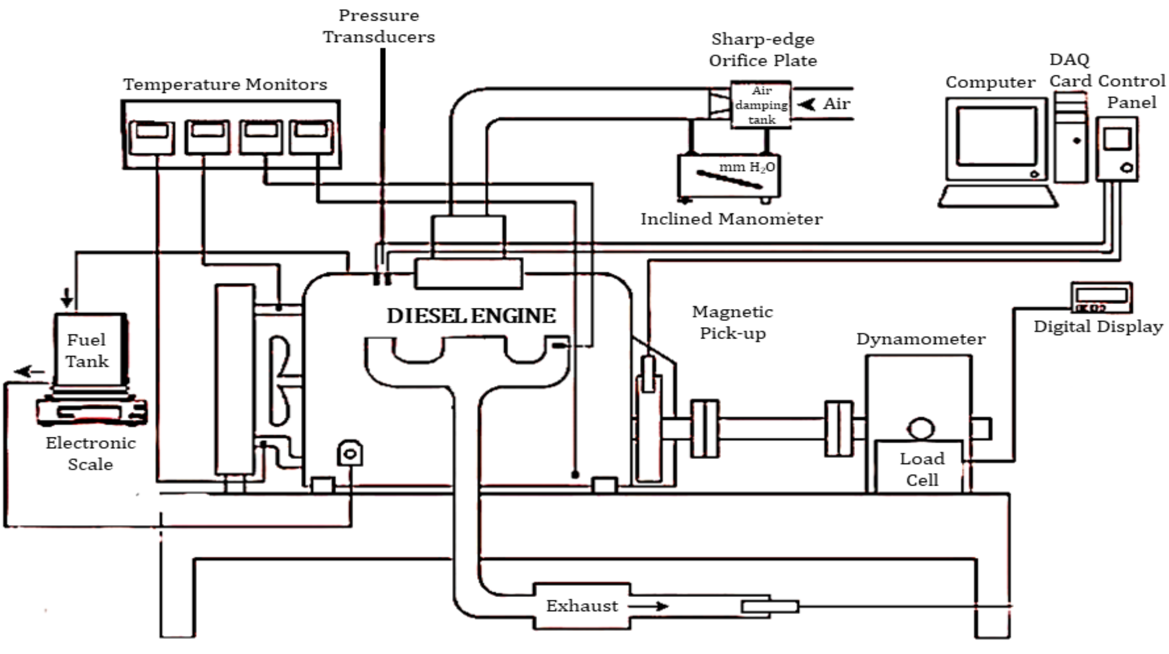

Fig.1. Schematic Diagram of the experimental setup for performance test

A series of tests were conducted using each of the soybean oil blends on the engine while varying the load and speed conditions. The experimental work was started with a preliminary investigation of the engine running on standard Diesel fuel in order to determine the engine's operating characteristics, constituting the 'base-line' that is compared with the corresponding cases when using soybean oil blends. The same procedure was repeated for each fuel blend under the same operating conditions.

Fig. 2. Laboratory setup

Following outputs were generated for each test fuel:

I. Performance:
   a. Brake Power
   b. Specific fuel consumption
   c. Volumetric efficiency
   d. Brake Thermal efficiency
   e. Indicated power
   f. Mechanical efficiency
   g. Heat Balance Sheet

II. Graphs:
   a. Torque vs. Brake power (BP)
   b. Torque vs. Brake specific fuel consumption (BSFC)
   c. Torque vs. volumetric efficiency
   d. Torque vs. Brake thermal efficiency
   e. Torque vs. various heats involved in the test (heat balance test)

The second test dealt with the estimation of viscosity of various soybean oil-diesel blends with the help of Redwood Viscometer. The redwood viscometer consists of vertical cylindrical oil cup. There is an orifice in the center of its base which can be closed by a ball. The cup is surrounded by the water bath. The oil is heated to a required temperature by heating the water bath with an electric heater, while simultaneously stirring the water to maintain the uniform temperature. The orifice is opened after reaching a certain temperature and the time is recorded for the flow of test oil. The temperature of oil and water bath are also recorded and are used to determine the kinematic viscosity of the oil. From the kinematic viscosity, the dynamic viscosity is determined.

