

**STUDIES ON DIESEL ALCOHOL EMULSIFICATION AND
PERFORMANCE EVALUATION OF C.I. ENGINE ON
EMULSIFIED FUELS**

Thesis

Submitted to the

**G. B. Pant University of Agriculture and Technology,
Pantnagar-263145 (U.S. Nagar),
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By

Vijay Kumar Gupta

**IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE DEGREE OF**

Doctor of Philosophy

in

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December, 2005

*Dedicated to
My Beloved Son
Master Pratik Kumar*

Acknowledgement

*"I give thanks and my heart kneels to pray;
God keep me, guide me and go with me today"*

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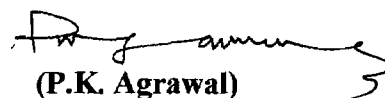
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CERTIFICATE

This is to certify that the thesis entitled “**STUDIES ON DIESEL ALCOHOL EMULSIFICATION AND PERFORMANCE EVALUATION OF C.I. ENGINE ON EMULSIFIED FUELS**” submitted in partial fulfilment of the requirements for the degree of **DOCTOR OF PHILOSOPHY** with major in **MECHANICAL ENGINEERING** and minor in **FARM MACHINERY** and Power Engineering of the College of Post Graduate Studies, G.B. Pant University of Agriculture & Technology, Pantnagar, is a record of *bonafide* research carried out by **Mr. Vijay Kumar Gupta, Id. No. 28851**, under my supervision, and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation has been duly acknowledged.

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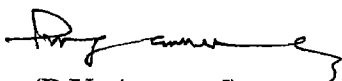


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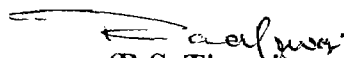
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SYMBOLS AND ABBREVIATIONS

SYMBOLS/ABBREVIATION	DESCRIPTION
A	= Cross Sectional area of the piston
°C	= Degree Celsius
API	= American Petroleum Institute
BSFC	= Brake specific fuel consumption
BTDC	= Before top dead centre
BMEP	= Brake mean effective pressure
C	= Dynamometer Constant
CAL	= Calories
CI	= Compression ignition
CC	= Centimeter Cube
CNG	= Compressed natural gas
CO	= Carbon monoxide
CS _t	= Centistokes
F _c	= Fuel consumption
Fig.	= Figure
gm	= Gram
Hr	= Hour
HP	= Horse power
H _c	= Heat of combustion
HC	= Hydrocarbon
HV	= Heat value of fuel
IC	= Internal combustion
IP	= Institute of Petroleum
IS	= Indian Standards
Kcal	= Kilocalories
Kg	= Kilogram
KJ	= Kilo Joule
KOH	= Potassium hydroxide
Ks	= Unit constant

KW	=	Kilowatt
l	=	Litre
LPG	=	Liquefied Petroleum gas
M/S	=	Messrs
mg	=	Milligram
MJ	=	Mega Joule
min	=	Minute
ml	=	Millilitre
mm	=	Millimeter
MMT	=	Million metric tonne
Ms	=	Mass of sample
N	=	No of cylinder
N-m	=	Newton meter
NO	=	Nitric oxide
NO _x	=	Oxides of Nitrogen
NO ₂	=	Nitrogen dioxide
PPM	=	Parts per million
PM	=	Particulate matter
Q	=	Energy input
Rs	=	Rupees
R.P.M	=	Revolution per minute
s	=	Second
SFC	=	Specific fuel consumption
t	=	Tonne
T	=	Torque
UBHC	=	Unburnt hydrocarbon
U. S.	=	United States
V _{cc}	=	Volume of fuel consumed
V _k	=	Kinematic Viscosity
Wc	=	Water equivalent
P _f	=	Density of fuel
P _w	=	Density of water
η _{th}	=	Brake thermal efficiency

Due to rapid increase in the number of automobiles and the finite resources of petroleum crude oil, the world is facing the problem of energy crisis. Our Indian petroleum consumption and demand during the end of financial year 2001-02 was 98.6 MMT (India, 2003), where as our indigenous production during (2002-2003) was 32MMT. Thus we had imported 67.5 percent crude petroleum to meet our consumption requirement. Further more, it is estimated that at the end of our 10th five year plan we will have to import 150 MMT of petroleum and its products which will amount to import bill of about Rs 15,000 crores at the present international prices.

Although, the fuel economy of engines has been greatly improved and will probably continue to be improved but there will be a great demand for fuel in the coming decades. India is not only facing an alarming situation in terms of huge import but also in respect of environmental pollution. It is the world's sixth largest and second fastest growing producer of greenhouse gases (www.indianngas.com). Keeping these facts in view, scientists, researchers and environmentalists are working in coordination to conserve the fossile fuels and explore the renewable ones. It has been realized that the further energy needs of the transportation sector may not be filled by

anyone fuel in the context of fast depletion of conventional non renewable sources and in view of the tremendous research efforts perused the world over developing viable alternatives. Ultimately the choice of alternatives will depend upon the availability and economics of the resources in a particular region. In this connection the interest shown in oxygenated fuels such as methanol and ethanol as potential fuels for transportation sector in India deserves serious attention.

There are several alternative fuels such as biodiesel, turpentine oil, methanol, ethanol, methane, hydrogen, natural gases (LNG, CNG), LPG (Propane) which are being explored across the world for use as engine fuels. Among the renewable alternative liquid fuels, alcohol has been most popular and widely used alternative fuels because it can be produced in most part of the world. It can be easily produced by fermentation of selected biomass such as sugar molasses and agriculture waste. Although both methanol and ethanol have been used as alternative fuels. At present, alcohols, particularly, ethanol/methanol are considered as one of the most likely near term alternatives to the petroleum based transport fuels. Physicochemical properties of methanol/ethanol make it well suited for use in spark ignition engines. Anhydrous methanol/ethanol being miscible with gasoline, the simplest approach to use is to blend it with gasoline.

Methanol is a low calorific value, high octane no. and low boiling point fuel. Difference in the physical properties of methanol and gasoline causes important changes in the fuel quality when blended together. Heat of combustion is reduced by about 5.8% for every 10 percent addition of methanol to gasoline. The stoichiometric air requirement of blended fuel is also reduced proportionately with increase of methanol content. This results in a leaning effect on carburetor when blends are used in the unmodified engines. Heat of vaporization is another property which changes significantly as the same mass of methanol takes approximately 3.5 times more heat than gasoline for vaporization.

