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Production and Application of Biodiesel – A Case Study

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***Abstract*—The true fact that everyone has to accept for search of alternative fuels apart from petroleum products is biodiesel for many reasons, mainly increasing demand and scarcity of petroleum products and to preserve the wealth of nature to be used for coming generations. The reason of non implementation of biodiesel in day-to-day life is because of few limitations. Many scientists are in progress for a new dimension of research in biodiesel plantation, cultivation and its usage in engines. This paper highlights the importance of biodiesel production techniques such as supercritical methanolysis, ultrasonication method and microwave technique by which maximum biodiesel can be produced. The new approach of using nano particle in biodiesel shows very good results in reducing the level of pollutant gases in the engine exhaust and increased performance without any engine modification is also discussed briefly in this case study.**

***Keywords*—Hydrodeoxygeneration, nano particle, ultrasonication, microwave technique**

I. INTRODUCTION

Energy is a major need for the development of country and the increase in population needs more energy for both economic and social development.The petroleum products and fossil fuels are a predominant source of energy, but the scarcity of those items and the environmental pollution caused by petroleum fuels are the major uncertainties in the challenging world. Biodiesel is considered to be an alternative fuel to petroleum-based fuel resulting in numerous environmental, economic, and social benefits.Biodiesel benefits include bio-degradable, non-toxic, free from sulphur (< 0.001 %) and 60% less net carbon dioxide emissions. In addition, it has high flash point (greater than 160 ^{0}C) which helps biodiesel by transportation and storage. The important quality that biodiesel posses is that it decomposes more easily when they expose to environment and most importantly they can be produced easily compared to petrol and diesel. Another advantage of using biodiesel is that it eliminates the compound such as polycyclic aromatic hydrocarbons (PAH) and nitrated PAH that causes cancer in humans. The lubrication property of biodiesel dominates more when compared to the diesel fuel and increases the engine life. Biodiesel causes less emission of carbon dioxide (CO_2), hydrocarbon (HC) and particulate matter (PM), which are the dominant factors while compared with diesel. A long run endurance test has been conducted by researchers around the world and proved that it can be easily used in compression ignition engines without any modification. The only drawback in the case of biodiesel such as NOx emission is to be reduced. Many researches are in process for reducing the NOx during and after the combustion process.

The process of production and application of biodiesel is discussed briefly in this case study. The block diagram of biodiesel production is shown in fig 1. The biodiesel is produced not only from the non-edible plants but also from edible plants, chicken fats, beef tallow and waste cooking oils. Balat [1] discussed the biodiesel production from edible, non-edible vegetable feedstock's, waste cooking oils and animal fats. The commonly used alcohols for transesterfication process are methanol, ethanol, propanol, and butanol, among them ethanol is mostly preferred, because it is produced from agriculture products and it is renewable. But methanol is used frequently because the cost is less compared to other alcohols.

Pereira *et al.,* [2] experimented the performance and emission characteristics in a CI engine using diesel, biodiesel and blend of biodiesel and diesel (15% beef tallow biodiesel + 85 % diesel). The transesterification of beef tallow was carried out using ethanol and acid catalyst as H_2SO_4 at a temperature of 45 ^{0}C by continuous stirring of mixture for one hour. The readings were taken in a direct injection single cylinder four-stroke air cooled compression ignition engine at a constant speed of 3600 RPM. Based on the experimental results, they inferred that NOx dominates more in both biodiesel and biodiesel blends when compared to diesel. Whereas CO level for both 100% biodiesel and 15% biodiesel blends was less compared diesel. The disadvantage they point out was it cannot be used in cold weather conditions, due to its relatively low pour point. Knothe [3] compared the difference between biodiesel from vegetable and biodiesel from animal fats. The biodiesel produced from vegetable oil are called as "biodiesel", whereas from animal fats are called as "Renewable diesel". For the production of vegetable biodiesel, alcohol such as methanol, ethanol and catalyst such as sodium and potassium hydroxide were used and for the production of renewable biodiesel catalyst such as NiMO and Al_2O_3 were used. Hydrodeoxygeneration process is carried incase of renewable diesel where the double bonds are replaced by oxygen atom producing renewable diesel. Table 1 shows the comparison of biodiesel and renewable diesel. Aroua *et al.,* [4] highlighted the drawbacks of the reacting agents and contaminants in biodiesel and also the factors that affect engines parts. Methanol contaminants results in low flash point, density and viscosity. More water content in biodiesel causes pitting in pistons, blockage of filters and reduces heat combustion in engines. Higher glycerol, aldehyde and acrolein result in fouling of injectors. In addition Carbon deposit formation in pistons, valves and nozzles occurs if glycerides dominate more.

II. HISTORY OF BIO-DIESEL

Biodiesel has been around for a very long time from 1900. Lin *et al.,* [5] described the study of various biodiesel productions and the experimentation of biodiesel in engine since 1893. In 1893 Rudolf Diesel for the first time used the peanut oil for running the diesel engine. Later in 1937, Chavanne, a Belgian scientist found the concept of running the engine with vegetable oil called to be "Biodiesel". However, it has not been widely used or widely manufactured till recent years. The reason that biodiesel cannot withstand long production run because Petroleum was cheaper and more widely available than biodiesel for many decades. However, the main problem of not using biodiesel commonly is the high NOx emission. According to OECD-FAO agriculture outlook report 2011-2020 [6] crude oil prices was assumed to increase in 2012 and continuous to show a rapid price rise by$107/barrel by 2020.The estimated biodiesel production is compared with the biodiesel trade around the world by 2020 is shown in fig 2. In order to go for a better alternative fuel and for replacing petroleum, many scientists have an eye on improving the qualities of biodiesel with some other blends and with nano particles to minimize the NOx

III. BIO-DIESEL CULTIVATION, HARVESTING TECHNIQUES

Biodiesel is produced by plantation of trees and shrubs such as Jatropha, Pongamia, Mahua etc. The jatropha biodiesel has advantages of low fatty acid composition and the low phospholipids content. The cultivation and production of edible and non-edible plants depends on high oil yielding plant, saline soil, high yield of fruiting, and fast growing plants. For harvestation, a plant seed with short gestation period has to be selected for production of biodiesel. For getting a high yield of oil, the seeds should be grinded properly after harvestation. Muys *et al.,* [7] carried out the Life cycle assessment of jatropha biodiesel in rural India. They highlighted the cultivation techniques of nursery practices such as Polybag, water, fertilizer and harvestation techniques. The technique such as polybag, fertilizers, plantation and oil extraction is described briefly by Pandey *et al.,* [8]. They experimented with jatropha biodiesel by polybag technique in which a black coloured poly-ethylene bags containing equal quantity of humus,sand and soil weighing 10 g per bag is used. The mixer is well mixed and left for growing with seeds and cutting in the nursery. Later for 3 days it is watered properly for obtaining good quality of about 70% germination seed rate. They carried out plant density of 2500 per hectare in which 25 kg of Urea was used as fertilizer in the mixer. Irrigation was carried out with the pipe attached to water tankers. Weeding, pruning and harvesting were carried out after 3 months of grow. For oil extraction, process such as Decortication, Seed pressing, Filtering and oil processing were carried out. The total energy utilized for the process from plantation to transesterification was 22 GJ for 4126.8 kg. Gheewala *et al.,* [9] compared jatropha oil production for both perenial and annual in Thailand . The perenial plantation (20 years) gives energy balance of 4720 GJ per hectare with net energy ratio of 6 which is focussed on biodiesel production only, Where as the annual plantion gives a net energy balance of 9860 GJ per hectare for a net energy ratio of 7.5 focussed on both wood and biodiesel production. So type of plantation has to be selected based on the energy and coproducts.

