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An Investigation on Performance and Emissioncharacteristics of DI Diesel Engine Fueled with Lemon Peel Oil and its Emulsions

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Abstract : Emulsions of fuels with water are effective in reducing NOx and particulate matter from diesel engines without any modifications in engine. So considering this as an objective emulsions of water in oil (W/O) type were prepared by taking pure lemon oil which is a non-edible bio-oil as base fuel and water with varying percentages in range of 5-10% with two different emulsifiers span 80 and a new emulsifier Methyl-dihydroxypropylimidazolium chloride having HLB value around 8 with varying quantities by volume. Then the investigations on their stability was done. Electromagnetic stirrer and ultrasonic technique of emulsification was used to prepare the emulsions. Totally eight samples were prepared out of which four samples were prepared with 5% water and remaining four were prepared with 10% water with varying emulsifier & its percentages. The sample with 1.5% of span 80 with 5% water by volume showed good stability with emulsified layer retaining up to approx. 65% and the sample with combined emulsifiers span 80 and Methyl-dihydroxypropylimidazoliumchloride for 5 % water also showed good emulsion stability up to 60% even after 7 days & from the 10% water the sample with combined surfactants span 80 2% and Methyl-dihydroxypropylimidazolium chloride 2% by volume retained its stability up to 60%. The emulsion stability was evaluated based on gravitational or stand still method where the emulsions were kept stand still for 7 days and the separation of layers was measured using measuring cylinders. The sample which exhibited less separation was considered as stable. To assist or validate our stand still method viscosity measurement of test samples was done at interval of each day for seven days using capillary viscometer. Then only stable emulsions samples with 5% water were tested for performance and emissions on single cylinder four stroke water cooled diesel engine in terms of brake power, brake thermal efficiency, brake specific fuel consumption and emissions of CO, HC, NOx. The results indicated that compared to pure lemon oil the brake thermal efficiency increased because of micro-explosion phenomenon of water and brake specific fuel consumption was increased. NOx emissions reduced but the HC & CO emission increased due to decreased calorific value of fuel because of addition of water.
Keywords : Emulsions, Methyl-dihydroxypropylimidazolium chloride,Stability, Ultrasonification, Engine performance and emissions HLB.

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I. Introduction

Gasoline and diesel fuel engines are the two primary sources of energy which have been widely used in transportation sector. Out of which gasoline engines are mainly used in motorcycles and small passenger segment cars. Diesel on the brighter side have higher thermal efficiencies, torque and are more economical in operation due to less brake specific fuel consumption and higher compression ratios employed as a result they have been dominating the transportation and heavy industrial sectors and also in passenger cars. The major climatic change which our world is facing as the global temperature is rising year by year mainly due to pollution occurring from industries and transportation sector has forced the researchers across the globe to strive hard for reducing the same. The major pollutants coming from any internal combustion engine are unburned hydrocarbon (UBHC), carbon monoxide (CO), carbon dioxide (CO2), oxides of nitrogen (NOx) and particulate matter (PM). These pollutants include greenhouse gas CO2 which is the main reason for global increasing temperature, NOx and PM are dangerous to health as they enter into lungs and cause respiratory problems. NOx produces photochemical smog in presence of sunlight and also leads to acid rains .CO which is colorless gas is toxic in nature and is harmful for humans as it reacts with hemoglobin present in the cells and deprives cells from getting oxygen. Due to the adverse effects of these emissions, stringent and hard emission norms have been imposed on both transportation and industrial sectors emitting these gaseous emissions. The major emphasis is given on control of NOx and PM emissions as these leads to health problems. The world reserves of fossil fuels are depleting at a very rapid rate due to increasing demand of vehicles day by day, increasing demand for lavish life style which all are ultimately met through burning of these fossil fuels. Biofuels are now finding their potential as a replacement for conventional fossils fuels due to their built in properties of renewability, availability, high oxygen content & combustible properties similar to those of conventional fuels and most importantly they have reduced emission capability compared to fossil fuels. Biofuels like methanol and pine oil have been used as a fuel in CI engines directly or with blends with diesel [1], wood pyrolysis oil emulsion with Jatropha methyl ester oil have shown increase in brake thermal efficiency and reduction in NOx compared to conventional diesel fuel [2], feasibility of using animal fat and its emulsions with ethanol and methanol have been studied and used in diesel engines in suitable proportion and results show that emulsified animal fats show decrease in NOx, smoke, HC & CO with increasing load [3,4].

Emulsifying diesel with water with certain percentages have shown good results in terms of reduction of NOx ,slight increase in brake power, brake thermal efficiency due to micro explosion phenomenon also there was increase in CO,HC at low engine loads and reduction in same at higher engine loads [6.7].

Lemon essential oil has also been used as a fuel for CI engine by blending it with different proportions of diesel .The results obtained indicated that brake thermal efficiency increases by 12% and 9% at high and low loads. UBHC, CO, soot emissions were low but NOx emissions were higher compared to standard diesel [8].The composition of lemon essential oil or pure lemon oil is such that it has less fatty acid contents which has a major advantage over conventional bio-oils obtained from biomass which have higher fatty acid contents, thus lemon oil doesn’t require transesterification process to convert fatty acids into corresponding esters. The major area where researchers have focused their attention is to reduce the NOx emissions and for that various methods have been developed in recent years to tackle the problem of NOx these include exhaust gas recirculation (EGR) which is introduction of waste exhaust gases into the combustion chamber through the inlet port. EGR is effective to control NOx but needs engine modification and is costly. Second is the introduction of water into the combustion chamber to control the combustion chamber temperature. This can be done in three ways: Water injection into the chamber by using separate injectors, water fumigation technique in which water is introduced into the inlet port of incoming air, water emulsified fuel in which fuel and water are mixed outside the engine chamber and introduced into the engine via single injector which doesn’t requires any engine modifications and has proved to be very effective in controlling NOx Formation from engines[8]. So this motivated us to do study emulsions of lemon essential oil lemon oil with water using suitable surfactants in focus of controlling NOx emissions and investigate its stability along with its performance.