Methanol has high antiknock quality and is being used by some oil companies as high octane blending component to gasoline. For a methanol content of 10 to 15 percent, the blending research octane number of methanol is about 131 and blending motor octane number is 110, [48]. Another important aspect of the use of methanol blend is phase separation at low temperatures and in the presence of even the traces of water. A typical gasoline when blended with anhydrous methanol may be completely miscible up to -100°C . However, a 15 percent methanol blend would split in two phases at 20°C in presence of 0.03 percent water [44]. Solubilizers of higher alcohols are required in a concentration of 1 to 3 percent to prevent phase separation. $\text{C}_4\text{-C}_6$ normal alcohols have been found to be better solubilizers than the branched chain alcohol [44].

Fuel consumption in terms of kilometres per energy unit is quite favourable for ethanol and methanol in comparison to gasoline even though their volumetric consumption are higher because of their low calorific values.

Besides the emission levels of most of the pollutants of the engines running on oxygenated fuel have been found to be lower than that of gasoline fuelled engines. For most hydrocarbons the ratio of moles of reactant to moles of product is the same. This ratio is higher for oxygenated fuels, however, such as alcohols, which produces a higher pressure in the cylinder, resulting in higher out put [48].

When comparing the various alternative fuels, ethanol has traditionally not been considered cost competitive. Recent advances in lignocellulosic feed stock processing technology may give ethanol a stronger cost position relative to the other alternative fuel [5]. **Dr. F.A. Backers** [18] UNESCO Project Co-coordinator for UNDP Project "Technical Memorandum on alternative fuels", advocated for ethanol saying "Ethanol has a special importance for developing countries because it's production from biomass is very easy and known since many years".

Again the use of ethanol as a substitute fuel for S.I./C.I. engine varies from country to country depending upon their economical, technological, structural, environmental and climatic condition. In 1983

Brazil had consumed about 1.6 million tons of ethanol as it is very rich in sugarcane from which ethanol can be produced.

There are some important differences in the combustion characteristics of alcohols and hydrocarbon fuels. Alcohols have high flame speeds (meaning higher energy efficiency) and leaner flammability limits (resulting in fuel conservation) [6]. Therefore, they generate a higher pressure in the cylinder. Due to lower molecular masses compared to diesel or gasoline the alcohol vapour disperses more readily into atmosphere rather than accumulating in lowering regions. So the greater concentrations of vapour are required for flammability with air. Due to polar nature of OH group, alcohols mix in all proportions with water and hence alcohol fires can be extinguished with water.

Low volatility is indicated by high boiling point and high flash point, both of which represent greater handling safety. When used in compression ignition engine, alcohols pose a problem owing to their low cetane number. So, it is necessary to add some ignition accelerator or other way to preparing suitable blends with using suitable surfactants having low octane no.

Use of ethanol-blended fuel can reduce the net emission of greenhouse gases. The "greenhouse effect" refers to the earth's atmosphere trapping the sun radiation. It is the term often used synonymously with "global warming" which refers to the increasing

average global temperature, arising from an increase in greenhouse gases from industrial activity and population growth. Greenhouse gases contributing to the greenhouse effect include carbon dioxide, methane and nitrogen oxide. It is expected that once ethanol is made from cellulose, the greenhouse gas emission reduction will further improve.

Since ethanol is an oxygenated fuel, the emissions produced by burning of ethanol and ethanol blended fuels are less reactive with sunlight than those produced by burning of gasoline/diesel. There is overall decrease in exhaust volatile organic compounds (VOC's) emitted from ethanol relative to conventional fuels. The volatile organic compounds are highly reactive with sunlight to form ground level-ozone in atmosphere, which in combination with moisture and particulate matters create "smog". These compounds include carbon monoxide, unburnt hydrocarbons and nitrogen oxides. Ground level-ozone causes human respiratory problems.

As far as environmental considerations are concern, unlike diesel and gasoline, the ethanol contains less sulphur and it promotes more complete fuel combustion. In diesel engines, where SO₂ and particulates are of concern, the use of ethanol blended diesel/neat ethanol shows a significant reduction in these emissions and hence the environmental damages, caused by sulphuric acid are reduced.

To solve the above problems, two alternate objectives are available. Firstly, one can search for an alternative fuel and alternative design which can fully replace the petroleum fuel. Secondly, one can search for the fuel which can partially or fully replace the petroleum fuels in the existing engines. The former choice involves modifications in fuel supply system, carburetion or fuel injection system and it also adds to the cost of the engine. If second objective, is achieved, then it will prolong the use of petroleum and will give opportunity to the present engine to be used their full life. The fuel such as ethanol is thought to be the good alternative.

The use of alcohol has been investigated mostly in the past as auxiliary fuels for their beneficial effects of reduced smoke emission and ability to supply more power for a given engine specification in compression ignition engines.

The duel fuel approach appears more promising with two separate fuel injection systems, the convention diesel fuel being injected first to promote ignition followed by the alcohol fuel.

Assuming the second objective as the viable solution of the problem, in present study stable microemulsions were prepared with the blending of ethanol, diesel and a suitable surfactant having low

octane number to minimize the cost of dual fuel approach. The main objectives of the present study are as follows :

1. To enumeration of suitable surfactants for miscibility of different proof of ethanol with diesel.
2. To study the stability of these different microemulsified fuels at different temperatures in a confined chamber.
3. To study the characteristic fuel properties of these microemulsions.
4. To evaluate the performance of constant speed C.I. engine on few selected stable microemulsions and high speed diesel oil.

2.1 Use of Unconventional Renewable Fuels in C.I. Engines.

The use of unconventional renewable and non-renewable liquid and gaseous fuels in compression ignition engines has been analyzed with the emphasis on engine performance, technical feasibility and economical viability. Ethanol is one of the several alternative transportation fuel considered for replacement of conventional gasoline and diesel fuel.

Recent researches on ethanol production from energy crop such as grasses and trees have indicated a potential for very favourable energy yields. When comparing various alternative fuels, ethanol has traditionally not been considered cost competitive. Recent advances in lignocellulosic feed stock processing technology may give ethanol an easy and low cost fuel relative to other alternative fuels [6]. Biomass a resource raw material for producing ethanol offers the possibility of replacing a large fraction of gasoline or diesel, now being used. Therefore, vehicle performance on blends and neat ethanol has gained renewed interest. As a renewable energy source, ethanol is expected to significantly reduce carbon dioxide emission [5].

Backers [21], UNESCO Project Co-ordinator for UNDP Project "Technical Memorandum on alternative fuels" advocated for ethanol saying "Ethanol has a special importance for developing countries because it's production from biomass is very easy and known for many years."

