3

EXPERIMENTATION

3.1 Introduction

This chapter includes the extraction of oil from different selected seeds, biodiesel production, and the testing of produced biodiesel on VCR engine. Several oil-bearing seeds including Jatropha (Jatropha curcas), Neem (Azadirachta indica), Karanja (Pongamia pinnata), Mahua (Madhuca indica), Simarouba (Simarouba glauca), Rice bran (Oryza sativa), Jojoba (Simmondsia chineaca), etc. are found in India [86-88]. The selection of oilseed for biodiesel production usually depends on the crops amenable to the regional climate and also on its availability. In Northern India: Jatropha, Karanja, Castor, Mahua, Neem, Mustard, Linseed, etc. are major oil bearing seeds. Among this Jatropha, Castor, Mahua, Neem, and linseed are the most common oil bearing seed are found in Uttar Pradesh [212]. Therefore, Castor, Mahua, Neem, Linseed, and Coconut are considered for biodiesel production and experimental analysis. This chapter presents an extensive study on the comparative analysis of engine performance (BP and BSFC) and emissions (CO and NOx) characteristics of selected biodiesel with variable compression ratio.

3.2. Oil extraction

Copra (coconut), Castor, Mahua, Neem, and Linseed oil seeds are selected for oil extraction (figure 3.1). The oil extraction unit has been installed in the Laboratory of IC Engine, Department of Mechanical Engineering, IIT (BHU) Varanasi (figure 3.2-3.4). It is conducted in three steps: breaking of seed into smaller with decorticator, then mechanically pressing under high pressure with continuous feed to expel the oil from the seeds. This oil obtained from the expeller is contains some impurities. Then oil is passed through filter press used to removes the impurities.

(a) (b)

(c) (d)

(e)

Figure 3.1: Selected vegetable oil seed for production of oil (a) Copra, (b) Castor, (c) Mahua, (d) Neem, (e) Linseed

3.2.1 Decorticator

The decorticator is used to stripping the fruit shell and also break the larger size seeds into smaller to make it easy for expel the oil. The decorticator (figure 3.2) contained a motor of 1.5 kW, which connected with the rotor. There are three blades mounted at the outer periphery of the rotor. The rotor is rotated with 2800 rpm. The seeds/kernel or copra are interred into the rotating rotor through a hopper. The seeds are strikes to rotor blade and results of that the larger seeds break into a smaller size. Similarly, while the dry fruits are a strike to this rotating rotor, fruit shells and kernel seed are separated with each other. This decorticated are transferred to expeller unit to extract the oil. The capacity and power of decorticator are 150 kg/h and 1.5 kW.

Figure 3.2: Seed decorticator

3.2.2 Expeller

The extractions of oil from decorticated seeds have been done with screw press expeller (also known as oil pressing) of 5.5 kW with capacity 50 kg/h (figure 3.3). This is a mechanical method for extracting oil from seeds. There is a continuous supply of seeds to expeller though hopper where the seeds are squeezed under high pressure. As the seeds are entering one side of the press and its cake is exit another side. The filtered oil seeps to bucket continuously through small openings. The by-product (seed cake) is obtained during this process can be used as organic manure, cattle feed, biogas production, etc. Table 3.1 show the amount of extracted oil and seed cake from Copra (coconut), Castor, Mahua, Neem, and Linseed oil seeds.

Figure 3.3: Expeller

3.2.3 Filter

The oil obtained from the expeller units having some impurities such as dust particles and seed cake residues. These impurities removed with the filter press (figure 3.4). It has a capacity of 600 kg/h with consuming 1.5 kW power. There are eight layers of cotton filter presents in this unit. The oil at high pressure is passed through these filters with the help of a pump. As per requirement of filtering level, the oil is passed through the different cotton layer.

Figure 3.4: Filter press

Table 3.1: Produced crude oil and seed cake at lab

Sr. No.	Seed (kg)	Extracted oil (kg)	Oil yield (%)	Seed cake (kg)	Cake yield (%)
1. Coconut	22.0	12.5	56.8	9.5	32.2
2. Castor	25.0	9.5	38.0	15.5	62.0
3. Mahua	23.0	9.0	39.1	14.0	60.9
4. Neem	25.0	10.0	40.0	15.0	60.0
5. Linseed	22.0	8.5	38.6	13.5	61.4

3.3 Biodiesel Production

The filtered oil obtained from the filter press is used for biodiesel production. Biodiesel production processes have been conducted on the transesterification unit (figure 3.6). The parts of this unit are acoustic mixing tank, reactor, condenser, receiver, washing tank and biodiesel storage tank. There is two motor also presents in this unit. The Acid-esterification (pre-treatment) and Trans-esterification have been adopted for conversion of biodiesel.

3.3.1 Acid-Esterification

This process has conducted on the trans-esterification unit. Generally, it is known as the pretreatment process. It has been conducted to decrease the fatty acid of oil and soap formation and hence increases the yield during the transesterification process. The esterification process is done only for those oils that contain more than 2% free fatty acids (FFA). Since the vegetable oil such as Neem, Coconut, Linseed, Mahua, Jatropha, Palm, Karanja, and Tung possess more than 2% FFA [39].

The esterification of oil has done with alcohol (methanol 30% of oil by volume) and acid catalyst (H_2SO_4 1% by volume). The acid catalyst H_2SO_4 and methanol are mixed in coustic mixing tank for half an hour. This mixture is transferred to the reactor, where crude oil already presents. These mixtures are heated in the reactor for 1.5-2 hour and maintain the temperature 65^{o}C. Then the mixture is poured into a separating funnel to separate the impurities, H_2SO_4 and excess methanol. The esterified oil is settled down below the impurities, H2SO4, and excess methanol. Thus, the esterified oil is separated for making the biodiesel (methyl ester) through alkaline transesterification process. Table 3.2 shows the amount of esterified oil, recovered methanol after esterification process of selected oil (Coconut, Castor, Mahua, Neem and Linseed)

3.3.2 Alkaline Trans-esterification

The esterified oil is separated from the funnel and poured into the reactor. After that, the trans-esterification reaction has been carried out at 65^{o}C temperature for two hours to convert in the Methyl Esters as Biodiesel (figure 3.5). Methanol (25-30% v/v of bio-oil) as alcohol and NaOH/KOH (0.5-1% wt/v of bio-oil) are taken as a catalyst during the transesterification reaction [213-215]. The mixtures of alcohol and catalyst have been prepared in the caustic mixing tank for half an hour. This prepared mixture is transferred to the reactor, where esterified oil already presents. The mixtures are heated in the reactor for 1.5-2 hour and maintain the temperature 65^{o}C for completion of transestertification reaction. After this period, the transestrified oil (mixture) is transferred to the washing tank, where it is mixed with water directly for the separation of methyl ester from glycerol. The whole mixture is left for 12, 24, 48 or 72 hours depending on the type of vegetable oil. Three layers are formed after this specified period. The vegetable oil methyl ester (biodiesel) settled at top, glycerine in middle and wastewater (impurities) at the bottom (figure 3.8: c). By gravity, glycerol and wastewater are settled down in the lower layer. The waste water is removed, and glycerin and biodiesel remain in the funnel (figure 3.8: d). The glycerine is separated (figure 3.9) and biodiesel transfer to the biodiesel storage tank.

The obtained biodiesel is having some impurities, such as the trace of catalyst, glycerol, and methanol. The washing process further purifies the impure biodiesel. The amount of biodiesel, glycerine, and recovered methanol after the transesterification process from the esterified Coconut, Castor, Mahua, Neem, and Linseed oil has been shown in table 3.2.

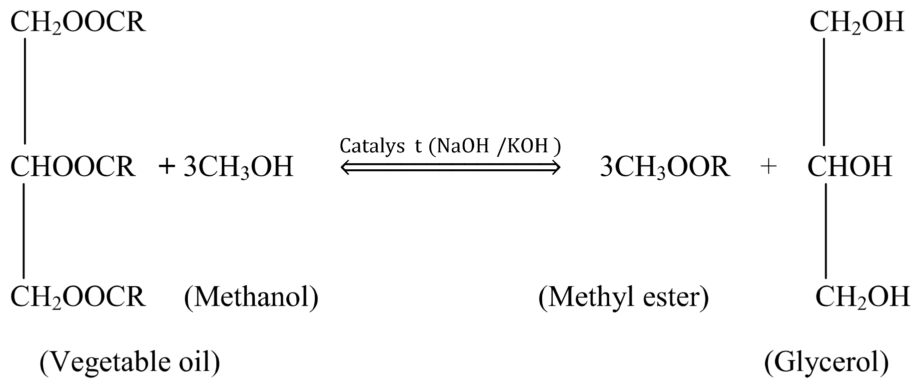


Figure 3.5: Transesterification reaction

3.3.3 Description of transesterification unit

(a) Caustic mixing tank

In this, alcohol and catalyst mixed. The caustic mixture connected with the electric motor as shown in the figure 3.6, part number-1. The motor has the power 0.37 kW and running at 1410 rpm. It runs for half an hour for proper mixing of catalyst (acid or base) and alcohol.