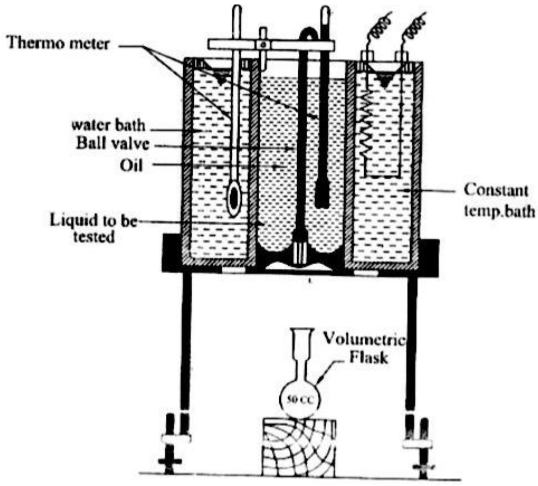

Fig. 3. Redwood Viscometer

The last test was calculation of the flash point and fire point of various blends using Cleveland's open cup device. (Fig 4)

Fig. 4. Determination of fire point and flashpoint in laboratory

3. Results & Discussions

For soybean oil blend, the physical properties such as density, viscosity, surface tension were found to be higher than diesel whereas calorific value was lower than diesel fuel. Among the blends, B10 has the highest brake power in most torque values. The properties of B10 are close to standard diesel as it contains only 10% of soybean oil and 90% of diesel. The brake power for B10 is seen to be higher than standard diesel in all the cases (Fig 5).

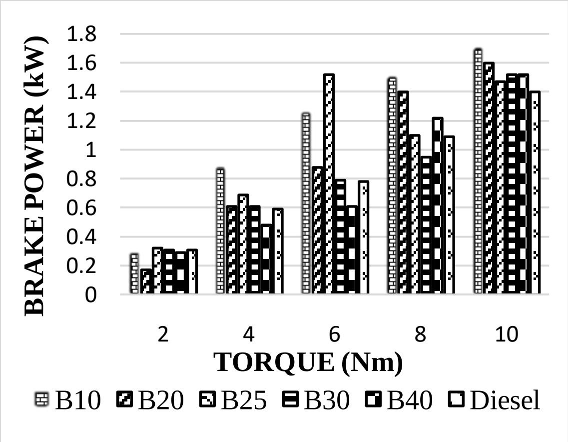

Fig. 5. Graph of Torque vs. Brake power for diesel and all the blends

Table 1: Properties of diesel fuel and soybean oil

Properties	Diesel	Soybean Oil
Density (kg/m^3) (at 20°C)	832	916
Kinematic Viscosity at 40°C (mm^2/s)	3*	33
Lower Calorific Value	42,700	37,000
Flash Point (°C)	35*	324
Fire Point (°C)	37*	360

*obtained from experiment

The soybean oil blend showed higher BTE (Brake Thermal Efficiency) than standard diesel oil for high load conditions. There was lower BTE at lower load and higher BTE at medium and higher load as compared to diesel fuel (Fig6).

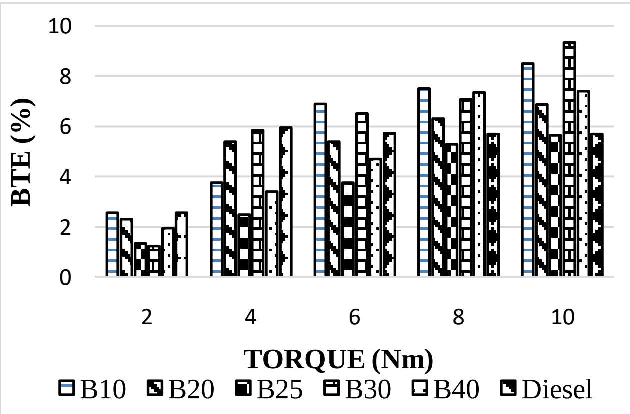

Fig. 6. Graph of BTE vs. Torque

It can be seen that the blends have significantly higher thermal efficiency than diesel fuel at full load condition. B30 has 9.33% BTE and diesel has 5.7 % BTE at10Nm torque. At low and middle engine loads, there is almost no fuel-rich zone because of the higher excess air/fuel ratio, and the lean fuel/ air mixture and poor ignitibility always lead to incomplete combustion. So, oxygen contents in the soybean oil blend play a moderate effect on the combustion efficiency at low engine load. The improvement of brake thermal efficiency at full load can be attributed to the promoted combustion in the fuel-rich zone due to the oxygen content of vegetable oil which leads to the fuel/air mixture becoming more homogeneous. As a result, the combustion efficiency was enhanced. Also at higher load, high cylinder temperatures occurred which improve vaporization and mixing process of fuel and air, thus leading to a shortened ignition delay and higher combustion efficiency. The blends had higher BSFC (Brake Specific Fuel Consumption) than standard diesel. Among the blends, B25 had higher BSFC and B30 had a lower BSFC in overall torque conditions (Fig 7).