2.1.1 Alcohol as an alternative fuel

Ethanol is one of several alternative transportation fuels considered for replacement of conventional gasoline and diesel fuel. In the past, the net energy yield for ethanol production from corn or sugar crops has been less than favourable. Recent research on ethanol production from energy crops such as grasses and trees (biomass) has indicated a potential for very favourable net energy yields. Use of renewable biomass or lignocellulosic materials such as feedstocks for ethanol production can decrease carbon dioxide emissions and significantly increase total production capacity potential by broadening the feedstock resource. New biomass processing technology for ethanol production has generated increased interest in ethanol as an alternative transportation fuel.

When comparing the various alternative fuels, ethanol has traditionally not been considered cost competitive. Recent advances in lignocellulosic feedstock processing technology may give ethanol a stronger cost position relative to the other alternative fuels [1]. Biomass as a raw material resource for producing ethanol offers the possibility of replacing a large fraction of gasoline or diesel fuel now being used. Therefore vehicle performance of blends and near neat formulations ethanol has gained renewed interest. Ethanol offers high octane quality for spark ignition applications.

2.1.2 Production of ethyl alcohol

Production of ethyl alcohol falls into two categories:

- i. Fermentation
- ii. Synthetic means

At present production from fermentation processes is greater than that from synthetic means. The raw materials are:

- a. Sugar containing materials-such as sugar beat and molasses
- b. Starch containing materials-such as potatoes and grains.
- c. Cellulosic materials and by products-such as wood saw dust and sulphate liquor from paper mills.

Synthetic process may be as under :

- a. from ethylene
- b. from water gas
- c. from calcium carbide

2.1.2.1 Ethanol from molasses

The molasses are first sterilized with steam to kill undesirable micro-organism which give unpredictable results on fermentation, then diluted and passed to the fermenters. The dilution and temperature are accurately controlled and yeast of special culture introduced. The yeast has been derived from a pure strain having maximum yield of ethyl alcohol and minimum of by products. The yeast induces fermentation of the carbohydrates in the molasses. During the fermentation, the carbon

dioxide is removed after forty hours and a fully fermented material is formed which is known as mash. On distillation of the alcohol from the mash, the strong alcohol vapours are produced (i.e. up to 94% strength) and then dehydration is completed.

2.1.2.2 Alcohol from potatoes

The production of alcohol from potatoes may be taken as representative methods using farm crops as raw materials. The potatoes are steamed for one to two hours at two to three atmospheric pressure to gelatin the starch. The resultant pulp is cooled to 50°C by adding an equal volume of water and 10% malt. This mixture is allowed to stand for ten to fifteen minutes while the starch is converted to dextrin. The temperature is then gradually raised to 55°C while the dextrin is converted first to maltose then to dextrose. Yeast is then added to liquid mash and fermentation allowed to proceed for 3 to 4 days. When the alcohol has reached its optimum percentage, corresponding to a 50% conversion of starch, the mash is distilled and the water is removed from the aqueous alcoholic distillate by a suitable method.

2.1.2.3 Alcohol from cellulosic materials

Vegetable waste material, such as tropical grass, straw etc is reduced to convenient size by means of chopping machine. It is then placed in wooden vat or lead lined container, together with 2% sulphuric acid and agitated with wooden paddles. Excess acid is removed by

passing the steeped material between rollers. In this residual mass, steam is passed for six hours. At the end of which, the insoluble semi-cellulose is converted to fermentable sugar. After that, fermenting organism is introduced and fermentation allowed continuing for six days. The available carbohydrate is converted into alcoholic mash. The alcoholic mash is then distilled to finally get ethyl alcohol.

2.1.3 Use of renewable liquid/gaseous fuels in C.I. engines

Adam et al. [1] conducted an experiment and observed the performance of a six cylinder direct injection, turbocharged John Deer 6404 TR, diesel engine having displacement volume 6620 cc. The tests were carried out with 1:1 and 1:2 blend of degummed soybean oil with diesel fuel for a period of 600 hrs.

It was observed that by using 1:2 blend of degummed soybean oil and diesel, the maximum corrected horse power dropped from 133 at the beginning to 121 at the end. The test horse power remained at 117.3 throughout the 200 hour test. The corrected thermal efficiency varied from 28.9% at the beginning to 28.6% at the end. During 200 hrs run using the blend 1:1 of degummed soybean oil-diesel, the corrected horse powder dropped from 131 to 120.5 at 129 running hours.

At the end of test (600 hrs) it was concluded that 1:2 blend of degummed soybean oil-diesel fuel may be a suitable fuel for the operation of diesel equipment during diesel fuel shortages.

Zubik et al. [66] conducted an investigation to study the performance of a 188 D, 4 cylinder, naturally aspirated 4 stroke diesel engine. He also compared the performance, combustion and exhaust emissions of diesel fuel, a blend of 25% sunflower oil-diesel fuel and sunflower oil-methyl ester (SME) in the above engine which had a bore of 69.4 mm, a stroke of 104.8 mm, displacement volume of 3080 cc and compression ratio of 16.5:1. He observed the use of sunflower oil in a blend, increase of peak engine cylinder pressure and hydrocarbon emissions, but lowering of the smoke level. It was also observed that all the fuel tested behaved similarly in terms of brake thermal efficiency, ignition delay, exhaust temperature and exhaust emission of carbon monoxide and nitric oxide.

Tahir [60] studied and conducted many tests to evaluate chemical properties of sunflower oil and its methyl esters along with the fuel performance characteristics of Buda diesel engine. Kinematic viscosity, cloud point, pour point, flash point, boiling point of sunflower oil and its methyl ester were observed higher than diesel. The specific fuel consumption and thermal efficiency for sunflower oil were 6 percent higher than diesel fuel at about 60 percent of maximum power.

Kaufman et al. [36] conducted a field evaluation of sunflower oil diesel fuel blends in a John Deere model 4440, having six cylinder, in line diesel engine. The test was conducted to determine the abnormal or

excessive deposits or wear. The two fuels used in the test programme were a blend by volume of either 25% alkali-refined, winterized sunflower oil or 75% diesel fuel or 50% alkali-refined, winterized sunflower oil and 50% diesel. The diesel engines were operated for a total period of 7617 hours and burned a total of 1458.92 litre of fuel.

The engine performance checks made during the test period indicated no significant power loss, no injector choking problems or ring sticking problems were reported. Most carbon deposits were found on piston of the engines, fuelled with 50% sunflower oil blend. A significant lower amount of deposits were found on the pistons of the engines, fuelled with the 25% sunflower blend. The lowest amount of deposits was found on pistons of engines, fuelled with diesel.