The emulsion are type of disperse systems which consists of two immiscible liquids mixed in certain proportion with the help of emulsifying agents or emulsifiers [9]. The liquid droplets of the dispersed phase are dispersed in a liquid medium of continuous phase. Drawback of emulsified fuels is that due to density variation of the two liquids they separate out after certain duration when mixed. So to stabilize the emulsions i.e. water in fuels we have to use suitable surfactants called emulsifiers in certain proportions which holds the water and fuel i.e. oil together. The stability aspect of emulsions is majorly governed by on the base constituents, type of surfactant, amount of surfactant, type of emulsificationi.e water in oil (W/O) or oil in water (O/W), droplet size, temperature, energy supplied during emulsification [10,11].

Surfactants reduce the interfacial surface tension between the two liquid surface molecules and increases the surface interaction which stabilizes the emulsion. W/O emulsions are generally preferred over O/W emulsions as in former case water molecules are enclosed in oil molecules compared to latter case and there is a less probability of water contact with engine parts. Emulsions are prepared using mechanical agitators or ultrasonic agitators which break the molecules into fine droplets and increase the molecular surface to surface interaction. Research shows that ultrasonication technique of emulsification gives finer droplets compared to mechanical agitators and increases the stability [12].Mixing speed and mixing duration of emulsions is also important for preparation of stable emulsion[13].Temperature while emulsification is vital as it decreases the viscosity and eventually destabilizes the emulsion. This method is used in oil refining industries to separate water solubilized in water [14].The type of the emulsifiers to be used for preparation of W/O emulsions should be able to stabilize the emulsions for longer duration . Surfactants have affinity to dissolve in both the parts of emulsified liquids given by its Hydrophile-Lipophile balance (HLB) scale which in range of 1-20. Hydrophilic nature indicates water solubility and lipophilic nature indicates oil solubility. If the Surfactant is having high water solubility and low oil solubility it have high HLB value while Surfactant having low water solubility and high oil solubility have low HLB value. Selection of appropriate surfactants like low HLB value Surfactants will create W/O emulsion due to its more affinity towards oil & selecting high HLB value surfactants will produce O/W emulsions due to its higher affinity towards water. Non-ionic surfactants are more effective in stabilizing the emulsions [15].

Generally any W/O emulsions to be prepared should have HLB value in the range of 3-6 to have stable emulsions [16].

Table 1 HLB values of surfactants and suitable range for applications [16]

HLB Range	Application
15-18	Solubilizer
13-15	Detergents
8-18	O/W Emulsions
7-9	Wetting Agents
3-6	W/O Emulsions

Surfactants form well-defined structures called as micelles when dissolved in emulsions. Micelles are having the simplest structures of spherical or cylindrical form, which are formed by molecules of surfactants having hydrophilic and lipophilic heads which holds the two constituents of emulsion within them. For preparations of W/O emulsions the non-ionic surfactants Span 80 (SorbitanMonooleate) having HLB value 4.3 has been widely used by the researchers [17,18] and the results have showed that emulsions remain stable for more than four days. When using the combination of two or more surfactants one having high HLB and other having low HLB the emulsion stability is improved as compared to use of single emulsifier. using span 80 and tween 80 (Polyoxyethylene glycol monopalmitate HLB=15) have improved the stability compared to single emulsifier as other emulsifier also overcomes the shortcoming of single emulsifier [19].So while preparing our emulsion of lemon oil and water we decided to go initially with single surfactant span 80 with varying percentages to study its stability. Percentage of water present in the emulsions also affects the stability of emulsions. Increasing the water content increases the viscosity of emulsions because the number of hydrogen bonding increases and the distance between the molecules increases the Vander Waals force of attraction and the droplets start to accumulate and the stability is reduced though viscosity is increased [20].The maximum percentages of water in the emulsions that have been used varies from 5-30% & the results show that increasing water percentage increases the ignition delay, B.S.F.C decreases upto a certain limit and then again increases as the water percentage exceeds 20%, brake thermal efficiency increases due micro explosion of water droplets due to difference in boiling points of water and diesel which results in secondary atomization of fuel droplets, also steam acts as a secondary medium and forces piston downward producing extra work. [3, 5, 17, 19, 21, 22].

NOx Emissions are low compared to diesel at all loads, but HC and CO emissions were found higher at low loads compared to conventional diesel due presence of water which absorbs the combustion heat to convert water into steam [23]. Consequently there is reduction in cylinder temperature when the cylinder temperature falls below 1400K the oxidation of CO to CO2 is stopped and amount of CO production increases [24]. As load increases the amount of charge inducted into the cylinder increases which leads to increase in the cylinder temperature and micro-explosion theory assists in complete combustion of charge which reduces the HC emissions & CO emissions.

The ultrasound emulsifying technique is better when compared to mechanical agitation as it supplies greater energy in form of mechanical vibrations which breaks the molecules into fine droplets which in turn effective surface interaction of the molecules and stabilizes the emulsion. There is certain disadvantage with the use of ultrasonification technique which rise in temperature of the emulsion when duration of ultrasonification increases which limits the duration upto maximum 15 min [12].Based on above literature review we will prepare the emulsion of lemon oil, 5-10% water and with varying percentages of span 80 and Methyl-dihydroxypropylimidazolium chloride & investigate the stable emulsions and test the most stable emulsions for its performance and emissions.