IV. BIODIESEL PRODUCTION TECHNIQUES

The oil obtained by vegetables cannot be used directly to the engine due to high density fatty ester and it has to be converted into more compatible fuels for engines operation. Generally biodiesel is produced by transesterification method. Transesterification is the process of converting vegetable oils into biodiesel, where the process involves triglyceride reaction with three molecules of alcohol in the presence of a catalyst, produces an end product of fatty acids and glycerol. The transesterification is carried out by new methods such as Supercritical methanolysis, ultrasonically assisted trans-esterification and microwave oven assisted Transesterification. The process of supercritical methanolysis is carried out in a reactor with a blender, preheater, condenser and funnel. An electric thermostat is used to control the temperature of the reactor. Both water and vegetable oil is undergone hydrolysis in a reactor 1 and separated by water phase treatment and made to undergo esterification reaction in a reactor 2 where the methanol recovery is done along with separating biodiesel. The block diagram of supercritical methanolysis is shown in fig 3. Lee *et al.,* [10] performed transesterification using supercritical methanolysis in palm oil. The experiments were conducted by varying temperature between 200–400 °C and the mole ratio of methanol to palm oil between 3to 80 under operating reaction time of (0.5–20 min). Under 300 ^{0}C FAME(Fatty Acid Methyl Ester) is affected by thermal decomposition, which was analyzed by gas chromatography. The experiments were conducted in the batch-type reactor at 40 MPa and the transesterification of palm oil is carried with catalyst such as KNO_3, $NaNO_3$ and Ca $(NO_3)_2$.The content of FAME increases at 350 ^{0}C and decreases by 375 $^{\circ}$C. They resulted that transesterification by super critical methanolysis was optimum at 350 $^{\circ}$C. Jachmanian *et al.,* [11] carried out experimental work in soybean oil by supercritical methanol and ethanol without catalyst. Water concentration of 0 and 10 wt% used for oil to alcohol ratio was 1:40 at 20 MPa and the temperature was in the range of 250 to 350 °C. Among the two levels 10 wt% concentration results in higher ester content and triacylglycerol depletion. The reacting condition of water level at 10 wt% increases the reaction rate and reduces the degradation of fatty acids in both methyl and ethyl ester content. The maximum yield of methyl ester and ethyl ester was obtained for a flow rate of 1.5 ml/min and 2 ml/min at 350^{0}C for 10% water respectively.

Ultrasonication method is used to increase the reaction speed and conversion rate in the biodiesel production. This method works under pressure of 1 to 3 bar gauge pressure by a feed pump and an adjustable back-pressure valve. This process of producing biodiesel is costly because of its apparatus cost. Armenta *et al.,* [12] carried out transesterification in fish oil by ultrasonic energy method with KOH as catalyst at 0.5, 0.75 and 1% with respect to fish oil. Fish oil of approximately 0.05 mol(45g) was taken in three 250 ml in Erlenmeyer flasks and sonicated for 30 min in case of both indirect and direct sonication at a frequency of 35 kHz and 20 kHz for 20 ^{0}C.Later 2% citric acid was added and mixed for 30 min to neutralize the catalyst. The mixture was allowed to get glycerol settled and washed with water to separate FAME.

Hydrogen Agilent 6890 GC System with a flame ionization detector (FID), and a FAME wax Column (Inner Diameter of 0.32 mm, 30 m of length and a film thickness of 0.25 micro meters) was used for testing the transesterified samples. The schematic diagram of ultrasonication method is shown in fig.4. Sheltawy *et al.,* [13] reported in detail about the production of biodiesel using microwave technique. They compared the yield of biodiesel with both microwave and catalyst technique of biodiesel production. By this way of production of biodiesel by microwave technique, scientific microwave with advanced vessel technology was used. It contains a fast vessel in which heat is distributed among the oven homogeneously throughout the cavity. The microprocessor was used to control the microwave power output up to 1200 W. A pressure glass reactor measuring 500 ml flask and a reflux condenser was placed inside the oven. The oven is controlled by a color touch screen controller for varying storage time, temperature and power. The oil was preheated to 65^0C using the microwave controller and temperature was maintained at 65 ^{0}C. Then mixture of alcohol and catalyst was then kept in the flask and the mixture was irradiated under reflux for various reaction times as 1, 2 and 3 min. They compared the microwave technique of obtaining biodiesel with base-catalyzed transesterification and the biodiesel they used for comparison of the yield is jatropha biodiesel. They used methanol as alcohol and KOH as catalyst in two loading of 1 and 1.5 wt. % KOH and three alcohols to oil molar ratios (4.5:1, 6:1, and 7.5:1).The result obtained in the yield % with that of reaction time was given in the graph with highest yield of biodiesel up to 97.4% was obtained for two minutes reaction time. The maximum yield in case of methanol as alcohol and KOH as catalyst in two loading of 1 and 1.5 wt % KOH and three alcohol to oil molar ratios (4.5:1, 6:1, and 7.5:1) was carried out for 60 min. but the maximum yield is obtained in the microwave technique was 2 min. hence the microwave technique of producing is much easier compared to the transesterification process. The block diagram of microwave technique is shown in fig 5.