(b) Reactor

It has 50 litre of capacity to produce the biodiesel. Both esterification and trans-esterification process have taken place in the reactor (figure 3.6, part number-2). Initially vegetable oil preheated (upto 100 ^{o}C) in reactor for removing the moisture. The prepared mixture of catalyst and alcohol is transfer to reactor where preheated vegetable oil already presents. For the esterification and trans-esterification the mixture of vegetable oil, alcohol and catalyst is heated at 65^{o}C for 1.5-2 hour.

(c) Condenser

While the mixture in reactor heated at 65^{o}C for esterification and trans-esterification the alcohol starts vaporising. This vaporised alcohol is condensed in condenser (figure 3.6, part number-3). This condensed alcohol is transfer to reactor or collected into receiver. The centrifugal pump is used to circulate the water in condenser for condensation of alcohol. The pump has run at 2800 rpm speed with consuming 0.75 kW power.

(d) Receiver

The condensed alcohol in condenser is collected in receiver (figure 3.6, part number-4). This alcohol is reused for biodiesel production.

(e) Washing tank

After 1.5-2 hour, the heated mixture of alcohol, base catalyst (NaOH/KOH) and vegetable oil transferred through the reciprocating pump to washing tank (figure 3.6, part number-5) where it directly mixed with water. The pump has the power 0.75 kW and running at 2800 rpm speed. After washing the mixture is kept for 12 hours, after that there are three layers formed. The vegetable oil methyl ester (biodiesel) settled at top, glycerine in middle and impurities at the bottom by gravity (figure 3.8; c). The glycerine and biodiesel are separated. The biodiesel is transfer to the biodiesel storage tank. Glycerine used for making organic shop and hand wash.