It was recommended that under emergency conditions, 25% and 75% sunflower oil with diesel blends may be used in diesel engines.

Peterson [46] investigated the use of vegetable oil as diesel fuel. He observed and suggested that the vegetable oil could be used as a direct substitute for diesel. The peak engine power on the vegetable oil fuels ranged from 91-109% of that on diesel fuel. The vegetable oils used in the test were rapeseed, soyabean, sunflower, peanut, palm, kernel, jojoba, coconut, linseed and canola. The long duration tests showed severe engine carbon deposits, ring sticking, injector choking and thickness of the lubricating oil.

Bhattacharya et al. [9] had studied the performance of a compression ignition engine on biogas diesel fuel. A compression ignition engine having two cylinder, 10 bhp, constant speed, water cooled, stationary and compression ratio 16.5 was modified to run on biogas-diesel fuel. The inlet manifold was modified in such a way that an entry point was incorporated at the centre of it for biogas mixture. The performance of the engine on diesel and dual fuel was studied at varying load conditions. The testing was carried out at standard injection timing of 20° BTDC. For dual fuel operation, the injection timing were selected 20°, 25°, 30° and 35° BTDC. At varying load conditions, the brake horse power, brake thermal efficiency, brake specific fuel consumption, volumetric efficiency, air fuel ratio and percent diesel replacement were measured. It was reported that at 30° BTDC injection timing, the engine developed 81.6% of the maximum power developed by it on diesel. At this injection time setting, the replacement of 70% diesel was found. At higher loads the brake specific fuel consumption (diesel) dropped significantly. It was also reported that for efficient operation of the engine, 0.813 m³/bhp-hr biogas was required.

Natusch [43] studied the feasibility for utilizing compressed natural gas (CNG) as a diesel substitute. Due to gaseous nature of CNG, it can not be injected for controlled auto ignition process. However, it can be used a partial substitute of diesel into combustion chamber,

retaining a reduced diesel fuel injection quantity. CNG can be used in diesel engine by conversion of diesel engine unit to otto cycle operation, thus, utilizing the combustion properties of CNG. It was reported that CNG would result in air quality improvement particularly, in the removal of black smoke emissions.

Rao and Gopalkrishnan [50] studied the performance of diesel engines on vegetable oils and methyl esters on karanji oil, soyabean oil, sunflower oil and neem oil. A compression ignition engine (Model-AVI), Kirloskar make, one cylinder, having compression ratio 18 was used to conduct the experiments on above fuels and it was observed that the brake thermal efficiency of engine was less on vegetable oils as well as on methyl esters of different vegetable oils. The exhaust smoke intensity was also more in vegetable oils and their methyl easters compared to diesel oil.

Ghosh and Bhattacharya [23] conducted an experiment on CNG in diesel engine. They reported that there was a maximum diesel replacement of 90% by CNG in an engine operating at 1600 rpm. The brake thermal efficiency on dual fuel was comparable with that of diesel fuel at low levels of loads. At higher loads, increase in thermal efficiency was observed on dual fuel. The reduced emission of oxides of nitrogen was also reported during lean A/F ratio, but there was a slight increase in emission of carbon monoxide at above setting.

Sarkkinen [54] carried a test on gasoline engines in order to minimize environmental pollution. It was observed that though methyl tertiary butyl ether (MTBE) and ethyl tertiary butyl ether (ETBE) are being used as oxy-generators in gasoline, it would be worth while to use ethanol for the same purpose. Ethanol produced from the fermentation of molasses would be alternative oxygenerators having high octane number and good combustion characteristics.

Pramanik [48] conducted a study to determine the properties and use of *Jatropha curcas* oil and diesel fuel blends in compression ignition engine. *Jatropha* diesel blends by volume prepared for experiments were as 70:30, 60:40, 50:50, 40:60, 30:70 and 20:80. The performance of constant speed diesel engine was evaluated in terms of specific fuel consumption, brake thermal efficiency and exhaust gas temperature. A single cylinder, water cooled, combustion chamber Kirloskar make, having compression ratio 15 was used at rated speed of 1500 rpm only.

It was reported that the blends containing up to 30% *Jatropha* oil had viscosity values close to that of diesel fuel while viscosity of blend having 40% *Jatropha* oil has slightly higher viscosity than diesel. The viscosity of the blends containing 70% and 60% *Jatropha* were close to the viscosity of diesel in the temperature range of 70-75°C and 60-65°C, respectively. It was observed that up to 50%, *Jatropha* oil can be substituted for diesel and can be used in CI engine without any major operational difficulties.

Nagrajan *et al.* [42] studied the performance and emission characteristics on homogeneous charge compression ignition (HCCI) mode of a diesel engine by utilizing liquefied petroleum gas (LPG) as a fuel and diethyl ether (DEE) as an ignition enhancer. The performance and emission characteristic in HCCI mode of LPG-DEE fuel was also compared with the conventional LPG-diesel, dual fuel operation and diesel operation. Homogeneous charge compression ignition concepts have an advantage of both spark ignition and compression ignition. In this new approach, LPG used as a fuel was carburetted with intake air and DEE was introduced into the cylinder through intake manifold by fumigation and then subjected to compression as in conventional diesel engine.

A single cylinder, direct injection, four stroke, water cooled diesel engine with a compression ratio of 16.5 with rated power 3.75 KW at 1500 rpm was used for the test purpose. It was concluded that thermal efficiency, NO emission and smoke emissions were found to be lower in HCCI mode of LPG-DEE at all loads than that in dual fuel mode and neat diesel operation. However, CO and HC in exhaust gases showed an increase at all loads in HCCI mode. At high load (80% and 100%) severe knock was observed due to admitting of too rich mixture having very rapid combustion. It was also concluded that by the use of HCCI approach, complete elimination of diesel fuel pipeline, fuel pump, fuel injector from the diesel engine and complete replacement of diesel fuel were possible.

2.1.4 Use of ethanol as fuel in C. I. engines

Wrage and Goering [64] carried a test on John Deer model 830 diesel engine on diesel fuel and a fuel, named "diesohol," a blend of 10 percent anhydrous ethanol and 90 percent diesel by volume. He evaluated the performance of the engine which had three cylinders, with rated horse power 26.3 KW at 2400 RPM. The variable parameter such as load, speed, fuel flow rate, exhaust smoke, exhaust temperature and engine coolant temperature were measured, on the basis of result of tests. It was concluded that at normal room temperatures, anhydrous ethanol formed a homogeneous solution with diesel fuel. In aqueous ethanol-diesel, (Solution), ethanol separated from diesel fuel and floated to the top of the container. Due to lower boiling point than diesel fuel, diesohol (blends) required closed container for storing purposes otherwise, ethanol evaporate from the blend.