I. Experimental Details

A. Emulsions preparation

The materials used were pure lemon oil purchased from Synthite industries, distilled water was taken from laboratory, surfactant span 80 was purchased from local chemicals dealer and new surfactant was synthesized chemically in the VIT SAS laboratory which is an ionic surfactant. The mixture of ionic and non-ionic surfactants are more effective in stabilization of emulsions [10]. The properties of pure lemon oil are given in the table 3. For preparation of emulsion electromagnetic stirrer along with ultrasonicator having specifications given in the table 2 were used. Emulsions were prepared with varying proportions of water and surfactants span 80 and Methyl-dihydroxypropylimidazolium chloride. Totally eight samples were prepared out of which four samples were prepared by fixing the water percentage to 5% and varying the surfactants quantity & other four samples were prepared by fixing the water percentage to 10% by volume & varying its quantity. The flow chart of steps followed during preparation of emulsions is given in fig 1 below.

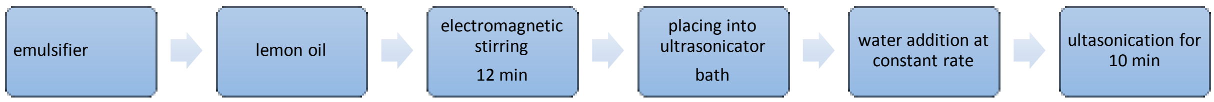

Fig. 1 Emulsification process followed for preparation of emulsions [12]

Table 2 Ultrasonicator Details

Ambient temperature° C	5-40
Working capacity in litres	1.5
Power watts	35
Operating Frequency	44

Table 3 Lemon Peel Oil Properties

Property	Unit	Value
Kinematic Viscosity	cst	1.06
Flash Point	ºC	54
Fire Point	ºC	64
Cetane Index		15
Calorific Value	KJ/kg	41000

First four samples with 5 % water as fixed quantity were prepared with different percentages of lemon oil and different surfactants and their proportions as given in above table 4.

Table 4Composition of samples prepared with 5% water.

Sample	Lemon oil %	Water %	Span 80 %	Methyl-dihydroxy Proyl imidazolium %	HLB	Density (gm/cc)
Emulsion 93/5/2	93	5	2	-	4.3	0.868
Emulsion 92/5/2/1	92	5	2	1	6.3	0.867
Emulsion 92/5/3	92	5	3	-	4.3	0.870
Emulsion 93.5/5/1.5	93.5	5	1.5	-	4.3	0.877

After that samples having 10% water with varying quantities of emulsifier and lemon oil were prepared. Their proportions are mentioned in table 5.

Table 5Composition of samples prepared with 10 % water.

Sample	Lemon oil %	Water %	Span 80	Methyldihydroxy Propyl imidazolium %	HLB	Density (gm/cc)
Emulsion: 87.5/10/2.5	87.5	10	2.5	-	4.3	0.8751
Emulsion: 86/10/2/2	86	10	2	2	6.32	0.8723
Emulsion: 87.5/10/3	87	10	3	-	4.3	0.8707
Emulsion: 87.5/10/3.5	86.5	10	3.5	-	4.3	0.8777

B. Stability Evaluation Techniques

The emulsion which retains the emulsified layer holding two immiscible liquids together and shows less phase separations for longer periods are considered as stable emulsions. The emulsions become unstable due to several breakdown processes occurring in emulsions. The break down processes are shown in Fig. 2. Creaming and sedimentation occurs due to density differences, flocculation occurs when Vander Waals forces of attraction overcomes repulsive forces created by surfactant action, Ostwald ripening viscometer in which, as the time passes the smaller droplets get disappear and their molecules get diffuse to become larger droplets due to finite solubility of two liquids, Coalescence in which the interfacial film becomes thin due to which molecules fuse and phase separation occurs because of surface film fluctuations in which droplets come close and Vander Waals forces between molecules dominates.

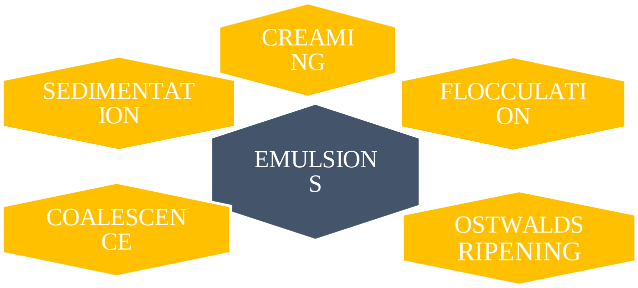

Fig. 2 various emulsion stability collapsing processes

Generally to measure the stability of emulsions four techniques are used [1] gravitational method in which the mixture is left stand still for 7 days and the separation of layers is observed visually. The emulsion which shows least amount of separation is considered stable. This method takes time but shows good results. [2] Centrifuge method in which emulsion is centrifuged at certain rpm for certain duration and separation of layer is observed. This method is fast but depends on rpm and time of centrifugation due to which there is variation in emulsion stability measurement. [3] Microscopy and droplet size measurement in which emulsion is observed under microscope to see the distribution of dispersed phase into the continuous phase. This method gives good results as finer droplets indicate more stability and coarse sized droplets indicate decrease in the emulsion stability. But this method requires sample preparation which is complex [12,4] Viscosity measurement in which the viscosity of the emulsions is measured at particular intervals and as previously explained viscosity indicates stability, higher viscosity means finer droplets, more surface to surface interaction lesser coalescence of dispersed phase molecules while lesser viscosity is the indication that emulsions is destabilizing by coalescence in which dispersed phase molecules grow into bigger molecules and by sedimentation in which dense phases generally water settles at the bottom under the action of gravity eventually separating the layers [12,20,26].So considering the above factors we used gravitational /stand still method to observe the stability of emulsions along with the viscosity measurement to validate our results.

EMULSION STABILTY (ES): $\frac{VOLUME\ OF\ EMULSIFIED\ LAYER}{TOTAL\ EMULSION\ VOLUME}$.