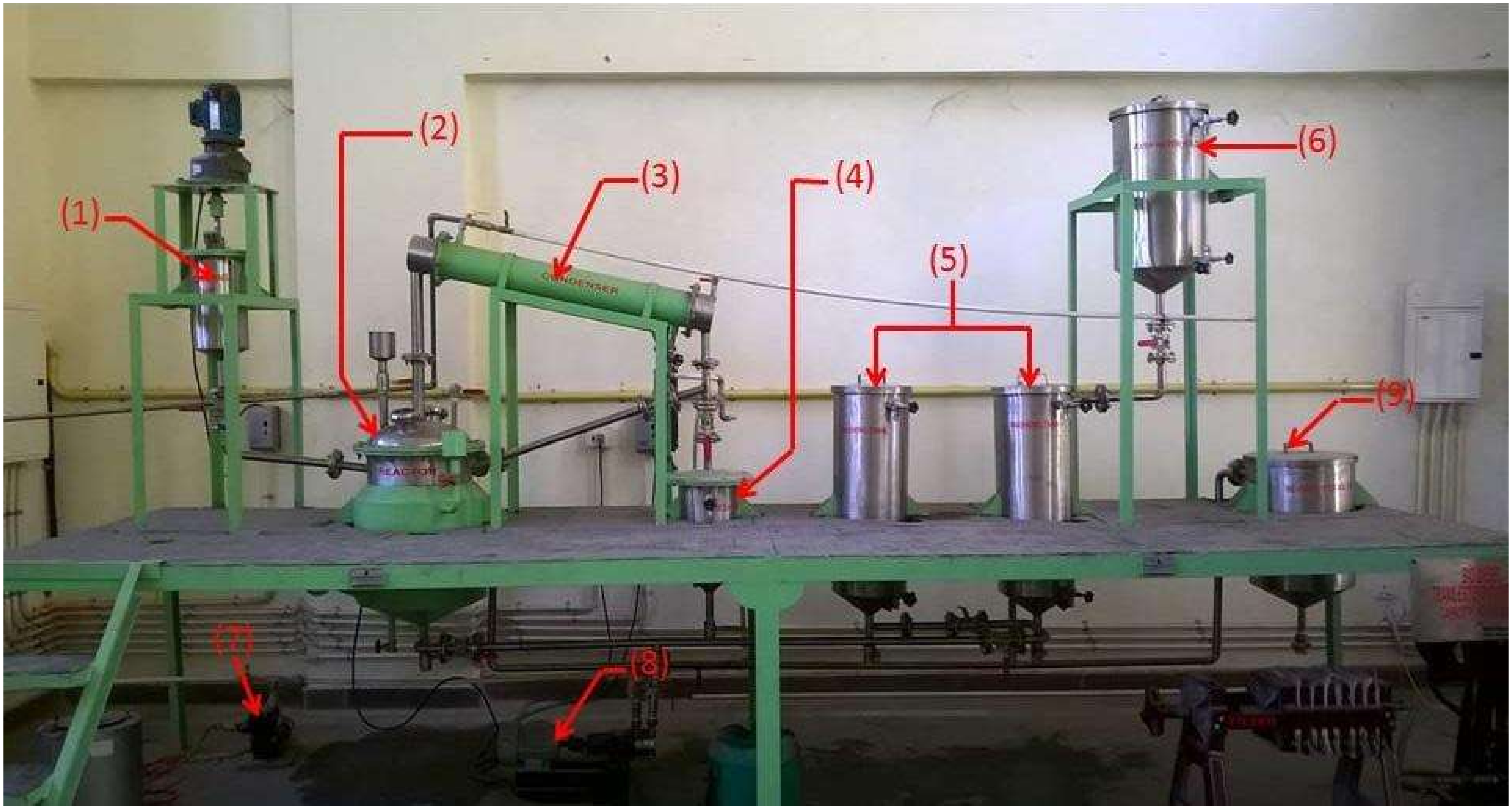


Figure 3.6: Transesterification unit

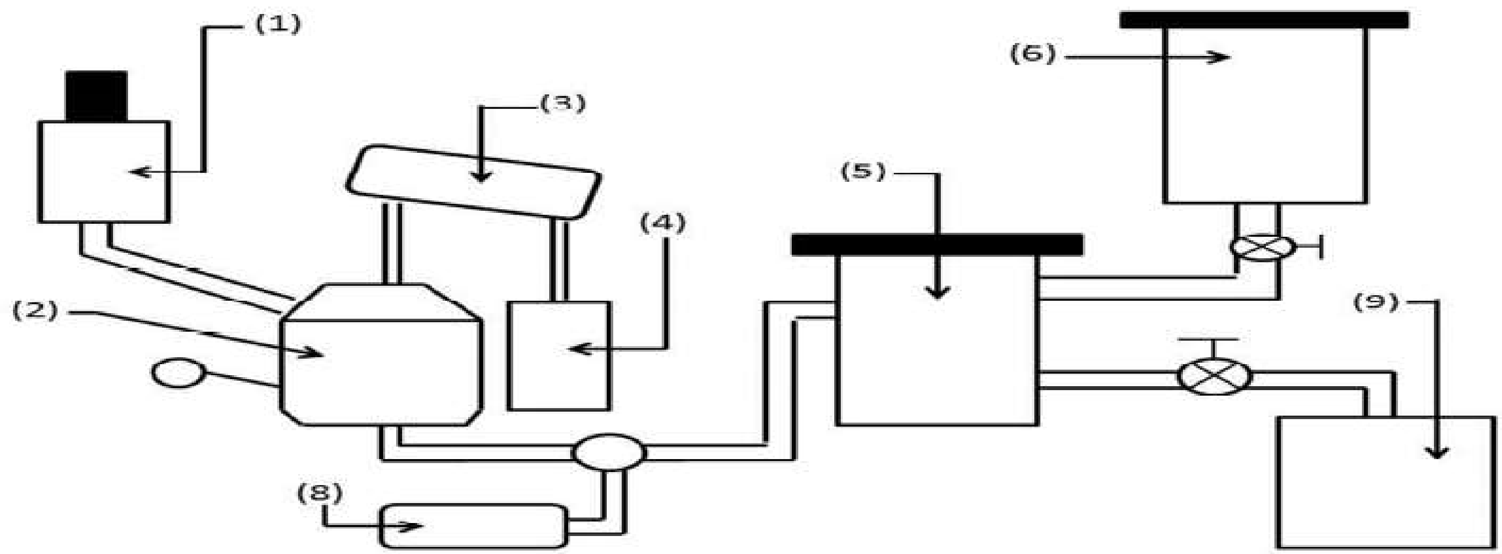


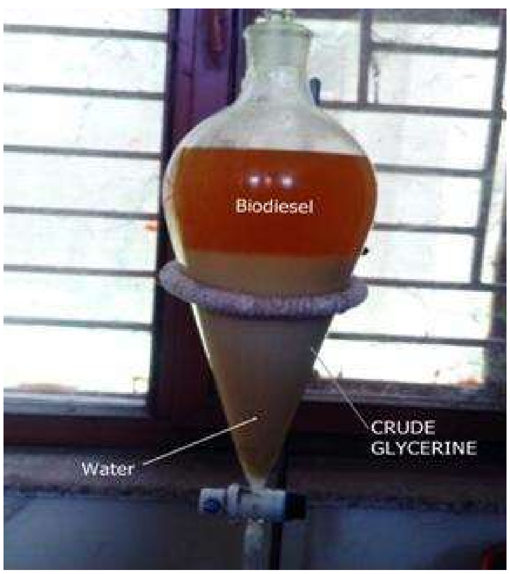
Figure 3.7: Schematic diagram of trans-esterification unit

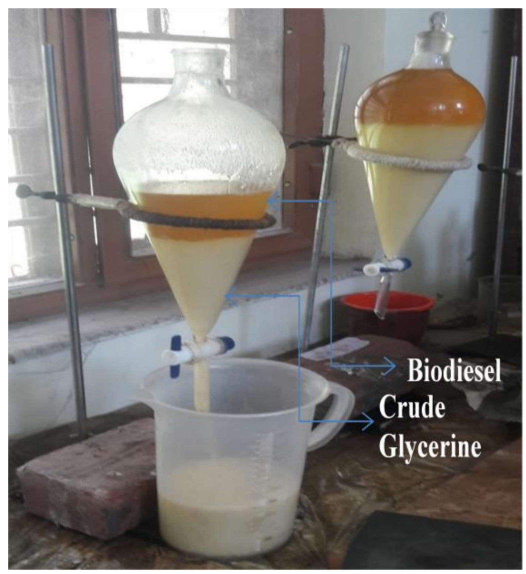
Name of part figure 3.6 and 3.7:-

1 = Caustic mixing tank 2 = Reactor 3 = Condenser 4 = Receiver 5 = Washing tank 6 = Washing water

7 = Centrifugal pump 8 = Reciprocating pump 9 = Biodiesel storage tank

(a) (b)





(c) (d)

Figure 3.8: Diiferent process during the production of biodiesel from the selected seeds

(a) Filling of oil in the reactor (b) Washing tank, (c) Three later (d) Two layer

Figure 3.9: Separation of gycerine and biodiesel

Table 3.2: Produced biodiesel at lab

	Esterification	**Trans-esterification**
1. Coconut	**Input:** Crude coconut oil = 7300 ml Methanol = 2190 ml (30% v/v) H_2SO_4 = 73 ml (1% v/v) **Output:** Esterified oil=7650 ml Methanol recovered = 1340 ml (61.19 %)	**Input:** Esterified oil=7650 ml Methanol= 2190 ml (30% v/v) NaOH =73 gram (1% w/v) **Output:** Coconut biodiesel = 6700 ml (91.78 %) Glycerine = 1400 ml (19.19%) Methanol recovered = 950 ml (43.37%)
2. Castor		**Input:** Crude castor oil = 8000 ml Methanol = 2400 ml (30% v/v) NaOH = 80 gram (1% w/v) **Output:** Castor biodiesel =7300 ml (91.25 %) Glycerine= 750ml (9.37%) Methanol recovered = 1200 ml (50%)
3. Mahua	**Input:** Crude mahua oil = 7700 ml Methanol = 2310 ml (30% v/v) H_2SO_4 = 77 ml (1% v/v) **Output:** Esterified oil=7900 ml	**Input:** Esterified oil = 7900 ml Methanol = 2310 ml (30% v/v) NaOH =77 gram (1% w/v) **Output:** Mahua biodiesel = 6800 ml (88.31%)

	Methanol recovered = 1355 ml (58.66%)	Glycerine = 700 ml (9.09%) Methanol recovered=1080 ml (46.75%)
4. Neem	**Input:** Crude neem oil = 8500 ml, Methanol = 2150 ml (25% v/v) H_2SO_4 = 85 ml (1% v/v) **Output:** Esterified oil=8500 ml Methanol recovered = 1450 ml (67.44%)	**Input:** Esterified oil=8500 ml Methanol = 2150 ml (30% v/v) NaOH = 85 gram (1% w/v) **Output:** Neem biodiesel = 7700 ml (90.58 %) Glycerine = 950 ml (11.18%) Methanol recovered = 950 ml (44.19%)
5. Linseed	**Input:** Crude linseed oil = 8000 ml Methanol = 2400 ml (30% v/v) H_2SO_4 = 80 ml (1% v/v) **Output:** Esterified oil = 8300 ml Methanol recovered = 1395 ml (58.12%)	**Input:** Esterified oil=8300 ml Methanol = 2400 ml (30% v/v) NaOH =80 gram (1% w/v) **Output:** Linseed biodiesel = 7150 ml (89.37%) Glycerine = 780 ml (9.75%) Methanol recovered = 1133 ml (47.21%)

3.4 Testing of biodiesel on VCR engine

3.4.1 Experimental Set-up

Figure 3.10 and 3.11 shows the view and schematic diagram of the experimental setup, respectively. The engine details are given in table 3.3. The experimental setup comprises of single-cylinder, 4-stroke, multi-fuel, and for varying load research engine connected to eddy current type dynamometer. Figure 3.12 shows detail of different supply line and temperature, and figure 3.13 shows the valve timing diagram of VCR engine. The mode of operation of the engine can be changed from Petrol to Diesel or from Diesel to Petrol mode with changing the engine load. Compression ratios in both modes can be varied without stopping the engine and without changing the geometry of the combustion chamber. During the operation, the compression is changed by tilting cylinder block arrangement. It helps to optimize the engine's performance in its entire operating range. The air temperature, the coolant temperature, the throttle position, and the trigger sensor are connected to the open ECU that controls the ignition coils, fuel injectors, fuel pumps, and idle air.

The experimental set-up is provided with the necessary instruments for measurements of combustion pressure, diesel line pressure, and crankshaft angle. During engine operation, the signals of a complete cycle of rotation of the crankshaft angle were transferred through the piezoelectric power unit for the pressure crank angle and the pressure-volume diagram. The experimental setup integrated with computer software "ICEngineSoft" to evaluate the engine performance and combustion. RTD, PT 100 and thermocouple are used for measuring the temperature at several points of the engine. Digital voltmeter (0-20 V) and strain gauge type load sensor (0-50 kg) are used for showing the voltage and load, respectively. Instruments are provided to interface airflow, fuel flow, temperatures, and load measurements. Set-up has a stand-alone panel box in which there is manometer, fuel measuring unit, the transmitter for air and fuel flow measurement, process indicator, hardware interface, air box and two fuel tanks for duel fuel test. Rotameters are provided for measuring the flow of cooling water and calorimeter water in the engine. The exhaust gas heat measured with a pipe type calorimeter, in which water circulated at a rate of 25-250 LPH (litre per hour). Engine cooling water circulated at the rate of 40-400 LPH. Selfpriming pumps have been used for circulation of water in the calorimeter. A battery, starter, and battery charger are provided for the engine electric start arrangement. The experimental setup was used to analysis of variable compression ratio (VCR) engine performance with respect to brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio, heat balance, and combustion analysis.