Diesohol had a lower fuel viscosity of $2.1 \text{ mm}^2/\text{s}$ and lower Cetane rating of 45. Engines consumed more diesohol than diesel but generated almost the same power with both the fuels.

Diesohol fuel produced approximately 30 percent less smoke compared to diesel. Ethanol diesel fuel blends did not corrode the seals of injector pump for ethanol concentration from 0 to 50% during the continuous test on it up to one year duration.

Use of diesohol in engine creates a vapour lock in the injector pump and stalled the engine. This is because engine temperature excluded the boiling point of ethanol, Vapour lock problem was overcome by chilling the diesohol or pressurizing it before it entered the pump.

Goering and Wood [25] investigated the performance of a diesel engine with carburetted ethanol. A side drift carburettor was used to fumigate ethanol into the air intake manifold of the engine. The test was carried on 3-cylinder, direct injection, naturally aspirated, Ford 2000, diesel engine. Both the choke and throttle plates were removed from the carburettor to avoid restriction of entering air. A calibrated rotameter was used to measure the flow rate of ethanol. The test was conducted on 200° proof and 160° proof ethanol with unheated and preheated air. It was reported that carburetting ethanol with unheated air increased peak engine power approximately by 8 percent while decreasing brake thermal efficiency by about 1 percent. Carburetted ethanol increased the exhaust smoke, exhaust temperature, unburnt hydrocarbon and carbon monoxides. The carburetted ethanol was fully vaporized unless the air was preheated.

Gupta C. P. [28] investigated the different ways of using alcohol as a diesel fuel extender. Carburetion and Fumigation were found available methods of using alcohol in existing diesel engines. Ethanol

fumigation was found to give substantial saving of diesel fuel consumption at all loads. The diesel replacement with ethanol at high load conditions was observed to improve energy use efficiency whereas at light loads, a small degradation was observed. Limit of ethanol substitution depends on maximum acceptable pressure rise and maximum tolerable, loss in efficiency at high loads.

If ethanol is carburetted, a suitable designed air-alcohol indicator would be used. The flexibility in engine operation may be obtained with diesel substitutions up to about 50%. It was reported, a marginal improvement in thermal efficiency and lower smoke intensity at the above diesel substitutions.

Meiring *et al.* [40] conducted an experiment on naturally aspirated, 3 cylinder, direct injection diesel engine fitted with a rotary distributor pump with ethanol-diesel blend having 15 percent anhydrous ethanol and 85 percent diesel fuel on volume basis. It was found that there was a phase separation when the ambient temperature was down to 0°C. However, there was no problem of cold starting during early morning hours. 3 percent ethyl acetate (phase inhibitor), on volume basis, was recommended to avoid such phase separation. It was observed that the blend had the tendency of reducing engine power by 3 to 5 percent of the maximum power at low level loads but this reduction in power was less significant at high level loads. Study of

smoke meter reading showed that complete combustion takes place with the blend than with the diesel. The soot emission was lower by 10 percent with the blend. Less deposition of carbon and reduced abrasive wear in the cylinders were observed due to greater combustion efficiency.

Ecklund *et al.* [20] studied different techniques of using ethyl alcohol in diesel. The techniques studied were alcohol-diesel blends, alcohol-diesel emulsions, alcohol fumigation and dual fuel injection. It was reported that in case of alcohol-diesel blend, the kinematic viscosity and the Cetane number were reduced due to addition of ethanol in diesel compared to diesel fuel. There was also a reduction in maximum brake power and thermal efficiency by addition of more than 20 percent ethanol. In general, HC emission increased with increasing ethanol addition. CO emission remained the same while NO_x varied slightly higher depending on the engine combustion configuration. Particulate in offers and smoke emission tended to decrease with ethanol addition.

Dual injection of ethanol and diesel through a separate injection system resulted in power output, which was equal to or more than diesel. This method would replace more than 90 percent of diesel fuel requirement (on the basis of energy) using alcohol at or near full load. At idle or low load, about 50 to 60 percentage of diesel replacement could be obtained.

Walker [63] conducted a test on Allis Chalmer D-16 tractor diesel engine on 190^o proof ethanol. The ethanol was injected at the rates of 0, 1.32, 2.02, 2.76 and 3.16 l/hr. The variable parameters such as torque, power, fuel consumptions, thermal efficiency, smoke and CO emission were measured for knowing the performance of the above engine. It was found that the fumigation of ethanol caused an increase in torque and power under maximum speed control setting. The thermal efficiency was improved at reduced speed control setting for light to moderate loads. The smoke and carbon monoxide emission increased with moderate to heavy loads with increase in alcohol input under full throttle setting.

Chaplin and Janius [14] conducted an experiment on fumigation of ethanol in a compression ignition engine using advanced injection of diesel fuel. A Ford 801, 4 cylinder, direct injection diesel engine was used in this study which had displacement volume of 2818.6 m³ and compression ratio of 16.8. Power was measured through a DC dynamometer and fumigation ethanol was accomplished by using a cone jet nozzle mounted on intake manifold extension pipe. Industrial grade ethanol i.e., 190^o proof was used during the experiment. Three different ethanol flow rates of 25, 32 and 45 gm/min and three diesel injection timings 18^o, 23^o and 30^o BTDC were used to determine the engine performance. It was seen that the brake thermal efficiency at two third and full loads were comparable to those found when operating on

diesel for all injection timings and fumigation rates. The effect of longer ignition delay associated with high heat of vaporization of ethanol might overcome due to improved ethanol air mixing. The brake thermal efficiency at one third loads for ethanol fumigation was lower than diesel operation especially at 18° and 23° BTDC. At a given ethanol fumigation rate, efficiency was mainly a function of injection timings and loads. A 2% increase in brake thermal efficiency was recorded when the engine was operated at full load, and 30° BTDC injection timing at 45 gm/min ethanol fumigation rate.

Stumborg [59] studied alternative fuel parameters for a diesel engine. The study was done to evaluate the parameters of direct injection, turbocharged, diesel engine that would give the allowable substitution limit of 190° proof ethanol for diesel fuel. Rate of energy consumed, rate of exhaust energy lost and exhaust temperature were evaluated with diesel fuel and dual fuel modes. The engine which was used for the above study was turbocharged, direct injection, six cylinder, Allis Chalmers make 649-T having a compression ratio of 15.0 and a maximum rated output of 82.5 KW at 2100 rpm. Injection timing was set at 18° BTDC and was not altered during whole experiment. This study indicated that a successful control might be adopted based upon normalized total fuel rate, exhaust power loss, intake air consumption. Fumigated ethanol was suggested to introduce into intake of the engine.