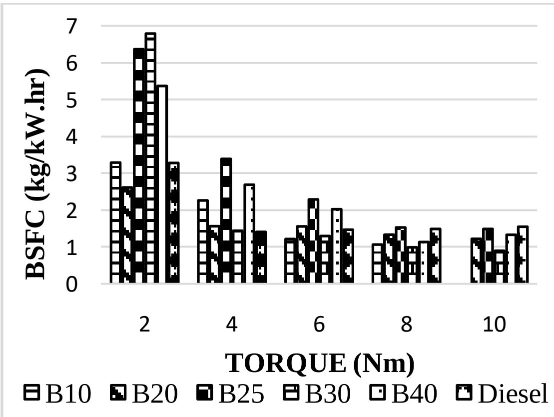

Fig. 7. Variation of BSFC vs. Torque

From the chart (Fig 7), we see that the BSFC decreases with increasing torque. BSFC is the highest for the minimum torque for all cases and it is lowest for high torque values. BSFC is the highest initially because the intake air is not throttled. The minimum BSFC is given by B30 at all engine torque values except for the initial torque value. And B25 is seen to have maximum BSFC at almost all engine torque values. Actual efficiency can be lower or higher than the engine's average due to varying operating conditions. BSFC numbers change a lot for different engine design and compression ratio and power rating.

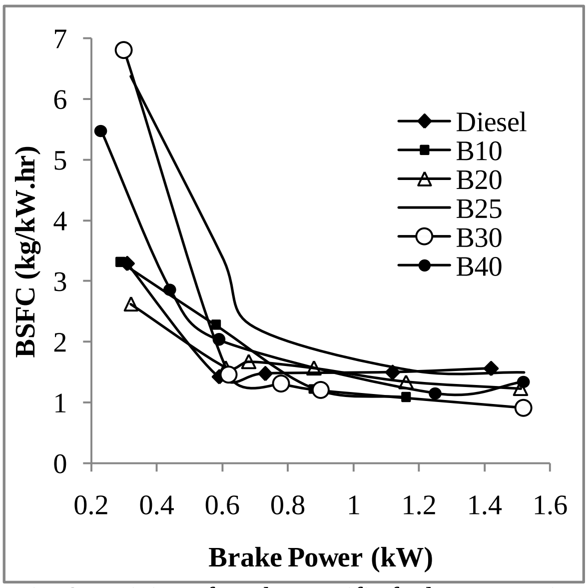

Fig. 8.Variaion of Brake specific fuel consumption with respect to Brake Power

(BSFC) with brake load for the oil-diesel blends and diesel fuel. It is seen that BSFC is slightly lower for blends at full load and is higher at lower load than that of diesel fuel. From the above graph, the blend with the most similar data with diesel is B10. Two factors are considered to explain the behavior. One is the enhancement of the premixed combustion duration and diffusive combustion duration, owing to the prolonging of ignition delay and increases the amount of fuel burned in the premixed burning phase, causing a high cylinder pressure rise and reducing the BSFC value. The comprehensive influence makes the increase of BSFC at lower load condition. The higher the engine load is, the higher is the gas temperature in the cylinder, and hence, the better are the fuel rich mixture burning conditions leads to lower BSFC. The other reason is the lower calorific value of the soybean oil and poor atomization due to high viscosity which requires more fuel to be injected into the cylinder to get the same power output, leading to the increase in the BSFC.

The flash points and fire points of soybean oil blends were measured to be a few °C higher than the diesel fuel (Fig 9).

The viscosity of soybean blends was calculated to be higher than that of diesel. The viscosity of the blend was found to increase with increase in the percentage of soybean oil in the blend (Fig10).