V. APPLICATIONS OF NANOPARTICLE IN BIODIESEL

Basha *et al*., [14] carried out the systematic experiment on performance and combustion characteristics of a diesel engine using alumina nano particle additive in water-diesel emulsion fuel diesel in a constant speed of 1500 rpm in single cylinder CI engine. Two surfactants namely span 80 (Sorbitane Monooleate) and Tween 80 (Polyoxyethylene sorbitane monooeate) were used as bridging agent along with D2S5W (93% diesel, 2% surfactants and 5% water), D2S5W25Al (68% diesel,2% surfactants and 5% water and 25% alumina nano particle), D2S5W50Al (43% diesel,2% surfactants and 5% water and 50% alumina nano particle) and neat diesel. The brake thermal efficiency obtained for alumina nano particle for D2S5W, D2S5W25Al, D2S5W50Al and neat biodiesel was 25.8%, 25.9%,27.7% and 25.2% respectively and the NOx emission obtained for D2S5W, D2S5W25Al, D2S5W50Al and neat biodiesel was 1046,1012,978 and 1340 ppm. The maximum reduction of CO emission decreases at full load obtained for D2S5W50Al is 0.19 % vol, similarly for HC emission 76 ppm is obtained for D2S5W50Al. The characteristic curve is shown in figure 6-9. The same team [15] carried out the experiment with addition of nanoadditive in the range of 25, 50, and 100 ppm with jatropha biodiesel by 83%, 15%water and 2% surfactants such as span 80 and tween 80. They used alumina as nanoparticle in biodiesel. They experimented evaporation rate analysis in a hot plate set up and resulted the high evaporation rate for JBDS15W. The NOx emission for JBDS15W100A fuel reduces emission by 870 ppm and HC emission by70 ppm. The maximum brake thermal efficiency at 29.4% and reduction of CO at 0.04 % vol is obtained for JBDS15W100A for the full load. The characteristics curve is shown in fig 10-13.The same team [16] performed the experimental investigation of CNT (Carbon nanotubes) with diesel emulsion fuels. They carried out the experiments in 3 phases by the order of one by using neat biodiesel, two by water diesel emulsion fuel and three by CNT blended with water diesel emulsion fuel. The emulsions they carried out for this experiment was Span 80 and Tween 80 in the mass fraction of 25 and 50 ppm. The advantage of using nano particle is that it enriches the surface area to volume ratio; results more fuel to get combustible easily. Reduction in NOx emission for D2S5W50CNT by 970 ppm and brake thermal efficiency by 28% for D2S5W50CNT is obtained. The characteristic curves are shown in fig 14-17. The same team [17] extended the experimental investigation by carrying out alumina-CNT biodiesel fuels with 25 ppm CNT and alumina blended with jatropha biodiesel. The maximum brake thermal efficiency obtained for JBD25A25CNT was 28.9% and importantly lower specific fuel consumption obtained was 0.31 kg/kW-hr at full load. The lowest NOx emission for JBD25A25CNT was 985 ppm and HC emission was 46 ppm at full load. This paper highlights the combined use of nanoparticle such as alumina and CNT at 25 ppm level which results a good solution by both performance and emission wise.

Arul Mozhi Selvan *et al.,* [18] carried out the experimental investigation of using biodiesel as addictive in diesel and alcohol mixture under various compression ratios such as 15, 17 and 19. They carried out the experiment in a computerized single cylinder DI variable compression ratio constant speed four stroke CI engine. They used the diesohol blends with jatropha biodiesel as addictive such as D85E5B10, D80E10B10, D75E15B10, D70E20B10 and D65E25B10 and resulted the performance and emission characteristics at bmep of 0.44 MPa. At compression ratio of 17 the maximum brake thermal efficiency obtained for neat diesel was 26.15% and at compression ratio of 15 CO emissions obtained for D65E25B10 was 0.37%. The lowest HC of 110 ppm is obtained for D85E5B10 was at compression ratio of 19. The lowest NOx emission obtained at compression ratio of 19 for neat diesel was 250 ppm. Whereas the lowest smoke absorption coefficient obtained for E25 blend at 15 as compression ratio was 2.1 m^{-1} K. The same team [19] carried out the experiment with castor oil as addictive in diesel and ethanol blends with compression ratio of 15, 17 and 19. They carried out the experiment with D15CR, D17CR, D19CR, 15CRD80E10C10, 17CR D80E10C10, and 19CRD80E10C10 where CR is the compression ratio values 15, 17 and 19; D is the diesel and E ethanol. They resulted with the lowest SFC was 0.33 kJ/kWh for neat diesel at the compression ratio of 19 and brake thermal efficiency was higher for compression ratio at 19 is 27% for D80E10C10. At 17 CR, lowest emission of CO observed for D80E10C10 was 0.37%, the lowest HC emission obtained for the neat diesel at the CR of 19 was 53 ppm and the lowest NO emission for the ethanol blend D80E10C10 at the compression ratio of 15 was 96ppm. The characteristic curves are shown in fig 18-21.

Sajith *et al.,* [20] carried out the experimental investigation using cerium oxide as nano particles in biodiesel. After the addition of nanoparticles in the biodiesel there was no change in the cloud point and pour point of the modified biodiesel at 40 ppm dosing level. The engine performance increases brake thermal efficiency by 1.5% when the dosing level was between 20 to 80 ppm. 25% to 40% reduction in HC was obtained when the ppm range was between 40 to 80 ppm. The reduction of NOx by 30% was obtained for the dosing level of 80 ppm. The characteristic curve is shown in fig 22-25. Hadirahimi *et al.,* [21] carried out the environmental fuel additive for reducing the emissions and performance. They used Diesetrol addictive with a combination of diesel fuel (D), biodiesel (B) and ethanol (E). They prepared bio ethanol from waste potato in the vapour phase of 3A Zeolite and the biodiesel with sunflower biodiesel. The flash point was reduces by 16 % with addition of 3% Bio ethanol to diesel and sunflower methyl ester. The transesterification of sunflower oil was carried with 1.8 g KOH and 33.5 cc methanol and the yield percentage obtained was 80-85%. They classified the fuel blends of biodiesel with addictives at various levels of composition which can be seen from the table 2. CO emission decreases for various blends because of more oxygen concentration in the blends and HC emission also decreases by 3 % for bio ethanol and 2% for sunflower methyl ester at 60 ppm. Qi *et al*., [22] carried out experimental investigation to validate the effects of diethyl ether and ethanol as additives to biodiesel and on various diesel blends. Different blends such as B30 (30% biodiesel and 70% diesel in vol.),BE-1 (5% diethyl ether, 25% biodiesel and 70% diesel in vol.) and BE-2 (5% ethanol, 25% biodiesel and 70% diesel in vol.) was used in a DI diesel engine. The result shows that the BSFC of B30 is slightly higher than that of BE-1, and equal to that of BE-2. They mentioned that due to the higher volatile character of diethyl ether and ethanol the mixing velocity of air/fuel mixture, improves both combustion and efficiency. The NOx concentration of blends increases due to its highest oxygen content in ethanol. The order of increase in NOx was BE1, BE30 and BE2. For HC emission compared to BE30 the other blends such as BE1 and BE2 are slightly high. For CO emission the BE30 is high when compared to the other blends. The characteristic curves are shown in fig: 26-29.

VI. CURRENT CHALLENGES IN BIODIESEL

The current challenges that the world is looking forward for new fuel should satisfy the following conditions such as environmental friendly, economically supported, readily available and easily decomposable. Further, the price of petrol and diesel is increasing day by day. So a need for alternative fuel is a must needed one. Biodiesel is struggling hard to survive in the world in which researches are looking forward to eliminate the disadvantages that biodiesel posses. Biodiesel has the potential of overcoming the challenges that is prevailing today. The disadvantages that biodiesel has to overcome was deposit formation in engine which results in clogging of fuel filters. So better refining techniques has to be followed in order to remove more fatty acids and glycerine completely. The other disadvantages that biodiesel posses was emission of high percentage of NOx emission. So reduction of NOx in biodiesel will results in commercial usages in engines. More non edible crops have to be encouraged for production of biodiesel than considering the edible crops. Biodiesel plants have to be planted around the country in order to produce more biodiesel. Simultaneously environmental factors have to be considered to prevent from pollution.