Table 3.3: Engine specification

General details	Kirloskar make, 4 stroke, single cylinder, water cooled, compression ignition, multi-fuel, VCR
Product code	240PE
Rated power	3.5 kW at 1500 rpm
Compression ratio	17.5:1 (range 12:1 to 18:1 variable)
Bore	87.5mm
Stroke	110mm
Capacity	661 cc
Injection timing	23^{o} bTDC (range 0-30^{o} bTDC)
IVO / IVC	4.5° bTDC / 35.5° aTDC
EVO / EVC	35.5° bTDC / 4.5° aTDC

Dynamometer	Type eddy current, water cooled, with loading unit
Temperature sensor	Type RTD, PT100 and Thermocouple, Type K
Calorimeter	Pipe in pipe
Fuel tank	Capacity 15 lit, Type: Duel compartment, fuel metering pipe of glass
Air flow transmitter	Pressure transmitter, Range (±) 250 mm WC
Fuel flow transmitter	DP transmitter, Range 0-500 mm WC
Piezo sensor	Combustion: Range 5000 PSI, with low noise cable Diesel line: Range 5000 PSI, with low noise cable
Load indicator	Digital, Range 0-50 Kg, Supply 230VAC
Load sensor	Load cell, type strain gauge, range 0-50 Kg
Crank angle sensor	Resolution 1 Deg, Speed 5500 RPM with TDC pulse.
Propeller shaft	With universal joints
Pump	Monoblock
Software	"ICEnginesoft" Engine performance analysis software
Digital voltmeter	Range 0-20V, panel mounted
Overall dimensions	W 2000 x D 2500 x H 1500 mm

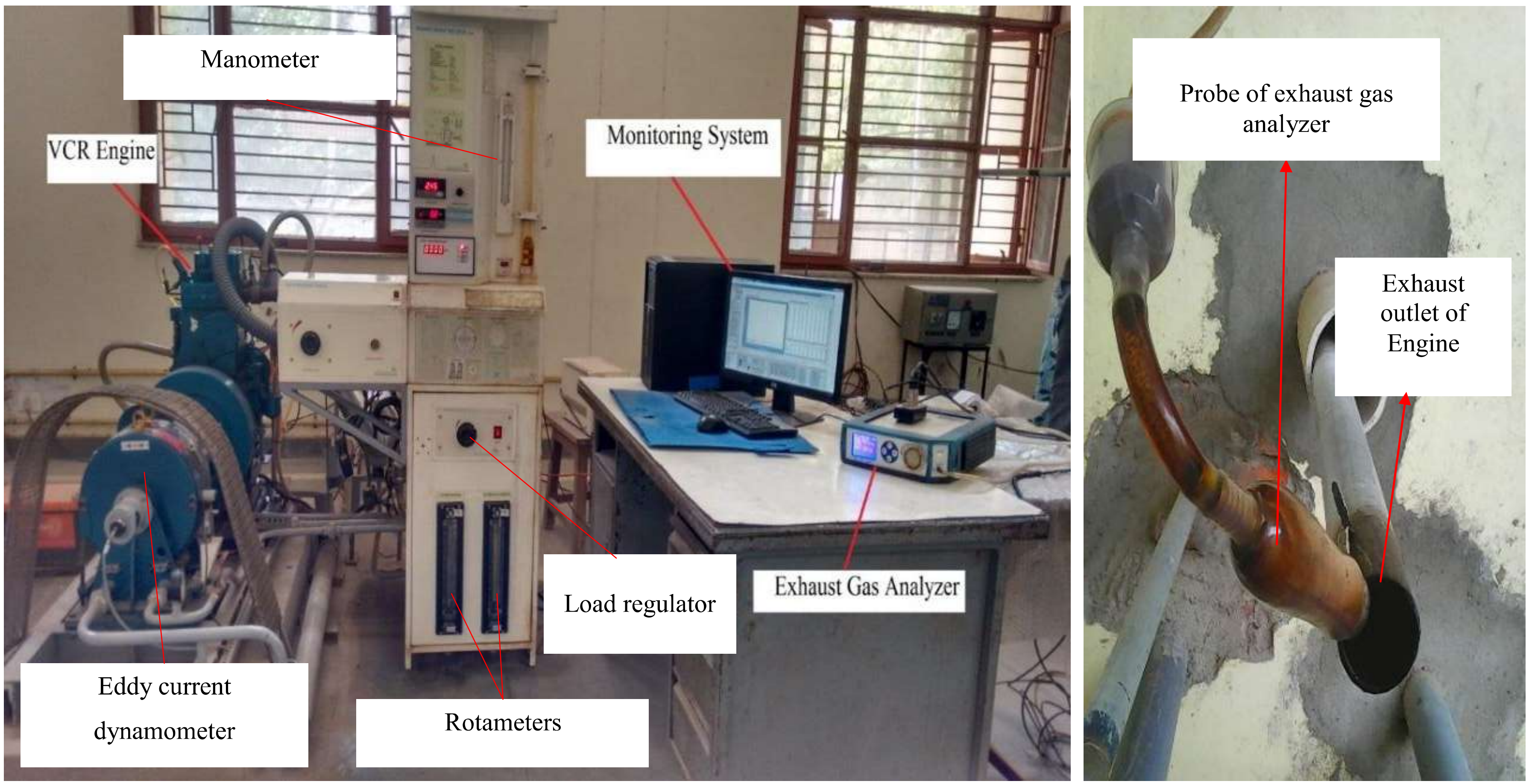


Figure 3.10: Experimental setup (VCR engine and Gas analyser)