Singh [56] studied the performance of a stationary, single-cylinder, water-cooled, 4-stroke, ignition engine by dual fuelling, ethanol with diesel. The engine was rated as 5 hp at 1500 rpm engine speed. The standard injection timing was 27° BTDC. The method used for fumigation of ethanol was carburetion. The process of dual fuelling was carried out in two phases. The first was by inducting ethanol into combustion chamber at the rate of 0.163 ml/sec and preheating air-ethanol mixture at 50° , 60° and 70° centigrade, respectively. In the second phase, the same process was carried out with the addition of 0.3, 0.5, 0.7 and 1% aniline (on volume basis) as an ignition improver. The engine on dual fuel was tested at 27° , 30° and 33° BTDC injection timing as compared to diesel fuel's 27° BTDC. The results displayed that the injection advance of 33° BTDC resulted in maximum power out put. Further, an increase in engine power was also observed on dual fuel for preheated air-ethanol mixtures. The diesel replacement for satisfactory operation of engine on dual fuel at 50°C was found to be 10%, 12% for preheated air-ethanol mixtures and for the case of 0.5 percent aniline as addition, it was 13.6%.

Goering *et al.* [26] studied the performance of the C.I. flexible fuel engine on ethanol and diesel fuel. To carry out this test a multipoint fumigation system was installed on an IH 52882, 6 cylinders, turbocharged, 128 KW and diesel farm tractor. An additive called Avocet

containing an ignition improver was mixed with ethanol to overcome the problem of auto-ignition. The primary injection system retained on the engine was its own original, governor controlled diesel injection system. Anhydrous ethanol enhanced with Avocet additive was injected through the primary injection system. After the primary injection pump adjustment, the engine was able to develop full power when running on ethanol. Finally it was observed that the peak cylinder pressure raised drastically when the engine was run on fumigated ethanol.

Ajav [2] studied the engine performance characteristics using dual fuels comprising ethanol-diesel blends and fumigated ethanol. The test was conducted on a 10 bhp, constant speed, C.I. engine. The test was carried on a Kirloskar make (Model TV-110) single cylinder, water cooled engine, having displacement volume of 1102 CC and C.R. of 15.6:1. Studies were made on the exhaust emission characteristics of the engine in respect of CO and NO_x emission and smoke intensity. It was suggested that, on the whole, the use of ethanol-diesel blends with up to 20% ethanol could be used in constant speed C.I. engines. The reason being that for the same load conditions the engine developed similar brake power with lower CO and NO_x emissions. It was concluded that with the use of ethanol diesel blends, there are no problems with fuel handling, no engine modification is required and thus, the technology can be easily adopted.

Bihari [10] studied the effect of ethanol proof on the performance of a stationary constant speed, low bhp, C.I. engine. Kirloskar make (Model TV-110), single cylinder, water cooled, C.I. engine having a displacement volume of 1102 CC and C.R. of 15.6:1 was used for the studies. The rating of engine was 10 bhp at 1500 rpm. The diesel ethanol blends in the ratio of 80:20 and 85:15 were the types of fuel used. Also, ethanol of 200^o, 190^o, 180^o and 170^o proofs were used. From the studies it was observed that the power producing capabilities, reduced bsfc, increased thermal efficiency of the diesel-ethanol blends prepared from 170^o to 200^o proofs were comparable to diesel fuel. It was recommended that the use of ethanol as supplementary fuel is feasible in small, constant speed, low bhp, C.I. engines. A blend comprising 15% ethanol of 170^o proof and 85% diesel was also recommended.

Ajav *et al.* [4] conducted a study to establish thermal balance of a constant speed, medium size, single cylinder, compression-ignition engine operating on ethanol-diesel blends and fumigated ethanol. The purpose was to determine the thermal balance of the engine at different loading conditions. A stationary, constant speed, single cylinder, 10 bhp, Kirlosker TV-110 diesel engine was used. The engine was operated on both fumigated ethanol and ethanol-diesel blends, having 5, 10, 15 and 20 percent ethanol on volume basis. It was observed that as the load on the engine increased, the percentage of useful work also increased,

whereas other losses decreased. In the initial stages of loading condition, the increase in useful work was more pronounced than at latter stages. The quantum of useful work for diesel was 28.68% whereas it was 28.73, 31.06, 31.95 and 32.89% for 5, 10, 15 and 20 percent ethanol-diesel blends, respectively. In comparison to diesel fuel operation, there was an increase of ethanol in ethanol-diesel blends. The cooling effect and combustion of ethanol is more efficient as compared to diesel. 28.52% of heat input was utilized as useful work in case of fumigated ethanol whereas in cold fumigation, 28.14% was utilized for the preheated fumigation case, thereby, resulting in higher heat input for the former than the latter. The thermal balance of the engine operating on diesel, 5 and 10% ethanol-diesel blends and fumigated ethanol was not significantly different at the 5 percent level, but on 15 and 20 percent ethanol-diesel blends, it was significantly different compared to diesel.

Beyerlein *et al.* [8] conducted a research by using a mixture of ethanol and water. The fuel had 68.8% anhydrous ethanol, 30% water and 1.2% isopropanol. The test was performed on a converted Ford Van which has engine power of 35.1 KW. A catalytic Plasma Torch (CPT-1) that acted as catalytic igniter known as SMART PLUG was equipped in the Van. The SMART PLUG had the ability of igniting high water mixture extending the lean limit of ignition and combustibility. The converted Van was followed the EPA federal (Road up) Test Protocol to

determine the emission characteristics. The vehicle was operated in severe weather condition ranging from subzero in the winter to 37.78°C in the summer. After completion of test it was found that emission of NO_x, CO, unburned hydrocarbon and particulate matter reduced significantly.

Ajav and Akingbehin [3] determined some basic fuel properties of local ethanol blended with diesel and compared with diesel alone to establish their suitability for use in compression ignition engines. For this six blends of ethanol and diesel containing 5, 10, 15, 20, 25 and 30 percent of ethanol by volume were used. It was found that relative density of all the blends was lower than that of diesel alone and was dependent on temperature. The cloud points were same for all the fuels tested but the pour points for all the blends were lower than diesel. The blends showed less viscosity than diesel. Flash point temperatures for the blends were below the ambient temperature resulting higher flammability. Calorific values of all blends were lower than that of diesel but the difference was not significant.