VII. CONCLUSION

The existing way of production of biodiesel, usage and application of nano particles in biodiesel was described briefly in this paper. In order to use the biodiesel as common for both domestic and transportation purpose, more effective way of plantation, cultivation, harvesting, oil extraction techniques and biodiesel preparation techniques has to be identified. Though biodiesel is considered as one of the major alternative source of fuel it is not practically possible because of high NOx emission. The advantages when compared to diesel are reduction of CO, HC and PM. So the NOx play a major role in the non-implementation of biodiesel. So many researches have to be carried out in reduction of NOx from biodiesel. The NOx reduction techniques is carried out by so many researchers in which the role of using nano particle is the easier and new emerging technique which is followed by many scientists around the world. In this case study the way of biodiesel production by methanolysis, ultrasonication, microwave technique and effect of nano particle addictives in application with biodiesel is reviewed briefly along with performance and emission characteristics. From this review we conclude that nano addictives and nano fluids are most effective way in the engine performance and emission in which further more research have to be carried out.

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***Table 1*: Production of Biodiesel and Renewable Diesel (ref [3])**

Fuel	**Process**	**Reacting agent**	**Catalyst**	**Product**
Biodiesel	Transesterification	Alcohol	NaOH, KOH	Glycerol & biodiesel (fatty acid alkyl esters)
Renewable diesel	Hydrodeoxygeneration	H_2	NiMo/ Al_2O_3 CoMo/ Al_2O_3	Renewable diesel (hydrocarbons) & C_3H_8, CO_2,H_20

***Table 2*: The test fuel blends and their composition (ref [21])**

	Fuel no											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Vol % Diesel	100	94.5	89.9	84.85	79.8	89.5	78.9	68.3	57.8	0	0	0
Vol % Bioethanol	0	3	6	9	12	0	0	0	0	100	0	60
Vol % Biodiesel	0	2.05	4.1	6.15	8.2	10.5	21.1	31.7	42.2	0	100	40
Mass % Oxygen	0	1	2	3	4	1	2	3	4	34	11	19.9

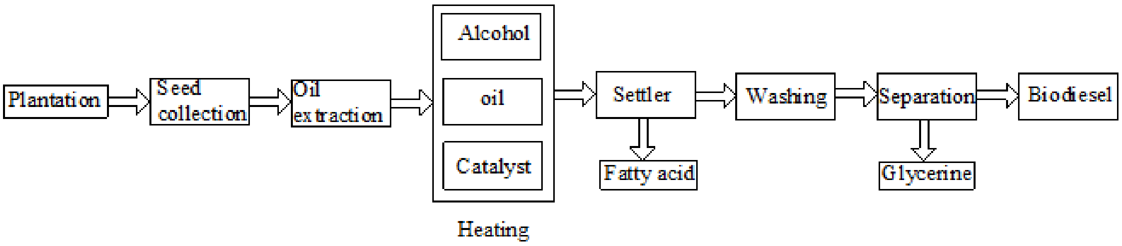

Fig 1 :General layout Of Biodiesel Production

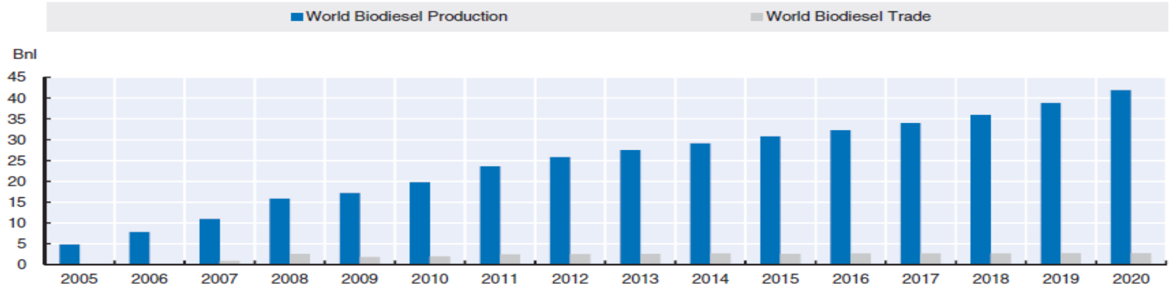

Fig 2: OECD-FAO agriculture outlook report 2011-2020(ref [6])

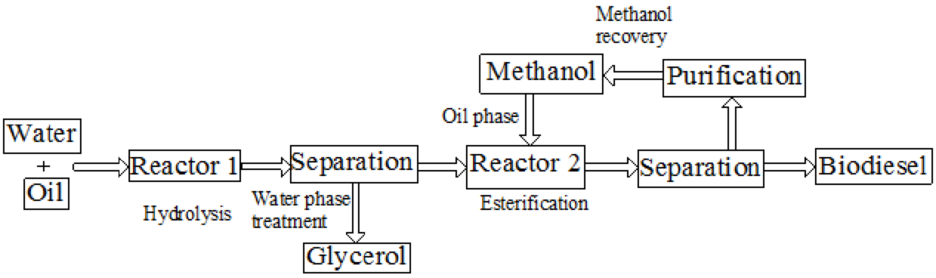

Fig 3: Schematic layout of supercritical methanolysis

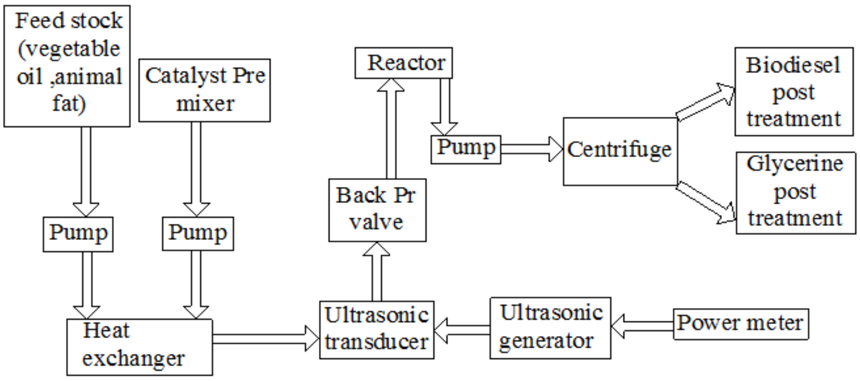

Fig 4: Schematic layout of Ultrasonication method

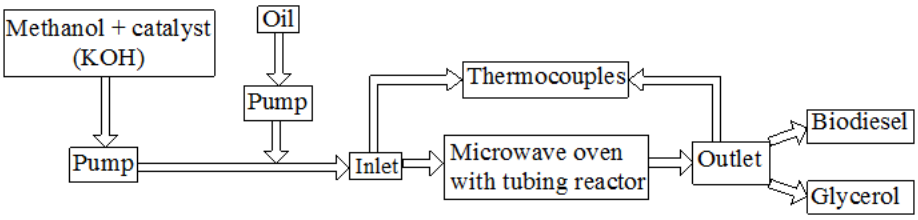

Figure 5: Schematic layout of microwave technique.