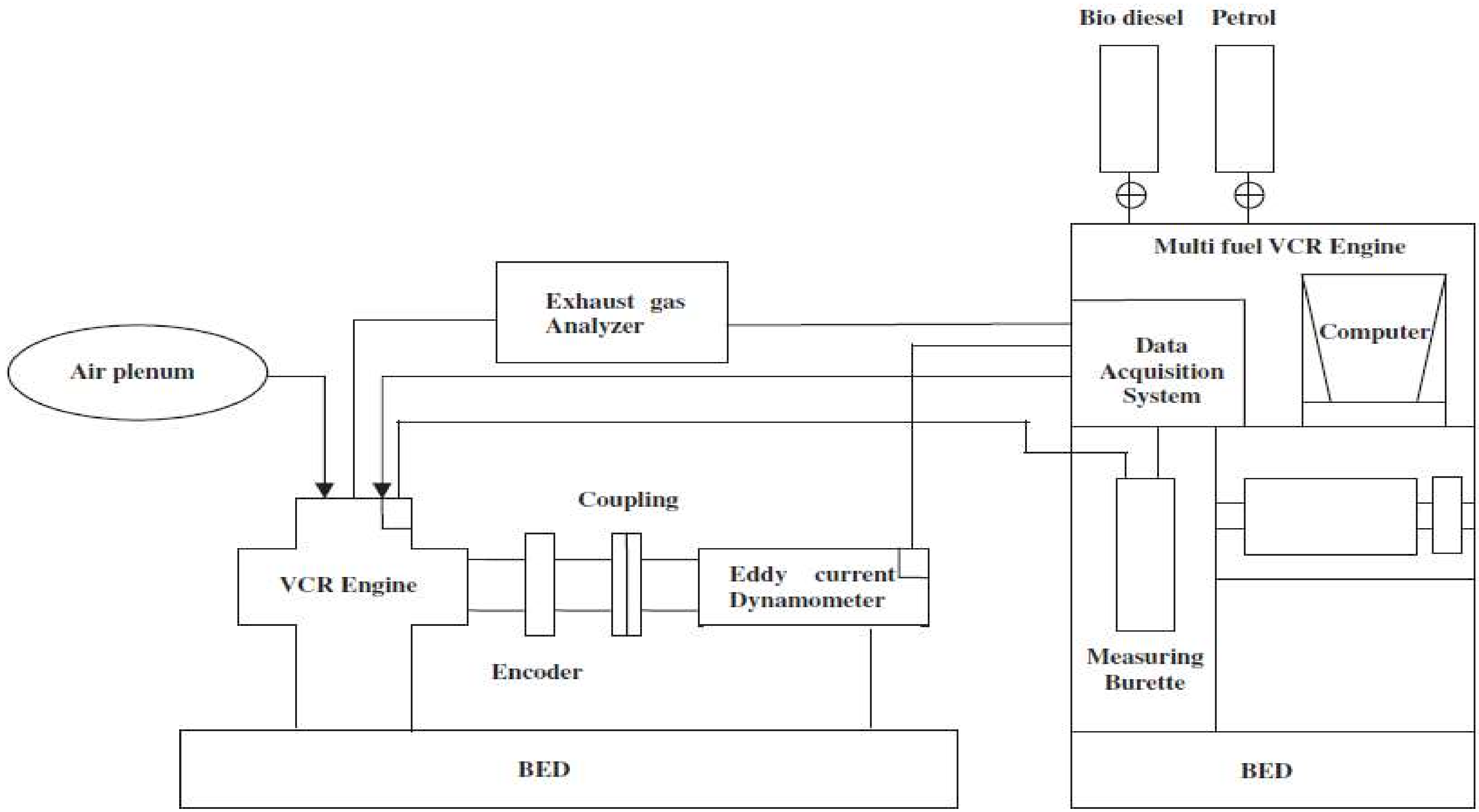


Figure 3.11: Schematic diagram of the experimental set up

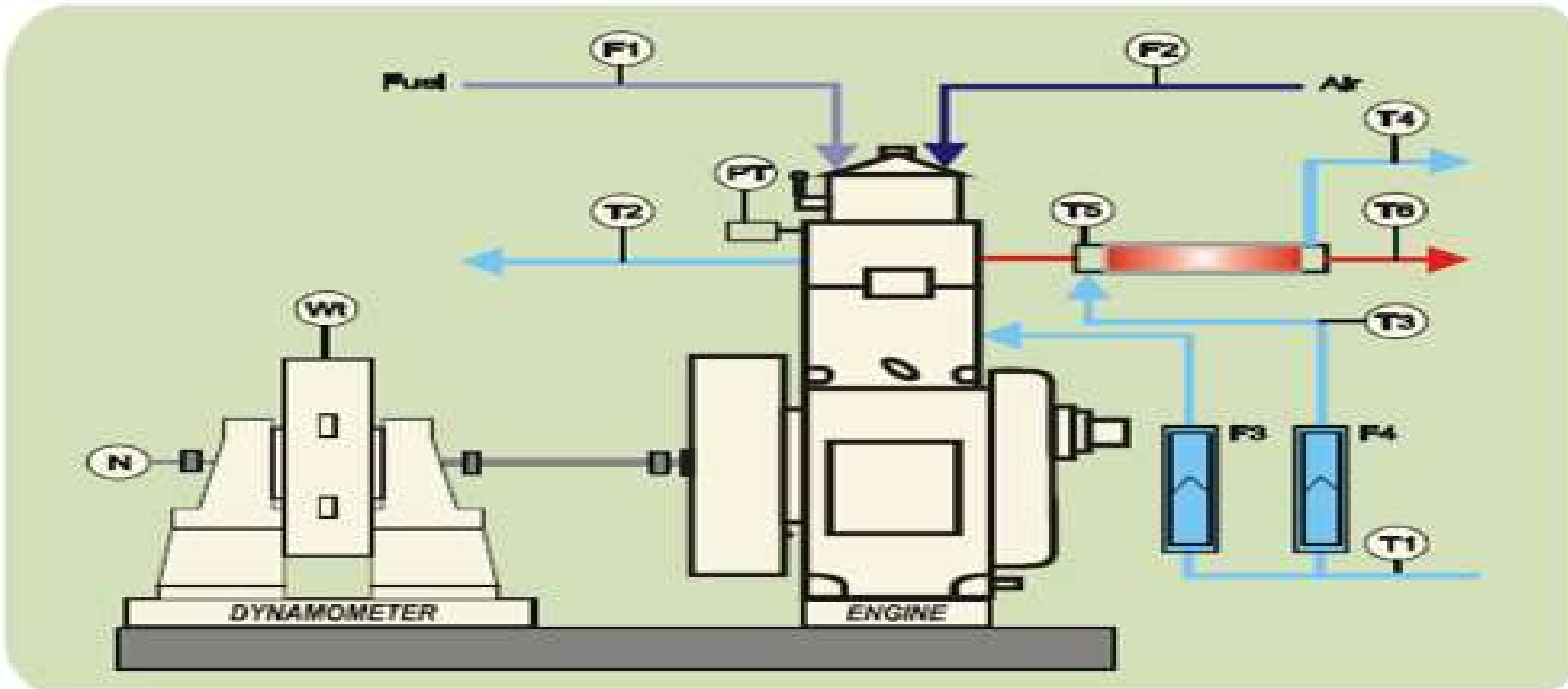


Figure 3.12: Schematic diagram of VCR Engine

Figure 3.12 shows the different supply line and temperature; Where, F1 = Fuel supply line, F2 = Air supply line, PT = Pressure transducer, T1 =T3 is the water temperature at the inlet of engine and calorimeter, T2 = Water outlet temperature, T4 = Water temperature at the outlet of calorimeter, T5 = Exhaust gas temperature, T6 = Exhaust temperature at outlet of calorimeter

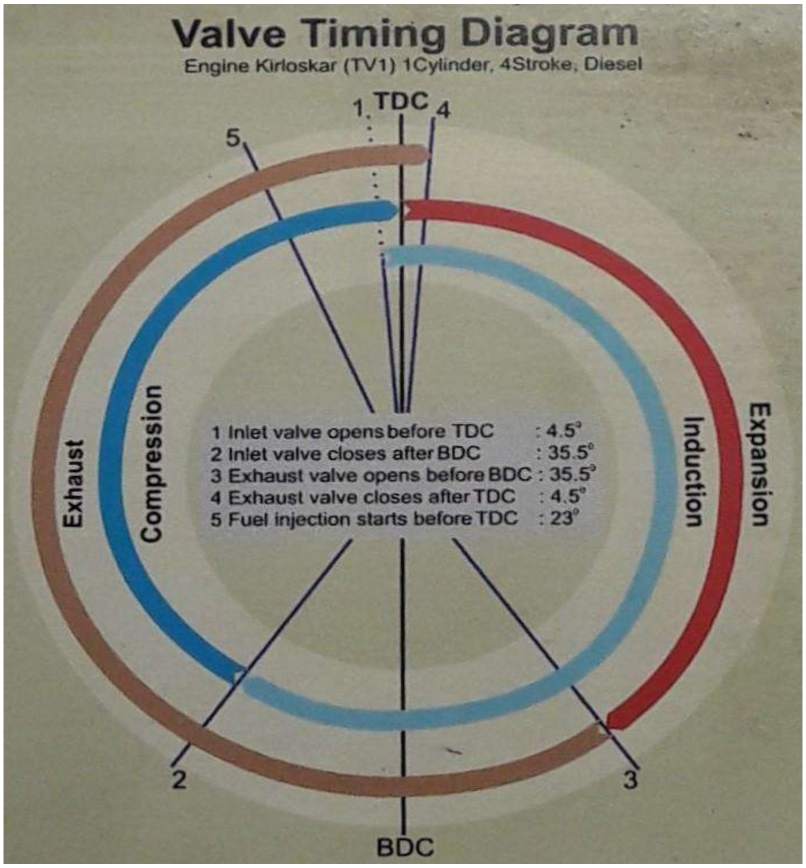


Figure 3.13: Valve timing diagram

3.4.2 ICEngineSoft

ICEngineSoft version 9.0 is a 32-bit interface, and it requires Microsoft Windows 7 and Microsoft Office Excel 2007 on the machine. The software has developed by Apex Innovations Pvt for monitoring the performance of the engine. It can serve mostly engine testing applications like monitoring, reporting, data entry, data logging. The software analyses the engine power, heat release, efficiencies, and fuel consumption. The several graphs and table have obtained at different operating condition of the engine. During RUN mode, the required signals are scanned, stored, and presented in the graph while conducting the online testing of the engine. The entire data file stored in the system, and it can be view in data graphical and tabular formats. The results and graphs report are generated. The data in Excel format used for further analysis. The following tests have been conducted with ICEngineSoft:-

(a) Combustion analysis

ICEngineSoft evaluates combustion data as:

- Cylinder pressure reference value
- TDC value
- Polytropic index
- Indicated mean effective pressure (IMEP)
- Indicated power (IP)
- Cylinder volume
- Log Pressure and Log Volume
- Rate of pressure rise
- Net heat release
- Start of combustion (SOC) and end of combustion (EOC)
- Cumulative heat release
- Mass fraction burned (MFB)
- MFB 5%, MFB 10%, MFB 50% & MFB 90%
- Mean gas temperature
- Fuel line pressure
- Respective average cycle data
- MAX values and corresponding angles

(b) Performance against load/speed for constant/variable speed engines

EngineSoft evaluates Performance data as:

- Brake power (BP)
- Frictional power (FP)
- Torque
- Brake mean effective pressure (BMEP)
- Frictional mean effective pressure (FMEP)
- Brake thermal efficiency (BTE)
- Indicated thermal efficiency (ITE)
- Frictional thermal efficiency (FTE)
- Mechanical efficiency (ME)
- Volumetric efficiency (VE)
- Air Flow
- Fuel Flow
- Brake specific fuel consumption (BSFC)
- Air fuel ratio (AFR)
- Heat equivalent to brake power (HBP)
- Heat in jacket cooling water (HJW)
- Heat in exhaust gas (HGas)
- Heat to radiation (HRad)