Koganti *et al.* [37] Engines power output, fuel economy and emission tests were carried out on 5% ethanol-diesel blend in tractors. Also cold startability tests were also conducted at 0°C. A suitable emulsifier was used to form a stable blend of ethanol in diesel. Octane number and lubricity improver were also incorporated in the test fuel. A

5% ethanol-diesel blend (ED) and commercial diesel (CD) were the fuels used. A tractor engine of four stroke, diesel injection, water cooled, three cylinder and in-line and rotary fuel injection pumps were used. For cold startability studies, again the same engine was used. The studies show a reduction in CO emission and particulate matter emission of the order 7.2% and 9.4%, respectively. However, NO_x emission increased to the order of 4.8%. It was also observed that more time was required for starting the engine at 0°C with in-line fuel injection pump arrangement and 5 percent ethanol in diesel. Performance studies showed that there was a slight drop in power and torque along with the loss in fuel economy.

2.2 Use of Microemulsified Fuels in C.I. Engines

Gillberg and Goering [24] compared the performance of three microemulsions fuels with a reference fuel of pure diesel oil having Octane number of 43 by using a single cylinder, direct injection, test engine. Maximum pressure, fuel consumption, exhaust temperature, CO, CO₂, NO, NO₂, O₂, HC and smoke at varied injection timings, loads and speeds were determined. The engine performance was evaluated on a microemulsion having a:

1. Octane number between 44-45 and containing 63 percent diesel, 27 percent emulsifier and 10 percent water by weight.

2. Octane number between 40-42 and containing 56 percent diesel, 24 percent emulsifier and 20% water.
3. Octane number of 35 and comprising 49 percent diesel, 21 percent emulsifier and 30% water.

It was observed that brake specific fuel consumption increased by 9% for the microemulsion fuel containing 10% and 30% water and by 4% for the fuel with 20% water compared to diesel. The increase in BSFC was independent of injection timings, engine speeds and loads. The amount of NO emission was found to be a function of injection timing and was reduced by 30 to 65%. The reduction was greater with the microemulsions having water content at higher speeds. Similar trends were observed for NO_x and smoke. In all cases the microemulsion fuels showed higher levels of O₂, CO and HC in the exhaust gas. The critical increase in UBHC at idling conditions also occurred at higher injection timings for the microemulsion fuels than the diesel fuel. It was also found that the changes in the Octane number and composition of the emulsifier seemed to improve the properties of the microemulsion fuels.

Boruff *et al.* [11] studied the effect of diesel-ethanol micro-emulsions on a Ford 2000, naturally aspirated, direct injection, diesel engine. The test engine had a displacement volume of 2589 cc and a compression ratio of 16.5:1. The engine used a CAV distributor type injection pump with injection timing of 19° BTDC. Two types of

microemulsion fuels were prepared. An ionic microemulsion was formed from unsaturated fatty acids, Emersol-315 and N-Dimethyl ethanolamine. A non-ionic microemulsion was prepared by using 1-butanol as surfactant. Ethanol used was 190^o proof. With proper adjustment it was found that the engine was capable of developing full power using either of the hybrid fuels. It was found that the brake thermal efficiency at full power was 4-5 percent higher with hybrid fuels than with diesel fuel. The hybrid fuel resulted in lower exhaust temperature compared with diesel fuel. The use of hybrid fuels reduced the exhaust smoke and carbon monoxide but an increase in the level of UBHC was observed in the exhaust gasses.

Goering *et al.* [27] studied microemulsion of soya oil-ethanol as diesel fuel on a John Deere Model-152 tractor with 3-cylinder, naturally aspirated, direct injection and 36.3 KW diesel engine at 2400 rpm. The engine used a Roosa Master distributor type injection pump with normal injection advance at 26^o BTDC. The engine was run on hybrid fuel formed by creating microemulsions of aqueous ethanol in soyabean oil. A non-ionic microemulsion was formed by using butanol as a micro emulsifying agent and a mixture of linoleic acid and triethylamine as surfactant. It was concluded that the non-ionic microemulsion produced nearly as much engine power as diesel fuel at the same speed despite having a 19% lower heating value. The increased viscosity of hybrid fuel

resulted, in 16% increase in the mass of each fuel injection at maximum power, but the injection contained 6% less energy than that of diesel fuel. The hybrid fuel burnt and yielded a 6% gain in thermal efficiency at full power. Brake specific fuel consumption was 16% higher at full load for hybrid fuels. The non-ionic fuel gave slightly higher thermal efficiency, higher engine power and lower BSFC than the ionic hybrid fuel. Diesel knock could not be sensed for the hybrid fuels and thus the low Octane number of the hybrid fuels was not reflected in engine performance. The hybrid fuel was less volatile than ethanol and thus, could be handled more safely.

Chatterjee [15] conducted a research work to study the engine performance and exhaust emission characteristics of ethanol-1-butanol-diesel microemulsion fuels in a low bhp, single cylinder, Kirloskar make (Model-TV-110), diesel engine having displacement volume of 1102 CC and compression ratio of 15.6:1. The engine was rated as 10 bhp at a engine speed of 1500 rpm. The engine was tested on different microemulsion fuels which were prepared by using 160^o, 170^o and 180^o proof ethanol in the proportions of 180^o-15/30/45, 180^o-10/25/55, 170^o-10/25/55 and 160^o-10/25/55 of ethanol/1-butanol/diesel on volume basis. The engine was tested at varying loads and speed conditions. It was observed that the prepared microemulsion fuels had similar power producing capabilities compared to diesel under each load condition.

Because of lower heating values of microemulsion fuels, a slight increase in BSFC was also observed. The thermal efficiency of the engine was recorded from 14.5% to 16.3% on microemulsions. However it was 19.4% higher on diesel fuel at full engine load. The exhaust emission levels of CO and UBHC were lower, however, NO_x emissions were found marginally higher on the microemulsion fuels compared to diesel fuel.

The amount of diesel replacement was found to vary from 39% to 50% on microemulsions. It was recommended that the use of 170⁰-10/25/55 could be a feasible fuel for constant speed, low bhp, compression ignition engines which replaced 39% diesel fuel without requiring any engine modification.