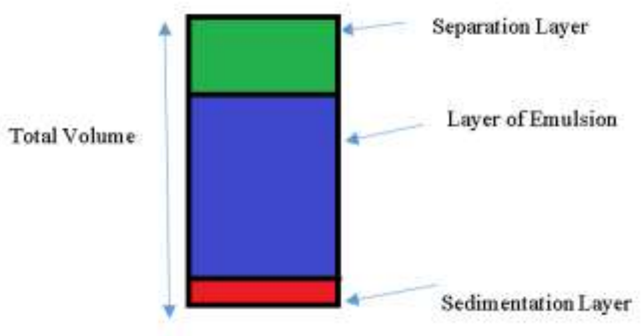

Fig. 3 different layers of emulsified liquids [27].

After preparation of samples with 5% and 10% water the relative viscosity was measured for seven days for each sample to validate the emulsion stability with the help of Ostwald viscometer. As previously mentioned viscosity is affected by percentage of water, droplet size distribution and directly affects the stability of emulsions. The graphs of emulsified layer compared to days and relative viscosity to days is discussed in the results section.

C. Engine Test Setup

To test the stable emulsified fuel samples a 4 stroke single cylinder water cooled diesel engine was used. Here in this report we tested only stable samples of 5% water & 10 % water, diesel and lemon oil. The specifications of the engine are given in the table no.6. The engine was operated at variable loads i.e. no load to maximum 75% as it was emulsified fuel the engine was showing knocking above 75 % load. The performance parameters like brake thermal efficiency, brake specific fuel consumption was calculated. Emissions like HC, CO &NOxcoming from the exhausts were measured at various loads. The results of performance and emissions were compared with diesel and lemon oil at same loading conditions. The measured properties of test fuels are specified in the table 7.

Table 6 Engine Specifications

Engine	Kirloskar diesel model AV1
Number of Cylinders	1
Power	3.7 kW (5 bHP)
Speed	Constant speed 1500 rpm
Cylinder Bore & Stroke Length	87.5 , 110 mm
Compression Ratio	17.5
Strokes	4 Stroke
Cooling	Water Cooled
Dynamometer	Eddy current

Table 7 properties of diesel fuel and experimental tested samples.

sample	Viscosity (cst) @ 40 °c	Density (gm/cc)	Flash point °c	calorific value (kJ/kg)
Emulsion: 93/5/1.5	1.1245	0.8683	53	39289.89
Emulsion: 92/5/2/1	1.1450	0.8670	53	390067
Lemon oil	1.60	0.8530	54	41000
Diesel	3.1	0.841	58	43500

II. Results and Discussion

The stability of 5% & 10% water samples along with the performance and emission parameters of 5% & 10 % stable samples are discussed in the sub-sequent sections.

1) Emulsion Stability and 2) Performance 3) emission characteristics.

A. Emulsion Stability:

The stability of emulsions were investigated by keeping the water percent, stirring speed of electromagnetic stirrer, ultrasonification time, temperature rise during ultrasonification constant. The parameters which were changed are surfactant concentration and oil quantity.

Referring to fig 4 and fig 5 the percentage of water used in these emulsions was fixed to 5 %, it is seen that the stability of the emulsions is decreasing as time passes and the most stable sample was emulsion 93.5/5/1.5, followed by emulsion 92/5/2/1.So the best optimum sample has surfactant span 80 1.5% by volume. The least stable samples were emulsion 93/5/2 followed by emulsion 92/5/3. Referring to fig. 6 and fig 7.The percentage of water used in these emulsions was fixed to 10 %, here also it is seen that the stability of the emulsions is decreasing as time passes and the most stable sample was emulsion 86/10/2/2 which is having combination of surfactants span 80 and surfactant Methyl-dihydroxypropylimidazolium chloride having combined HLB of 6.3, followed by emulsion 87.5/10/2.5 and the least stable samples were emulsion 87/10/3 and emulsion 86.5/10/3.5 having only one surfactant span 80. From these results it is clearly seen that surfactant and surfactant quantity plays a vital role in stability of emulsions.

a. Effect of surfactant and surfactant concentration

For 5% water emulsions 1.5 % span 80 was optimum indicates that this percentage was optimum in reducing the surface tension and increasing the interfacial interaction between the molecules of oil and water.For 10 % water the quantity of water is more so obviously the amount of surfactant quantity has to be increased. For 10 % water emulsion the individual span 80 was not so effective in stabilizing the emulsions even higher quantities of surfactants were not so effective the reason can be said that with increasing water percentages the proportion of dispersed phase into continuous phase increases and hence chances of destabilization of emulsion due to sedimentation or flocculation is more due to more dispersed phase attraction. As earlier mentioned the effect of combined surfactant is more than single emulsifier, this is verified by the stability result of emulsion 86/10/2/2 which was more stable than emulsion 87.5/10/2.5. If surfactant concentration is below 1.5 % for 5 % water emulsions & 2.5% for 10 % emulsions the emulsion will be more unstable due to higher droplet size and less reduction in interfacial surface tension & there will be aggregation of higher droplet size molecules i.e. flocculation in this case lemon oil molecules and stability decreases. In case of increasing the surfactant quantity for 5% water samples above 1.5 % and above 2.5 % for 10 % water samples we see that more separation of layers is observed the reason for this could be that the surfactants itself tries to aggregate within the emulsion and increases polydispersity, the condition in which the molecules of emulsifiers are randomly oriented and disproportion occurs which is ineffective in performing its emulsifying function i.e. decreasing the interfacial surface tension and increasing the droplet size and decreasing the stability.

b. Effect on viscosity

The viscosity was measured using Ostwald viscometer. While preparation of emulsion since ultrasonication technique was used which breaks the molecules into finer drops. Final droplet size increases the effective surface to volume ratio and hence molecular interactive forces dominates and viscosity increases. From fig 4 to fig 7 it is clear that by addition of water to the base oil the viscosity of emulsions is increasing and is greater than lemon oil. With increasing percentage of water the emulsion viscosity increases as number of hydrogen bonds increase. It is also evident from the graphs that relative viscosity is decreasing with days. These results validate the stability as viscosity is a measure of emulsion stability .The viscosity is showing a decreasing trend because the repulsive forces created by the emulsifier action is counteracted by gravity forces and intermolecular forces between the constituent molecules. This results in increase in the interfacial surface tension and droplets aggregates and the effective droplet size increases and the emulsified layer shows separation. The emulsion 93.5/5/1.5 showed lesser drop in viscosity compared to other 5 % water emulsions. The emulsion 92/5/2/1 had larger viscosity comparatively to other 5 % water emulsions. For 10 % water emulsions the emulsion 86/10/2/2 showed also showed higher viscosity due to large water percentage and also due to viscous nature of Methyl-dihydroxypropylimidazolium chloride compared to other 10% water emulsions.