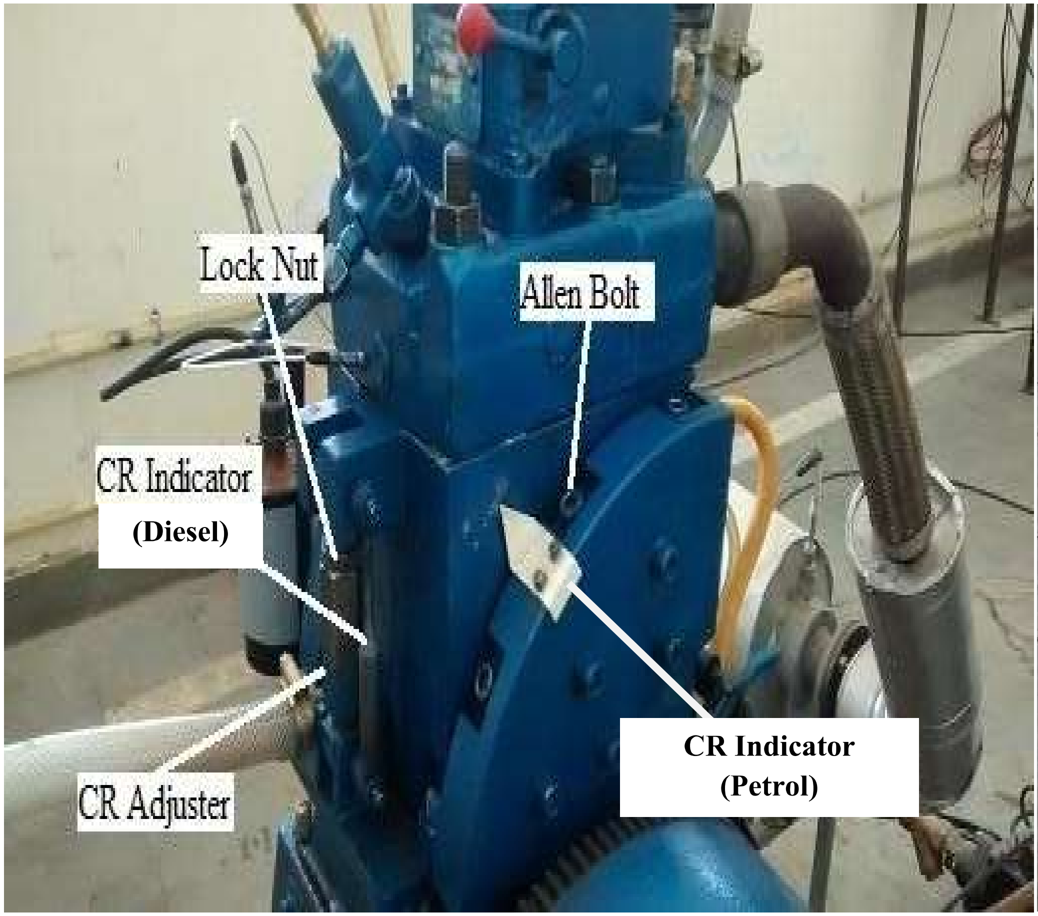
3.4.3 Experimental methodology

The experiments have conducted on Kirloskar made VCR diesel engine. After production of biodiesel, performance and emission analysis have been performed at different compression ratio. Fuel injection timing is fixed (23^{o} bTDC). All the tests performed at the constant speed (1500 rpm) of the engine. Castor, Linseed, Mahua, and Neem biodiesel are blended with diesel in a proportion of 10%, 20%, 30% and 50% (B10, B20, B30, and B50) are used to run the VCR engine at different compression ratios (15, 16, 17 and 18). There are different steps which are required to perform testing of biodiesel blends:-

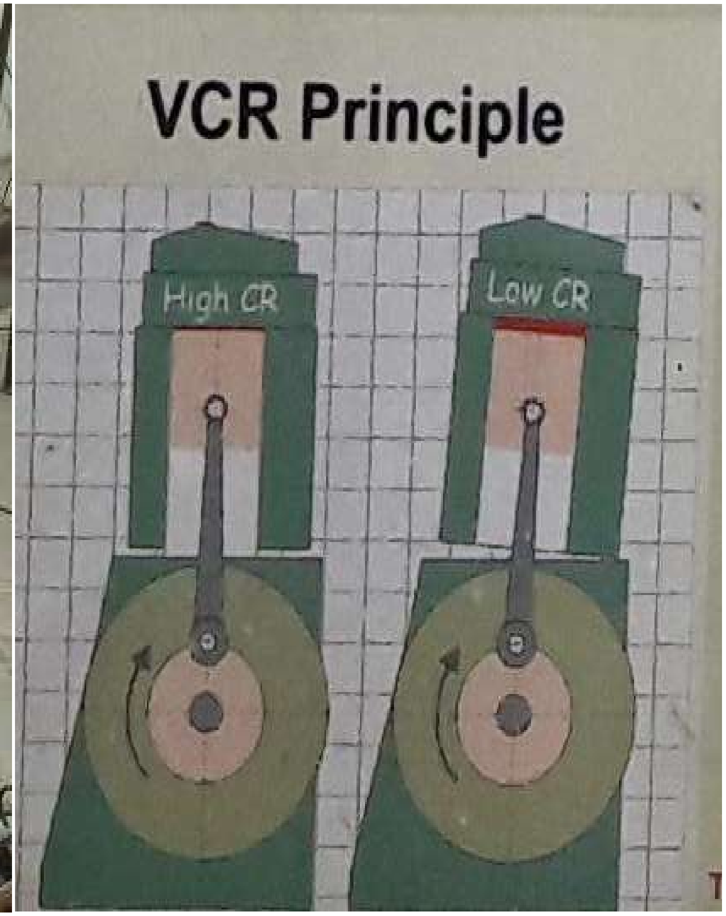
- Before filling the oil in fuel tank, find out the value of calorific value (by using bomb calorimeter) and density (by measuring mass and volume) of fuel.
- Then run all pumps, maintain water flow rate in calorimeter 200-250 litre/hour and through engine 80-100 litre/hour.
- Start engine at no load condition and at compression ratio 18 so that it can be start easily. And after steady running CR was changed from 18 to 15 during the running condition and load is increased by 0-12 kg for analysis.
- Portable AVL digas 444 gas analyzer has used for measuring the exhaust emissions-CO (vol %), CO_2 (vol %), NOx (ppm), unconsumed oxygen O_2 (vol %) and unburnt HC (ppm) at tail pipe of the engine.
- After that start taking reading at compression ratio 18 and reading from gas analyzer which gives the constituent of exhaust gases.
- After taking all reading and generate the performance and combustion report by ICEngineSoft.
- The exhaust gas emissions such as carbon monoxide (CO) and oxides of nitrogen (Nox) are measured and noted.
- After that changed the compression ratio while engine running condition. Before changing the compression ratio engine is set to zero load condition.
- The procedure of changing the compression ratio: - Arranement for adjustments of the compression ratio have been shown in figure 3.14. It has done with slightly

loosen 6-Allen bolts which provided for clamping the tilting block. All the lock nut loosens on the adjuster and rotates the adjuster so that the compression ratio is set to “maximum”. Refer the marking on the CR indicator. Lock the adjuster by the lock nut and tighten all the 6 Allen bolts gently.

- Compression ratios are manually adjusted in VCR engine and its value also changed in the program.
- After taking all reading at 18 CR set the engine at full load condition and changed the compression ratio from 18 to17 and follows the same procedure up to CR 15.
- Repeat the same procedure for the experimental analysis for 20%, 30% and 50% biodiesel blends.
- The value of density and calorific value are changed in EngineSoft program with corresponding fuel used for testing.



(a)



(b)

Figure 3.14: (a) Variable compression ratio adjustments; range of CR for CI: 12-18 and for SI: 6-10 (b) Tilting cylinder block

3.5 Emission analysis

The engine tail-pipe emission measured with portable AVL digas 444 gas analyser (figure 3.15). Table 3.9 shows the technical specifications and uncertainty of AVL gas analyser. It displays the different emissions including; carbon monoxide (CO), carbon dioxide CO_2 unconsumed oxygen O_2 in vol% while nitrogen oxides (NOx) and unburned hydrocarbons (UHC) in ppm (parts per million). The leakage test and hydrocarbon residue test have performed to start the AVL gas analyser. The leakage test conducted for ensuring there is no leakage in the pipeline. The hydrocarbon (HC) residue test performs for checking any HC residue is present in the analyser. If any of these tests failed, then changes the filters and the whole test again conducted.