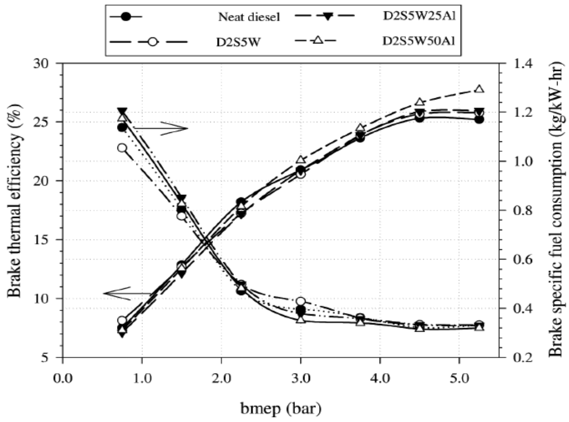

Fig 6: Variation of BTE vs BMEP for different blends (ref [14])

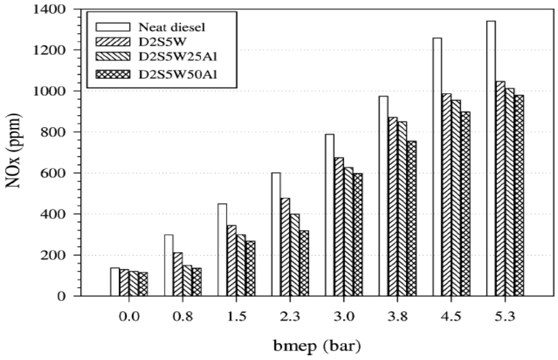

Fig 7: Variation of NOx vs BMEP for different blends (ref [14])

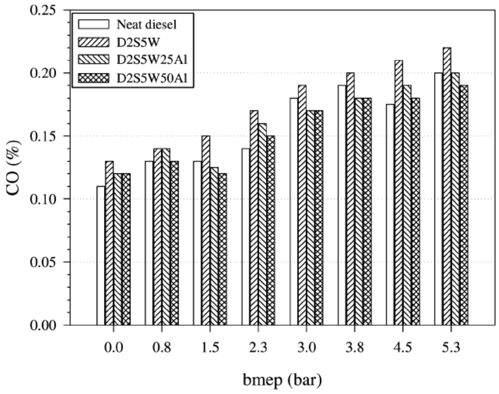

Fig 8: Variation of CO vs BMEP for different blends (ref [14])

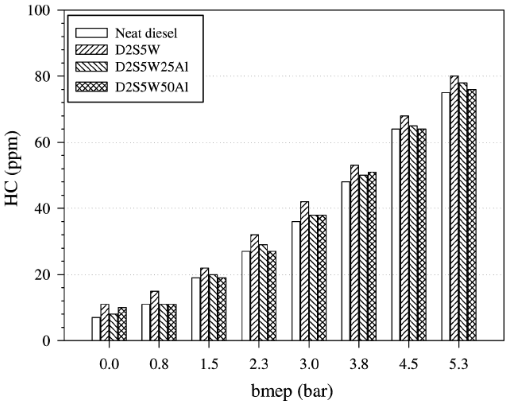

Fig 9: Variation of HC vs BMEP for different blends (ref [14])

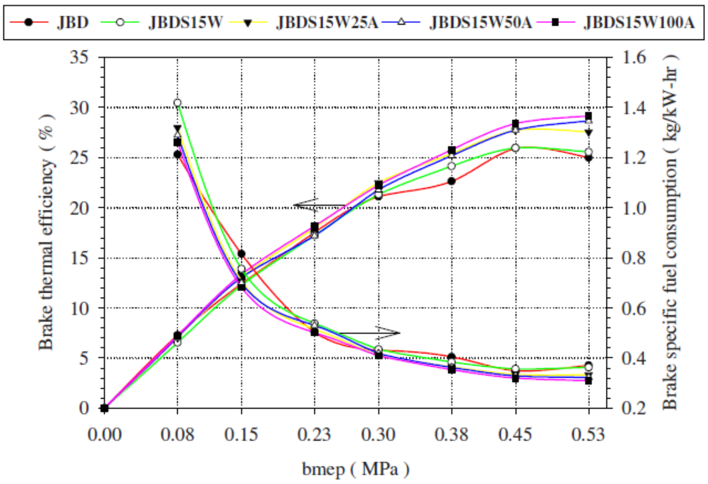

Fig 10: Variation of BTE vs BMEP for different blends (ref [15])

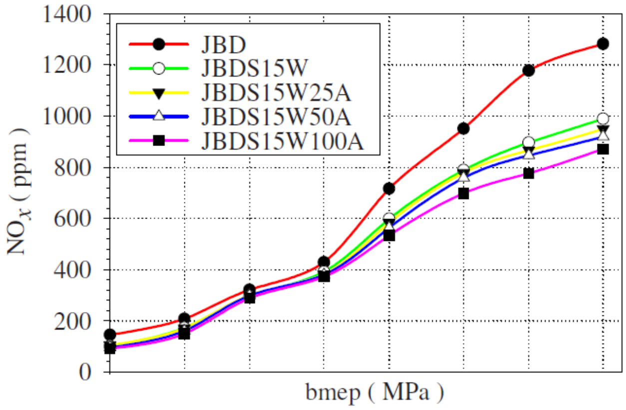

Fig 11: Variation of NOx vs BMEP for different blends (ref [15])

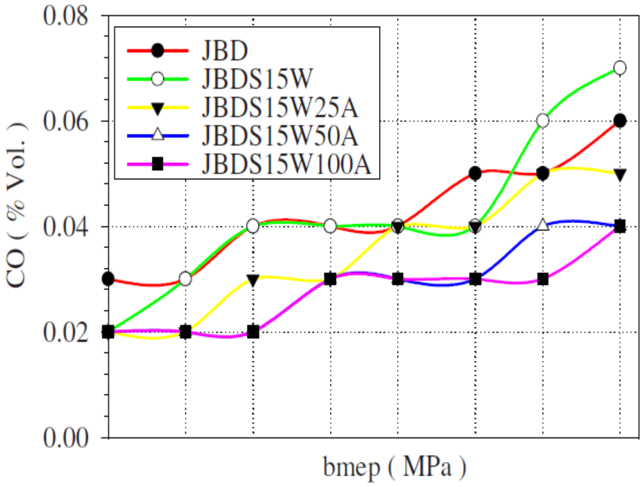

Fig 12: Variation of CO vs BMEP for different blends (ref [15])