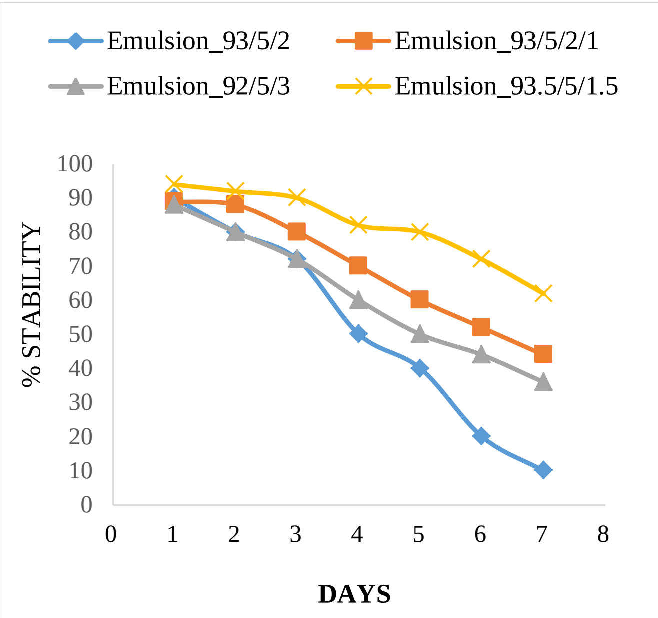

Fig. 4 Effect of surfactant and surfactant concentration on stability of emulsified samples when kept motionless with 5 % water by volume.

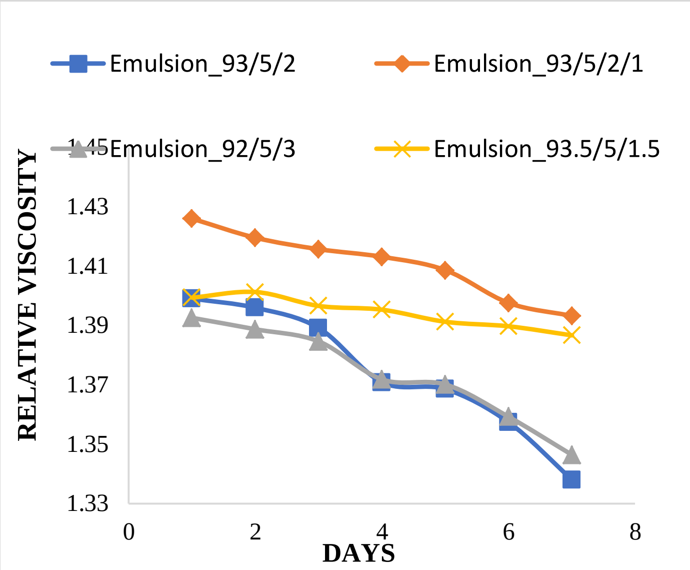

Fig. 5 Effect of surfactant and surfactant concentration on relative viscosity of emulsified samples when kept motionless with 5 % water by volume.

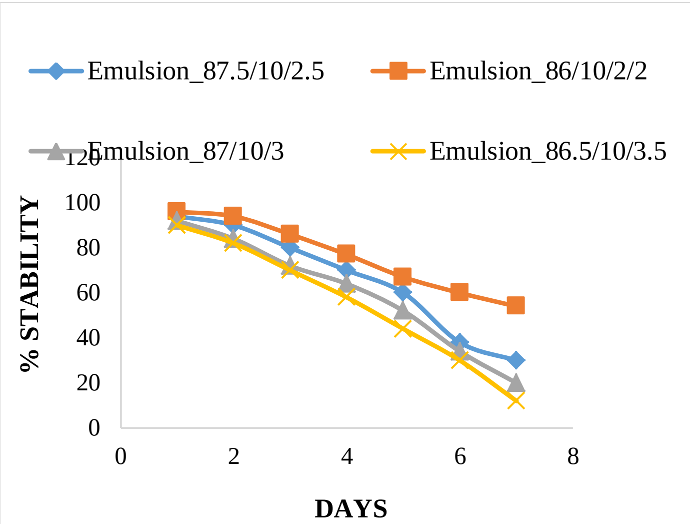

Fig. 6 Effect of surfactant and surfactant concentration on stability of emulsified samples when kept motionless with 10% water by volume.

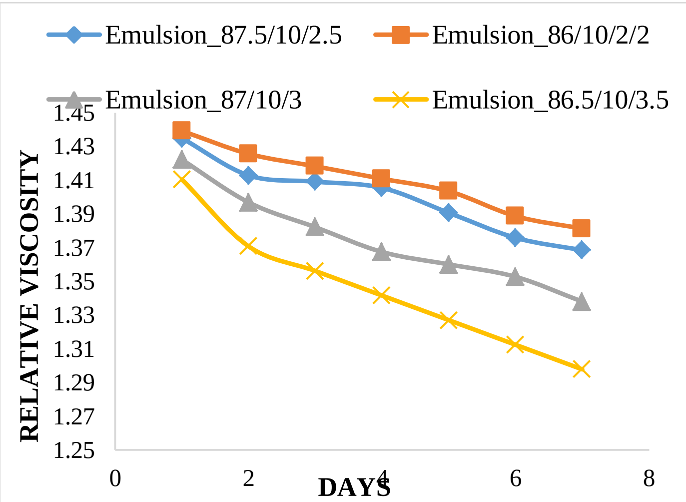

Fig. 7 Effect of surfactant and surfactant concentration on relative viscosity of emulsified samples when kept motionless with 10% water by volume.