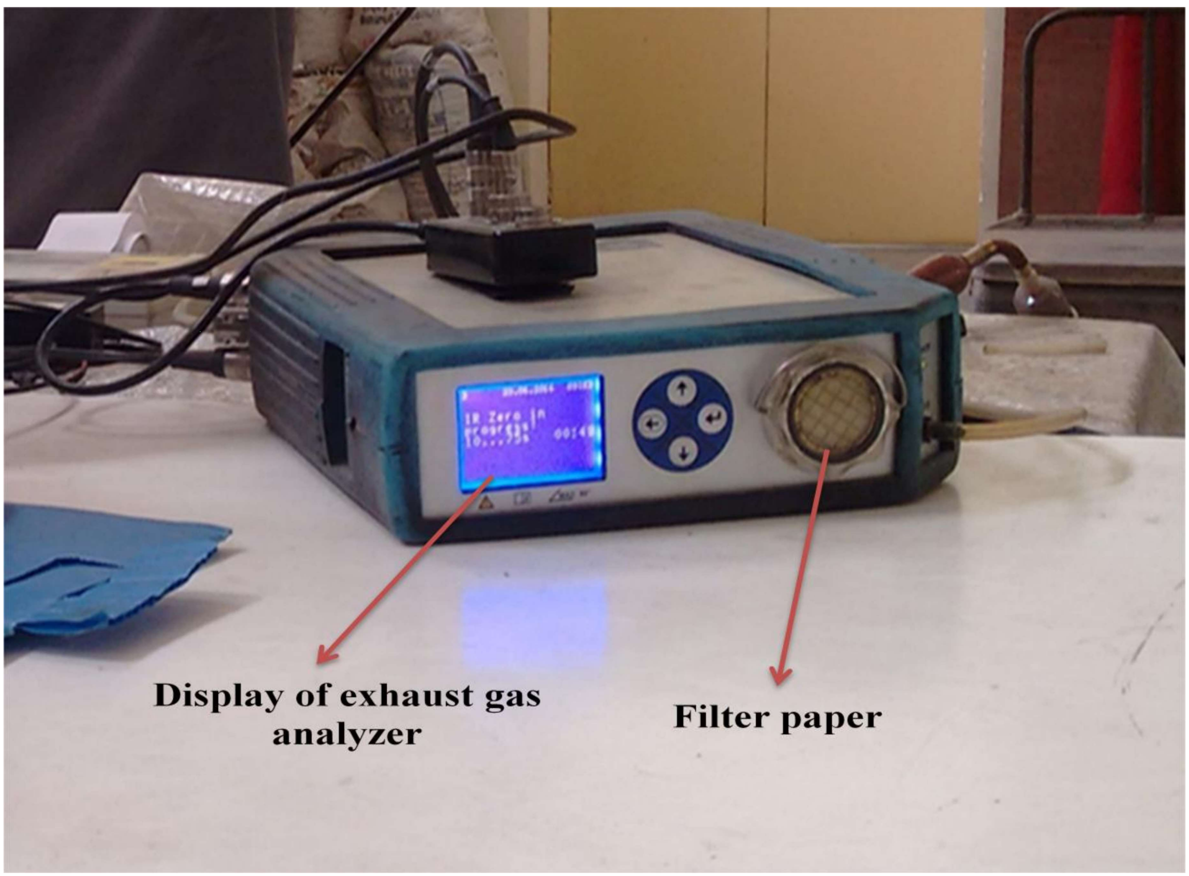


Figure 3.15: AVL 444 Gas analyser

3.6 Instrumentation

3.6.1 Measurement of calorific value

It is the amount of heat energy released with combustion of the unit value of a fuel. It is of two types: higher calorific value (HCV) and lower calorific value (LCV). In HCV water vapours in product condense. Thus, HCV includes latent heat of vaporization while in case of LCV water vapours formed by combustion leaves as vapour itself. The Bomb calorimeter is used for calculating the higher calorific value of diesel, biodiesel and its blends, which installed in our IC Engine Lab (figure 3.16). It is also known as constant volume calorimeter that used for measuring the heat of combustion. Table 3.4 shows the measured higher calorific value of different selected crude oil including; Coconut, Castor, Mahua, Neem and Linseed and its biodiesel blends. Among these, the calorific value of Neem biodiesel is comparable to diesel. In the current calorimeter design, the bomb is pressed with pure oxygen 25-30 times, in which there is a known mass of fuel (usually taken 1 gram) is dipped beneath the known amount of water. The Bomb forms a closed system, and it ignited electrically. The energy released with the combustion of fuel present in the Bomb as a result of this increases the temperature of the bombs and surrounding water jackets.

The calorific value is calculated by following formula:-

$$M_{fuel} \bullet CV_{fuel} + M_{thread} \bullet CV_{thread} + M_{wire} \bullet CV_{wire} = M_{water} \bullet C_{p_{water}} \bullet \Delta T$$

Where: M_{fuel} = Mass of the fuel

M_{thread} = Mass of cotton thread in grams

M_{water} = Mass of water (2 kg)

CV_{fuel} = Calorific value of fuel

CV_{thread} = Calorific value of thread (4.18 kcal / kg)

CV_{wire} = Calorific value of Nichrome ignition wire (0.335 kcal / kg)

$C_{p_{water}}$ = Specific heat capacity of water (1.0 kcal / kg)

ΔT = Increase in the temperature of the surrounding water jacket

Figure 3.16: Bomb calorimeter and bomb with carrier

3.6.2 Measurement of density

It is defined as the mass per unit volume (kg/m^3). Some of the searchers preferred the specific gravity, which is the dimensionless term and defined as the ratio of the density of the fluid to density of the standard fluid (water). Generally, biodiesel has a higher density compared to diesel fuel. That means the injector will inject a greater amount of biodiesel fuel volumetrically in comparison to diesel. The density of different crude oil, biodiesel, and biodiesel blends are measured manually. Table 3.5 shows the comparative density of selected crude oil and its biodiesel blends.

Table 3.4: Calorific value of different biodiesel (measured)

S.No	Biodiesel	Calorific value (Kj/kg)					
		Crude oil	B100	B10	B20	B30	B50
1	Coconut	29957	31755	35125	34893	34460	33986
2	Castor	31073	32993	35486	35225	34580	33184
3	Mahua	30945	32838	35552	35445	34398	34396
4	Neem	31373	33124	35828	35971	35089	34664
5	Linseed	28876	31887	34986	34871	34332	34314

Table 3.5: Density of different biodiesel blends (Measured)

S.No	Biodiesel	Density (kg/m^3)					
		Crude oil	B100	B10	B20	B30	B50
1	Coconut	916	895	840	863	868	885
2	Castor	957	949	890	910	930	945
3	Mahua	926	903	870	875	880	890
4	Neem	923	915	860	880	900	910
5	Linseed	921	900	850	860	870	890

3.6.2 Measurement of viscosity

It is the property of fluid by which it offers resistance to flow. The viscosity of fuel affects the injector lubrication and fuel atomization. The fuel with lower viscosity cannot give sufficient lubrication for the exact fit of fuel injector pumps, and the result of this increased the wear and leakage. On the other hand, smaller droplets are formed using low viscous fuel, which provides the proper combustion. The viscosity of coconut, castor, neem, mahua, and linseed oil is very high. The viscosity of these selected oils is reduced with the transesterification process and comes very close to diesel. Brookfield viscometer (figure 3.17) is used to measure the viscosity of these oils and its biodiesel. Table 3.6 shows the comparative viscosity of different crude oil and its biodiesel.

Figure 3.17: Brook field viscometer

Table 3.6: Viscosity of different crude oil and biodiesels (measured)

S.No.	Oil	Crude oil (cSt)	Biodiesel (cSt)
1	Coconut	35.23	4.50
2	Castor	45.83	6.52
3	Mahua	32.23	5.58
4	Neem	38.89	6.02
5	Linseed	22.63	3.32

3.6.3 Measurement of flash point and fire point

The flash point is the minimum temperature at which fuel ignites with the application of the ignition source under specific condition. The flash point of a fuel inversely varies with the volatility. The fire point of a fuel is the minimum temperature on which the vapours of that fuel will continuously burn at least 5 for seconds after application of the ignition. A high flash and fire point temperature are required for proper safety and operation of fuel. Generally, all vegetable oil and its biodiesel having higher flash and fire point than diesel fuel. Pensky Marten's Apparatus (figure 3.18) used for measure the flash point and fire point of Coconut, Castor, Neem, Mahua, and Linseed crude oil and its biodiesel. Table 3.7 shows the measure flash point and fire point of different crude oil and its biodiesel.