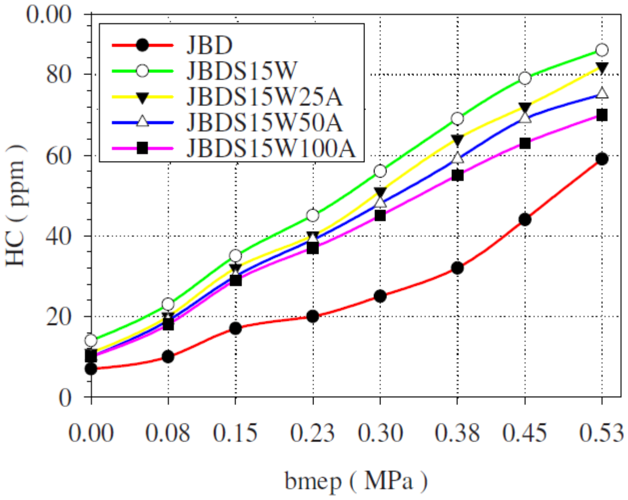

Fig 13: Variation of HC vs BMEP for different blends (ref [15])

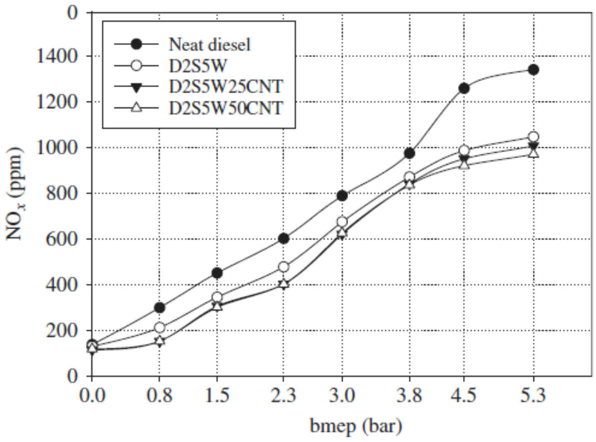

Fig14: Variation of NOx vs BMEP for different blends (ref [16])

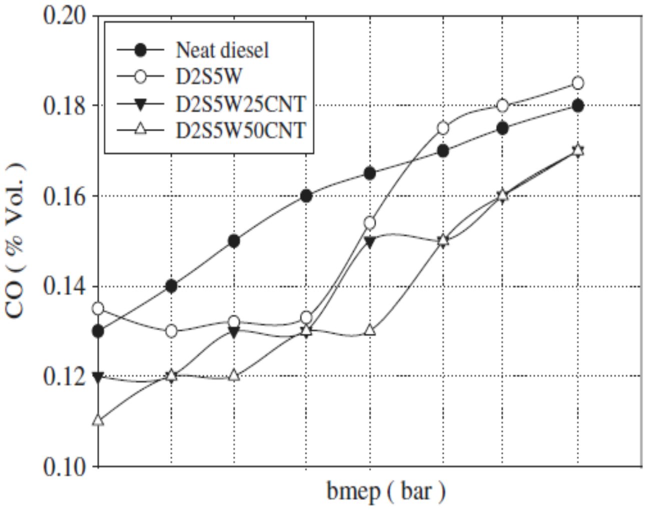

Fig 15: Variation of CO vs BMEP for different blends (ref [16])

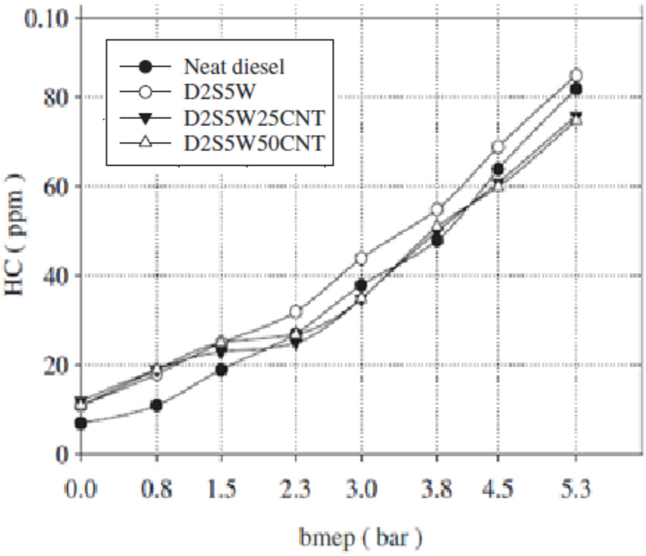

Fig 16: Variation of HC vs BMEP for different blends (ref [16])

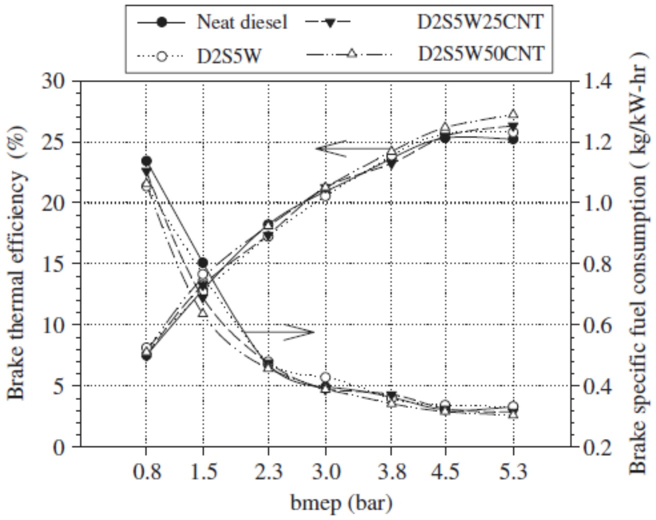

Fig 17: Variation of BTE vs BMEP for different blends (ref [16])

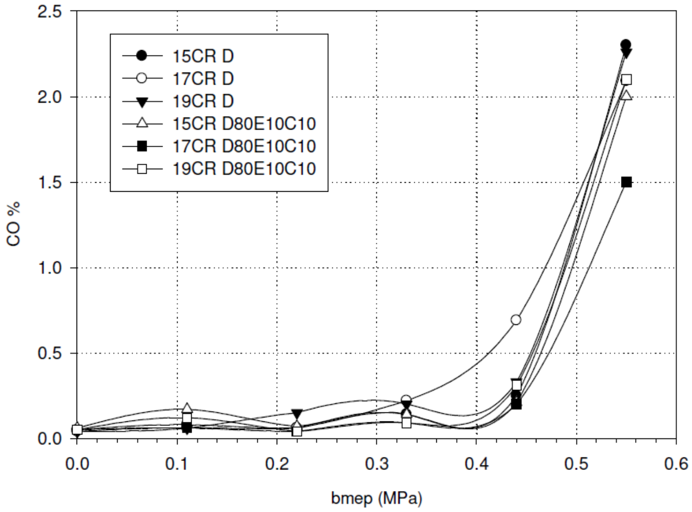

Fig 18: Variation of CO vs BMEP for different blends (ref [19])