B. Performance Investigations

Only stable samples of 5% water were tested for performance and emission in this experiment and the results will be compared with lemon oil and diesel. The engine test setup is shown in Fig. 8

Fig. 8 Engine Test Setup

a. Break thermal efficiency

Brake thermal efficiency denotes how much energy is being developed by the engine at flywheel side by burning of fuel. High thermal efficiency indicates better economy and high conversion efficiency of fuel. From the fig 9 its is observed that the thermal efficiency of emulsion 93.5/5/1.5 was 12 to 15% better than lemon oil and 13 to 22% higher than diesel at low loads and high loads respectively and for emuslion 92/5/2/1 BTE was comparable to diesel at all loads.The reason for the higher thermal efficiency for 93.5/5/1.5 sample at all loads can be attributed to the micro-explosion phenomena of water.In emulsion the water droplets is surrounded by oil and due to differences in the boiling points of water and lemon oil the water droplets evaporate and explodes creating secondary atomization of oil which increases the effective surface to volume ratio and the heat transfer from the air to fuel increases which improves the combustion efficiency compared to lemon oil and diesel, also the steam produced serves as a extra force on the piston & as a result the engine belts out higher power output. The thermal efficiency of emulsion 92/5/2/1 was comparatively lower than emulsion 93.5/5/1.5, lemon oil and also disesl. The reason for this behaviour could be associated with higher viscosity than emulsion 93.5/5/1.5 and along with lower calorific value the combined effect have led to decrease the effect of micro-explosion of water and the emulsion was not able to burn or combust properly so it couldn’t release the energy. Lemon oil has lower viscoity, as compared to diesel and two emulsions and higher gross calorific value, it even has more oxygen content due to this its combustion quality is good and hence the thermal efficency was better than diesel at all loads.

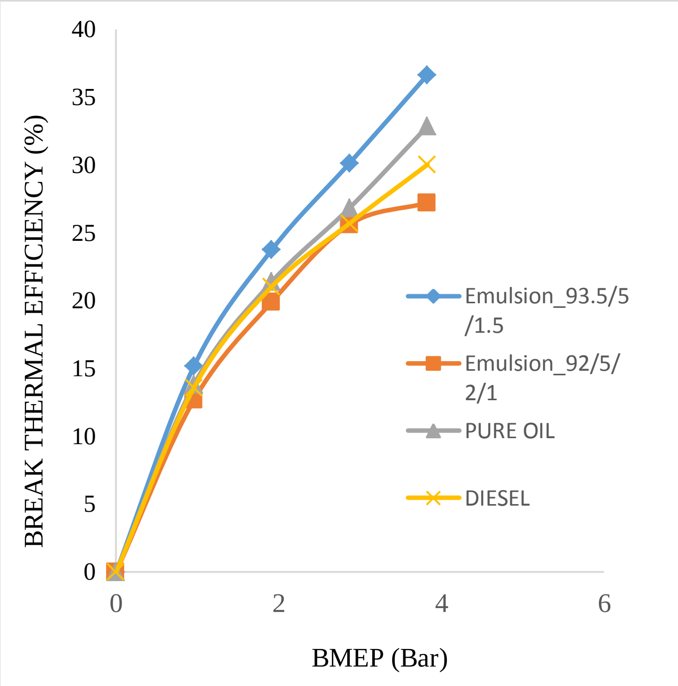

Fig. 9 Brake thermal Efficiency of emulsion 93.5/5/1.5, emulsion 92/5/2/1, pure oil and diesel at varying BMEP

b. Brake Specific Fuel Consumption

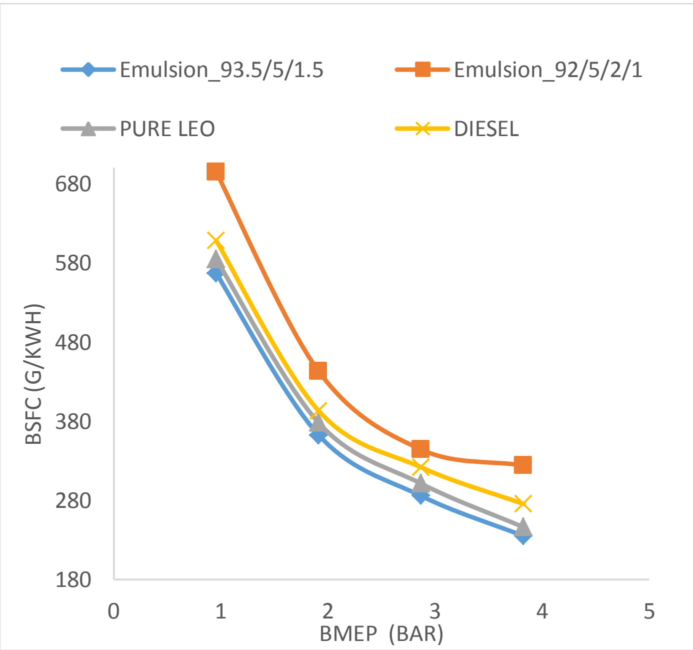

Fig. 10 BSFC of emulsion 93.5/5/1.5, emulsion 92/5/2/1, pure oil and diesel at varying BMEP

BSFC is an amount of fuel required for engine to produce one kW power output. The variation of BSFC with different loads is shown in above Fig.10. For each and every fuel sample BSFC decreases first becomes minimum and then again its increases. At the time of starting the temperature of engine is low so heat transfer to the combustion chamber walls and frictional loss is proportionally greater this results in higher fuel consumption for desired output. [5] So when BMEP is low the amount of fuel required to produce power is high so BSFC will be high. BSFC reduces with increase in the load on engine this is due to the fact that total energy release increases with increase in load but the frictional power remains same so total output power increases. [21, 31]

BSFC of emulsified sample 93.5/5/1.5 was observed 6% to 14% less compared to diesel at all loads .And observed value of BSFC was the least of all the samples tested this is because water content in the sample enables micro explosion thereby increase in break thermal efficiency of the sample. So the mass of fuel required to produce one KW power becomes less thereby decreasing BSFC.