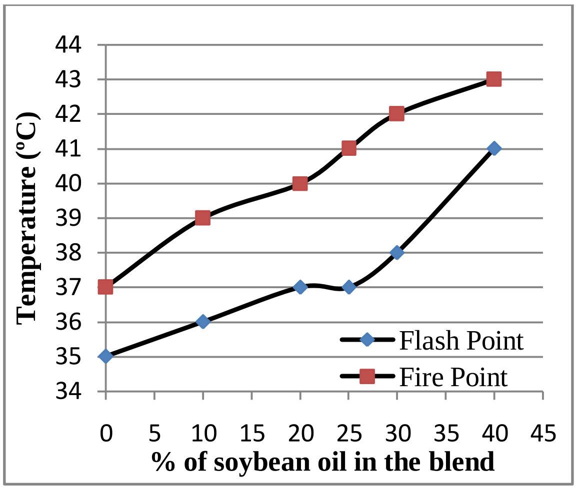

Fig. 9. Variation of flash point and fire point with respect to the percent of soybean oil in the blend

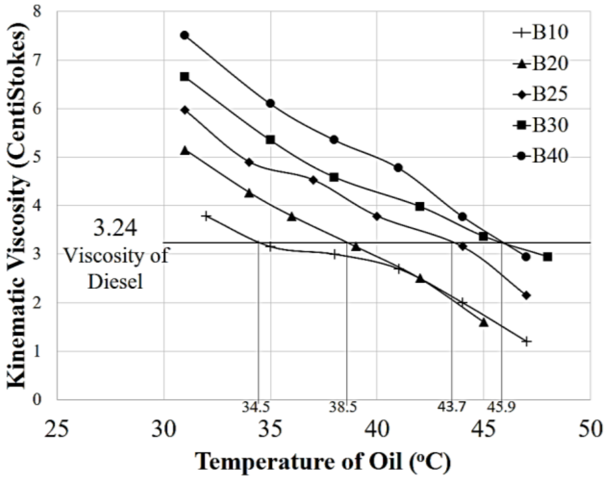

Fig. 10.: Variation of viscosity vs. temperatures of various blends

The kinematic viscosity of the blend decreased with the increasing temperature. As the percentage of soybean oil increases in the blend, the temperature required is higher so that the kinematic viscosity of the blend is comparable to that of diesel. For B40, to attain the viscosity of diesel i.e., 3.24 cSt, it has to be heated to 45.9°C. Similarly, the temperature required for each blends can be known from the graph. As viscosity is a temperature dependent parameter, we can vary the viscosity of the blend by some preheating mechanism such that high viscosity problem is eliminated. Barsicand Humke(1981) attempted to decrease the viscosity of SVO by employing a pre-heater before injection and found improvement on performance.

Table 2: Kinematic viscosity at 31ºC

Blends	Kinematic viscosity at 31ºC (centistokes)
B0(Diesel)	3.24
B10	3.78
B20	5.15
B25	5.97
B30	6.65
B40	7.5
B100(soybean oil)	40

The volumetric efficiency of diesel was about 10% higher than that of the blends (Fig 11). From the data and graph, the volumetric efficiency of all the blends are in the same range for all the torque values whereas the volumetric efficiency of the standard diesel is about 10% more than any blend. Among the blends, B40 has maximum volumetric efficiency for medium loads and B10 has maximum volumetric efficiency for the higher loads.

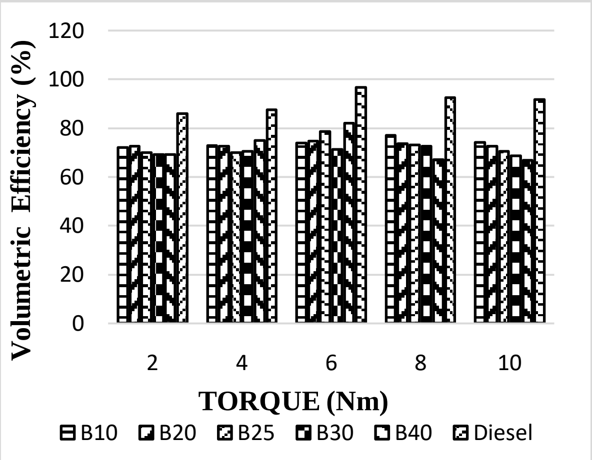

Fig. 11.Volumetric efficiency vs. Torque

4. Conclusion

The differences in the performance parameters of blends and diesel are insignificant, as their absolute levels are already very small. The engine performance with the soybean oil blends was similar to that of the neat Diesel fuel with higher brake thermal efficiency and higher brake specific fuel consumption for the high load.

The test results revealed that the blends of soybean oil and diesel can be effectively used in diesel engine without any modifications at least in small blending ratios with normal Diesel fuel. Hence, usage of the soybean oil blend as an alternate fuel in a diesel engine is an appealing option in rural and remote areas of developing countries like Nepal where agriculturally produced soybean oil can be utilized which in turn will enhance the economic growth too.

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