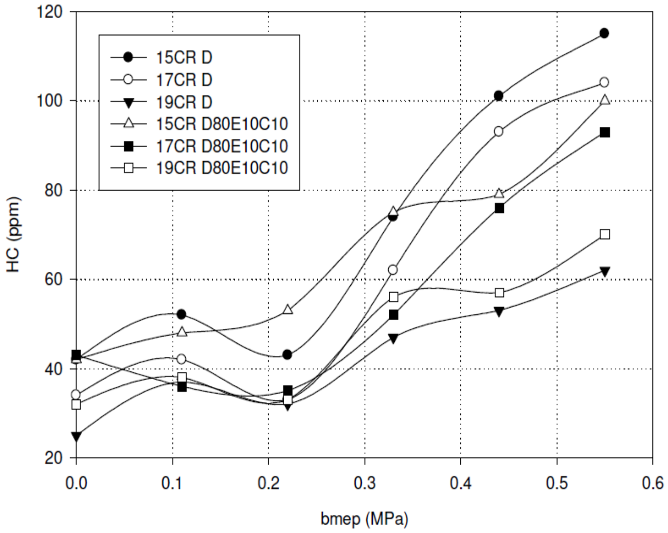

Fig 19: Variation of HC vs BMEP for different blends (ref [19])

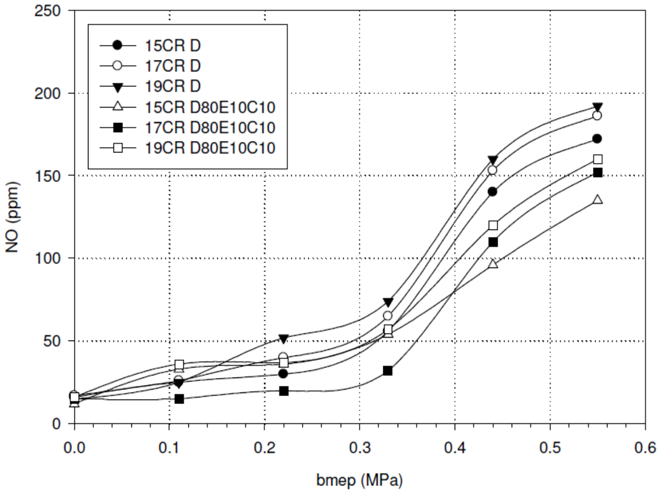

Fig 20: Variation of NO vs BMEP for different blends (ref [19])

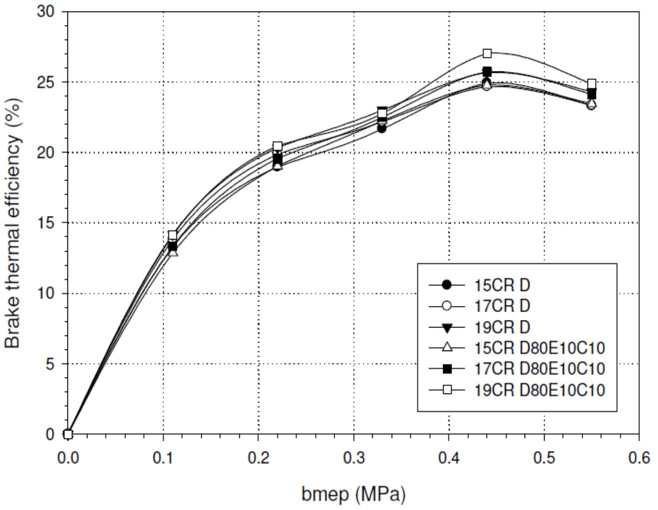

Fig 21: Variation of BTE vs BMEP for different blends (ref [19])

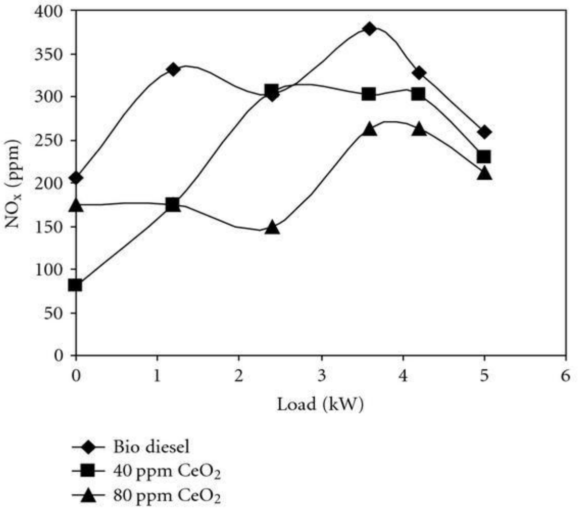

Fig 22: Variation of NOx emissions with load for various ppm of CeO_2 (ref [20])

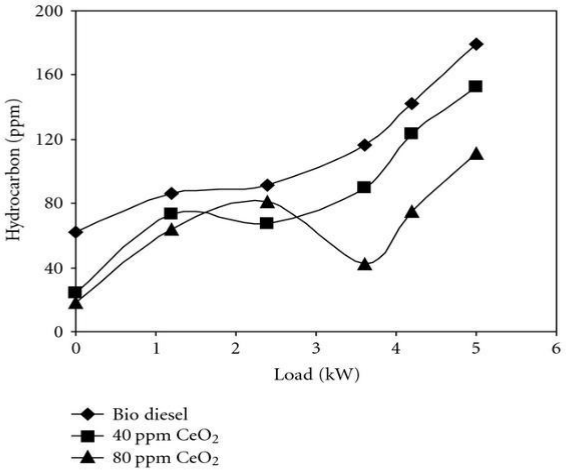

Fig 23: Variation of HC with load for various ppm of CeO_2 (ref [20])

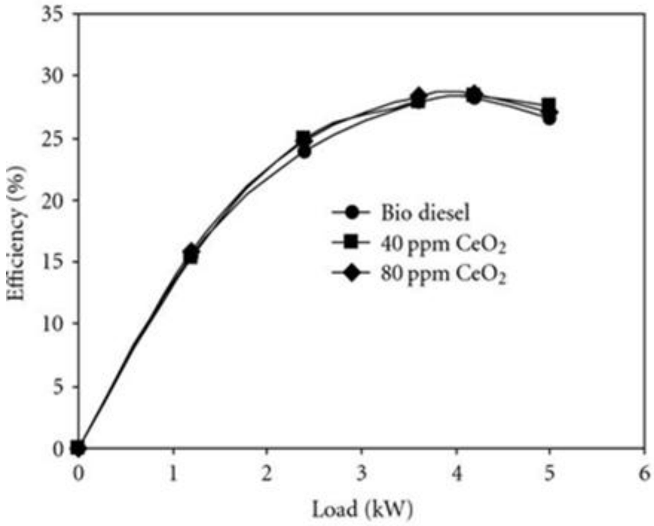

Fig 24: Variation of BTE with load for various ppm of CeO_2 (ref [20])