BSFC of sample 92/5/2/1 was highest among all the samples tested. Increased viscosity and lower calorific value of sample may be the reason to increase in BSFC. Due to higher viscosity of the sample, there may be problem while injecting the sample into the cylinder along with this it has low calorific value so BSFC of sample observed was high.

C. Emission Investigations

The emission were tested using gas analyser and the details of the exhaust gas analyser can be seen in Table.8 given below.

Table 8 Details of Gas Analyser

Model no.	QRO-402	
Power source	AC 220V	
Operation temperature	0-40° C	
Measuring range	CO	0-9.99%
	CO2	0-20%
	HC	0-20000ppm
	O2	0-25 %

a. NOx Emissions

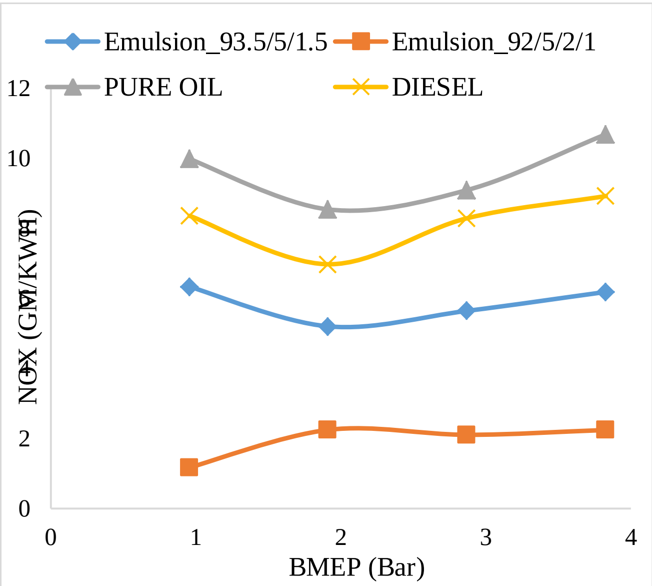

Fig.11NOx emissions of 93.5/5/1.5, emulsion 92/5/2/1, pure oil and diesel at varying BMEP.

Oxides of nitrogen emissions (NO) for diesel, Lemon oil and its emulsion with 5% water with different surfactants at varying engine loading conditions is illustrated in Fig. 11. It is noted that emissions of NOx with pure lemon oil are up to 17 % higher than diesel. This is because of more oxygen content in the oil which reacts with air at high temperature. NO emissions are seen decreased 9% to 30% at low loads and high loads respectively when oil is emulsified with 5% water. This trend is seen because sensible and latent heat of vaporization of water, the heat released by chemical reaction is absorbed by water to convert into vapors so the temperature attained in a combustion chamber reduces. [28]

Testing sample of composition 93.5/5/1.5 shows the results of reduced level of NO emissions, the reason may be water has absorbed heat released during the chemical combustion reaction and temperature inside the combustion chamber got reduced. NO emissions with sample of composition 92/5/2/1 are further reduced because the mixture was not able to combust properly and release the combustion heat and hence there was reduction in cylinder or combustion chamber temperature. Due to which NO emissions emissions were low at all loads. As load on the engine increases the temperature attained also increases so NO emissions also increases.

b. CO Emissions

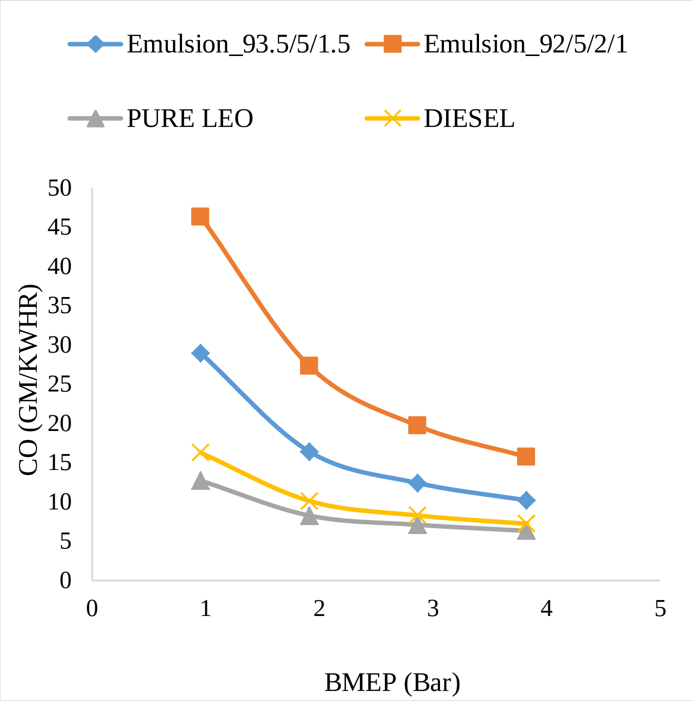

Fig.12 CO emissions of 93.5/5/1.5, emulsion 92/5/2/1, pure oil and diesel at varying BMEP

The temperature attained during combustion, pressure developed, equivalence ratio and ignition delay of fuel is important in CO emissions from diesel engines. Fuel injection quality, spray penetration, wall quenchingalso affect emissions of CO from diesel engines. Generally CO emissions comes into picture when temperature attained is low. When temperature is less than 1400 K, the CO oxidation process comes to a halt [24].