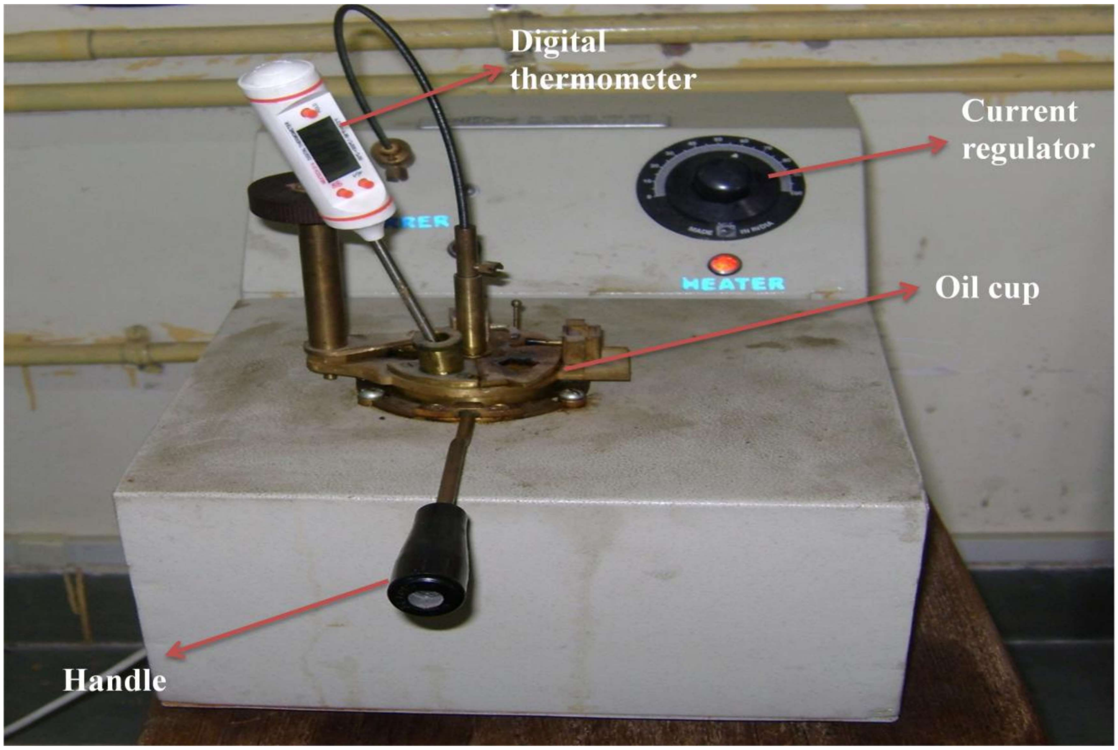


Figure 3.18: Pensky Marten' Apparatus

Table 3.7: Flash and Fire point of different Biodiesel (Measured).

S.No	Name of Oil	Crude oil		Biodiesel (methyl ester)	
		Flash Point (°C)	Fire Point (°C)	Flash Point (°C)	Fire Point (°C)
1.	Coconut	235	265	205	242
2.	Castor	298	335	260	302
3.	Mahua	285	328	248	292
4.	Neem	260	290	240	280
5.	Linseed	225	255	215	270

3.6.4 Acid value and iodine value

Acid value (or acid/neutralization number) is the measure of the number of carboxylic acid groups present in a chemical compound. It also determines the degree of degradation of fuel. It defined as the mass of potassium hydroxide (KOH) in milligrams needed for neutralization of one gram of chemical substance. The acid value of Coconut, Castor, Neem, Mahua, and Linseed crude oil and its biodiesel are measured; in a conical flask, 10 milligrams of crude oil or biodiesel mixed with 100 millilitres and these mixtures are heated in a water bath for 2 to 5 minutes to dissolve completely. In a burette, 0.1N KOH solution is taken. The solution in the conical flask titrated with the 0.1N KOH solution by using phenolphthalein indicator. The titration continued until obtain the continuous pink colour.

Table 3.8: Acid & Iodine values of different biodiesels

S.No. and Name	Crude oil		Biodiesel	
	Acidic value (mgKOH/gm)	Iodine value (mgKOH/gm)	Acidic value (mgKOH/gm)	Iodine value (mgKOH/gm)
1. Coconut	14.025	121.1	0.336	117.8
2. Castor	5.68	84.18	4.36	62.23
3. Mahua	30.0	65.0	0.50	60.00
4. Neem	11.144	75.6	2.87	64.23
5. Linseed	34.5	193.4	0.46	169.50

The iodine number or iodine value is a parameter which used in the determination of the degree of unsaturation in vegetable oil or animal fat. It indicates amount of iodine in grams required to saturate the 100 grams of molecule of given oil completely. Generally, the iodine values of feedstocks vary from 7.8 (for satutared FAME) to 184.5 (for unsaturated FAME), and its average value of 98.4. Table 3.8 shows the acid and iodine values of different crude oil and its biodiesel.

3.7 Experimental Uncertainty

The uncertainty analysis has been used to evaluate the accuracy of the experimental setup (VCR engine and exhaust gas analyzer). Selection of instruments, working condition, results calibration, data observation, reading, and planning of test are responsible for the appearance of system uncertainties and the experimental error. Table 3.9 shows the list of instruments applied, methods of measurement, instruments range, resolution, system accuracy and percentage uncertainties of the system. The experimental parameters, for instance, brake power (BP), brake specific fuel consumption (BSFC), and the formation of nitrogen oxide (NOx) and carbon monoxide (CO) were computed with the use of percentage uncertainty of corresponding measuring instruments. The following equation has been used to calculate the total uncertainty of experimental setup.

Total percentage uncertainty = $\sqrt{}$uncertainty of {$(\text{brake power})^2$ + $(\text{brake specific fuel consumption})^2$ + $(\text{NOx})^2$ + $(\text{CO})^2$ + $(\text{speed})^2$ + $(\text{pressure transducer})^2$ + $(\text{load})^2$ + $(\text{thermometer})^2$ + $(\text{crank angle sensor})^2$ + $(\text{fuel measurement})^2$}.

$$= \sqrt{\{(0.39)^2 + (1.07)^2 + (0.5)^2 + (0.3)^2 + (0.33)^2 + (0.16)^2 + (0.2)^2 + (0.04)^2 + (0.2)^2 + (1.0)^2\}}$$

$= \pm 1.69$ %.

Table 3.9: Instruments details and its uncertainties

Instrument	Method of Measurement	Range	Resolution	Accuracy	Percentage uncertainties
Tachometer	Engine speed :-Magnetic Pick-up	1200-1500 rpm	1 rpm	± 5rpm	±0.33 %
Thermometer	Temperatures:- K-Type Thermocouple	0-1200°C	1 °C	± 2°C	±0.16 %
Eddy current type Dynamometer	Load :- Strain gauge type	0-50kg	0.01 kg	± 0.1kg	±0.2 %
Pressure Transducer	Cylinder Pressure :-Piezo sensor	0-5000psi	---	± 2psi	±0.04 %
Crank angle sensor	Crank angle:- Magnetic pickup type	0^o - 360^o	1^o	± 1^o	±0.2 %
Burette Fuel flow measurement	Volumetric method	---	---	± 0.1 cc	±1.0

AVL digas 444 gas analyzer	Nitrogen oxides (NOx) :- CLD	0-5000ppm vol.	1 ppm vol	< 500 ppm vol: ± 50 ppm vol ≥ 500 ppm vol: ± 10 % of ind. val	±0.5 %
	Carbon monoxide (CO) :- NDIR	0-10 % vol.	0.01 % vol	< 0.6%: ± 0.03 % ≥ 0.6%: ± 5 % of ind. val.	±0.3 %
	Carbon dioxide (CO_2) :- NDIR	0-20 % vol.	0.1 % vol	< 16.0 % vol.: ± 0, 3 % vol. ≥ 16.0 % vol: ± 5 %	±1.0 %
	Oxygen(O_2) :- Electrochemical sensor	0-22 % vol	0.01 % vol	< 2 % vol: ± 0.1 % vol ≥2 % vol: ± 5 % vol	±0.15 %
	Hydrocarbon (HC) :- FID	0-2000ppm vol.	≤ 2000: 1 ppm vol	< 200 ppm vol: ± 10 ppm vol ≥ 200 ppm vol: ± 5 % of ind. val	±0.1 %