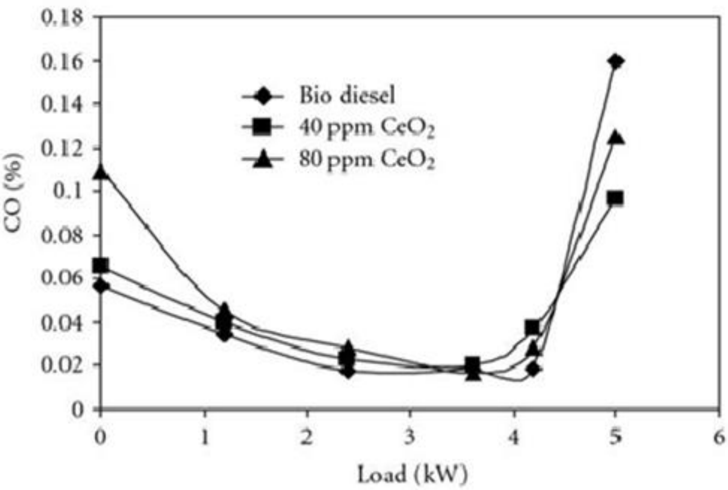

Fig 25: Variation of CO with load for various ppm of CeO_2(ref [20])

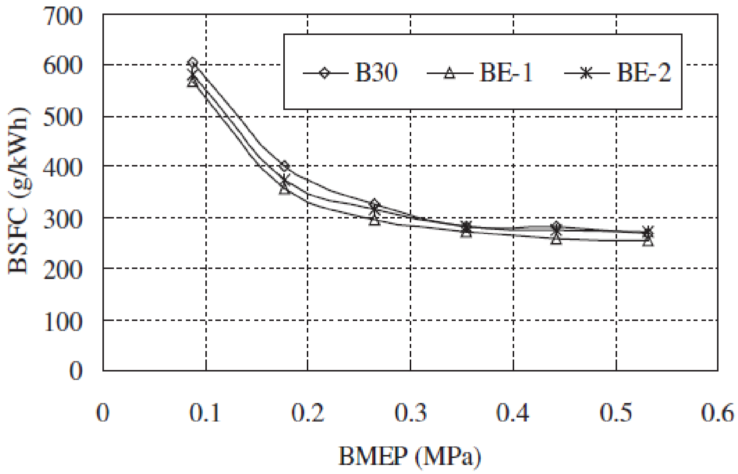

Fig 26: Variation of BSFC vs BMEP for different blends (ref [22])

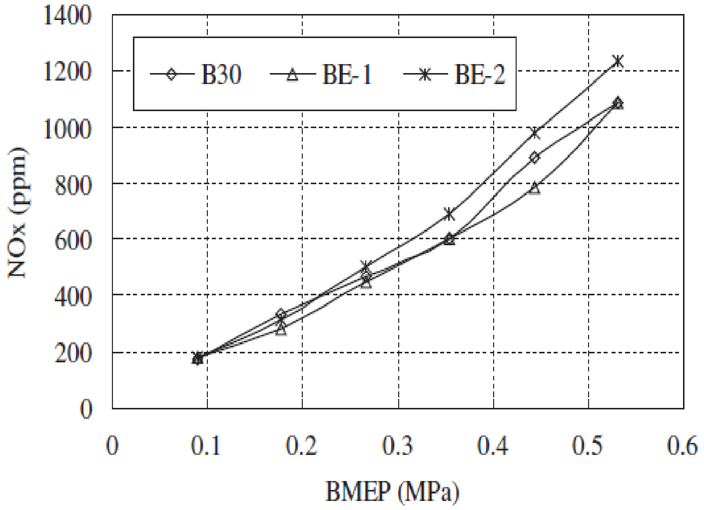

Fig 27: Variation of NOx vs BMEP for different blends (ref [22])

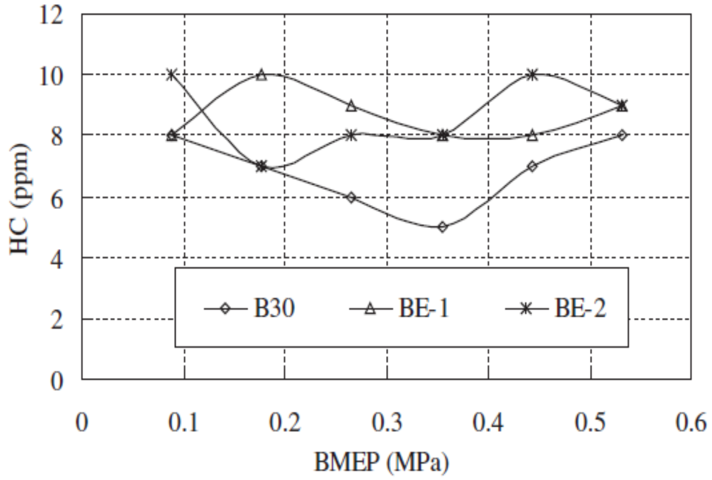

Fig 28: Variation of HC vs BMEP for different blends (ref [22])

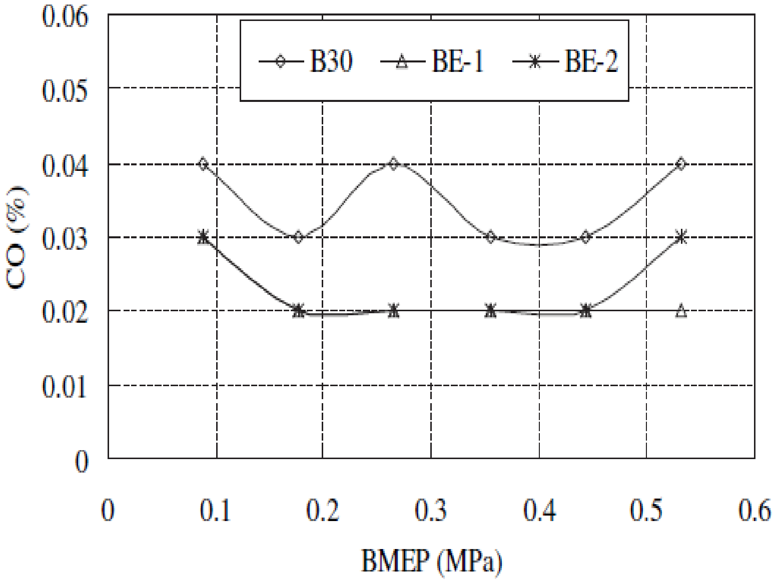

Fig 29: Variation of CO vs BMEP for different blends (ref [22])