In this study we have investigated the CO emissions at different loading conditions. Fig.12 shows CO emissions output with respect to varying BMEP or load. It is observed that at low load or BMEP condition CO emissions from emulsified samples were 100 % higher than diesel due to lower combustion temperature. The reason for this may be cetane number and heating value of emulsified samples is low so it will have more ignition delay so temperature and pressure attained in the combustion chamber will be low thereby producing incomplete combustion of emulsified samples. If combustion is complete CO will be converted into CO_2 at higher temperatures [29, 30]. As the load increases temperature also increases this supports the micro-explosion phenomenon favoring complete combustion so at high loads CO emissions decreases. Even at high loads CO emissions were observed 22 % higher than conventional diesel fuel.

With the sample of composition 92/5/2/1 CO emissions recorded were too high here viscosity of sample has played an important role because the surfactant used in the sample was more viscous so overall viscosity of sample got increased. Moreover, the calorific value of sample was low compared to all the other samples so combine effect acted on its ignition quality and ignition characteristics became poor so CO emissions were high.

For pure Lemon oil since it has high concentration of oxygen it helps for combustion and combustion nearly tends to complete there by less CO emissions from engine was observed.

c. HC Emissions

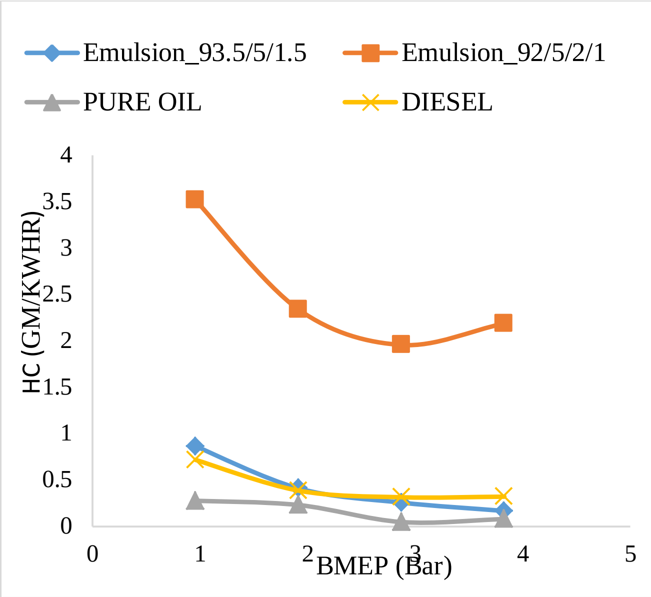

Fig. 13 HC emissions of 93.5/5/1.5, emulsion 92/5/2/1, pure oil and diesel at varying BMEP.

HC emissions from diesel engine are due to attainment of low temperature and less amount of oxygen available for combustion. The trend we got in Fig.13 for HC follows the same trend for CO as given in [2]. The reasons for production of CO and HC is same both are due to incomplete combustion of fuel and insufficient oxygen. With pure lemon oil the HC emissions were least compared to all the samples tested. HC emissions for diesel were slightly higher than emissions from pure lemon oil. For emulsified samples, sample of 93.5/5/1.5 composition was observed emitting 50% to 69% more HC than conventional diesel. Sample of composition 92/5/2/1 observed emitting more HC compared to all the samples tested because it was not able to combust properly during combustion. As the load on engine increases the temperature also increased this high temperature accelerated the rate of combustion and temperature achieved was high so there was proper burning of fuel so at high load HC emissions were less compared to lower loads for all test samples.

III. Conclusion

The aim of this experimentation was to investigate the stability, performance and emissions of lemon oil emulsions. Lemon oil was emulsified with 5% &10 % water. Stability of 5 % and 10 % emulsions were investigated and only stable emulsions with 5 % water were tested for performance and emissions. The conclusions from performed experiment are as follows:

1. The emulsion 93.5/5/1.5 with only span 80 as a surfactant 1.5% by volume proved to be effective for stabilizing the emulsions with 5 % water.Increasing the span 80 percentage beyond this leads to destabilization of emulsions.
2. The emulsions with only span 80 as a surfactant was not effective in stabilizing the emulsions with 10 % water. The emulsion 86/10/2/2 was more stable because of combined surfactant action of span 80 and new Methyl-dihydroxypropylimidazoliumchloride followed by emulsion 87.5/10/2.5 with only span 80.
3. The emulsion 93.5/5/1.5 showed increase in brake thermal efficiency over diesel & lemon oil at all loads. Emulsion 92/5/2/1 gave opposite results i.e. the efficiency decreased at all loads compared to all other test samples.
4. The bsfc of emulsion 93.5/5/1.5 was least compared to all other test samples owing to higher thermal efficiency, but the bsfcemulsion 92/5/2/1 was highest compared to all test samples the reason is associated with combined effect of increased viscosity over sample 1 and lower calorific value.
5. As mentioned earlier emulsions are effective in reducing the NOx, Both the emulsions 93.5/5/1.5 & 92/5/2/1 showed drastic reduction in NOx emissions compared to lemon oil and diesel.
6. 6)CO & HC was highest for emulsion 92/5/2/1 compared to all other samples reason for this is incomplete combustion & for emulsion 93.5/5/1.5 CO & HC emissions were comparatively less than emulsion 92/5/2/1 but was more than diesel and pure lemon oil.

7. The Engine has cold starting problem with lemon oil. Once the engine started the lemon oil and its emulsions ran smoothly up to 75 % load above that engine started to show knocking.
8. The precipitation of emulsions is the problem, which may block the fuel filters.

IV. **Future Scope**

The experimental results from the work proves that Lemon oil and its emulsions can be used as alternative fuel for CI engine. With addition of cetane improvers the NOx can be further reduced. The research can be further extended to testing lemon oil and diesel blends with water emulsions.

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