Chandra [13] carried out a research study on the emphasis of the use of ethyl acetate surfactant for diesel-alcohol microemulsions as C.I. engine fuel. Ethanol proofs of 200⁰, 190⁰, 180⁰ and 170⁰ were used to prepare diesel-ethanol microemulsions using ethyl acetate as emulsifier. A Kirloskar make, AVI model, constant speed, four stroke, single cylinder, water cooled, diesel injection, C.I. engine was used. The rating of engine was 5 bhp (3.73KW) at a speed of 1500 rpm. The tests were performed with respect to brake power, fuel consumption, thermal efficiency and emissions of CO, UBHC and NO_x. It was seen that the phase separation characteristics of ethanol-diesel microemulsion was dependent on the proof level of ethanol as well as on the quantity of

emulsifier used for microemulsion formulation. There was a decrease in kinematic viscosity of ethanol-ethyl acetate-diesel microemulsions with increase in the level of ethanol and ethyl acetate. The gross heat of combustion of different proofs of ethanol and microemulsion was found to decrease with decrease in proof level of ethanol and an increase in the level of ethanol and ethyl acetate in the microemulsion. The brake power, fuel consumption and brake thermal efficiency of engine were found to increase with increase in brake load for all fuels tested. However, the BSFC of engine decreased with an increase in brake load and was found to be maximum at 25% brake load on all fuels. There was an increase in the emission of CO, NO, NO₂ and exhaust gas temperature with an increase in brake load. Also, UBHC emission was found to increase with decrease in proof level of ethanol and with an increase in the level of aqueous ethanol in the microemulsions. Finally, use of 190°-20/29/51 (ethanol/ethyl acetate/diesel) microemulsion, replacing 49% diesel by volume was recommended for constant speed, low bhp, C.I. engine.

Review of the past research works showed that the use of alcohol as C.I. engine fuel is generally restricted on two most commonly used modes, viz., blending and dual fuelling. Out of the two techniques, blending method is lucid and requires no engine hardware modification but is limited to ethanol proof and ambient temperature conditions. This

results into phase separation and limits the amount of diesel requirement.

Dual fuelling approach is somewhat promising but incorporates engine modification and diesel replacement is limited by the engine knock. The possible use of microemulsions as C.I. engine fuel has not yet been investigated in detail. The microemulsion fuels offer a simple way to overcome the problems of phase separation encountered in blending the diesel fuel with lower proof ethanols and engine alterations with dual fuelling approach.

The experimental tests were carried in the Alternative Energy Laboratory of the department of Farm Machinery and Power Engineering, College of Technology, G.B. Pant University of Agriculture and Technology, Pantnagar. In this chapter, experimental details, various parameters studied and methodology used in the analysis are described in detail.

3.1 Fuels and Emulsifiers

The experiments were conducted on preparation of stable microemulsions with different ethanol proofs and high speed diesel oil (HSD) using different emulsifying agents or surfactant.

3.1.1 Emulsion and emulsifiers or surfactants

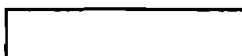
An emulsion is a mixture of two or more immiscible liquids, being present in the other in the form of droplets. The liquid usually present in excess is termed as the closed, continuous or external phase while the liquid dispersed in it is termed the internal or dispersed phase.

The preparation of an emulsion is termed as an emulsification and the agents used for this purpose are termed emulsifies or surfactant.

Emulsions are found in nature. Two practical examples being milk (o/w emulsion), butter (w/o emulsion) and rubber latex. These emulsions are stabilized by natural emulsifying agents.

Emulsifiers or surfactants are surface active agents having a polar and non polar regions. A surfactant adsorbs or attracts molecules of a liquid to its surface. These are two groups in the molecule.

1) Hydrophobic group (water hating) A hydrophobic part



Water disliking

2) Hydrophilic group (water liking) A hydrophilic part



Water liking

The non polar molecules can be hydrophilic if they contain electronegative atoms capable of associating with the hydrogen bonding in water. The oxygen atom in alcohols, ethers, aldehydes are hydrophilic group when they are attached to a hydrophilic group. Their effect is diminished or even eliminated if the hydrophobic group is large enough.

The aqueous stability of an alone surfactant molecule will depend upon the relative strengths of the hydrophobic and hydrophilic effects. They are not independent, since both rely on the structure of the hydrogen bonds around the hydrophilic and hydrophobic groups.

The most stable emulsions are found when the surfactant is more soluble in the continuous phase that is for w/o emulsions. A water soluble surfactant is most efficient, and for o/w emulsions an oil-soluble surfactant is most efficient.

Many attempts have been made to correlate surfactant structures with their effectiveness as emulsifier. The most successful method, still used, is the hydrophilic/lipophilic balance (HLB) first developed by **Griffin [30]**. Griffin proposed to calculate the HLB number from its chemical structure.

HLB = % of the hydrophilic group (molar) divided by 5. Thus the maximum HLB numbers was 20 and represented a product composed entirely of ethylene oxide with no hydrophobic group. HLB zero represented a completely water in soluble product with no ethylene oxide.

Table 3.1.1.2: Hydrophilic/Lipophilic balance

HLB Number	Appearance on adding Surfactant to water	
1 – 4	Insoluble	w/o (water in oil emulsion)
4 – 7	Poor dispersion un stable	w/o
7 – 9	Stable opaque dispersion	-
10 – 13	Hazy solution	o/w (oil in water emulsion)
13 –	Clear solution	o/w

Diesel oil – Hydrophobic group (water hating)

Ethyl alcohol – Hydrophilic group (water liking)

Microemulsions must be optically clear and indefinitely stable.

3.1.1.2 Selection of emulsifier or surfactant

The following considerations may make selection of surfactant or emulsifier samples.

- (i) **Chemical Structure:** - The chemical structure of emulsifier should match the chemical structure of the internal phase. For example, fats can be emulsified in fatty acid esters.
- (ii) **Particle size:** - The particle size of a liquid emulsion is related to the method of preparation, the energy input, the viscosity difference between the phases and the type and amount of surfactant used.

With reference to small particle size, formation emulsions may be classified into two categories.

- (a) The emulsion having low emulsifier that requires appreciable mechanical input.
- (b) The emulsion having high emulsifier that requires only moderate mechanical effort.

Particle size generally decreases with vigorous agitation. Smaller viscosity difference between two phases, and the use of a longer amount of proper surfactant.

In an emulsion, longer the particle size, the greater is the tendency to disperse. Thus fine and very small particles promote stable emulsion.

The particle size of an emulsion may be reduced by-

- Increasing the amount of emulsifier.
- Improving the HLB of emulsifier.
- Improve agitation.

- (iii) **Stability:** Here stability means the physical stability, not chemical changes resulting from oxidation etc. Instability of emulsion occurs by setting and coalescence, i.e., phase separation and precipitation.

3.1.1.3 Testing of various emulsifiers for formation of stable emulsions

Alcohols and diesels form separate layers, when mixed together. This behaviour is due to their different types of chemical structure. Diesel is a mixture of different long chain hydrocarbons including some aromatic compounds. Those hydrocarbons have non polar bonds. The molecules in diesel are connected by Vander Wal forces, while alcohols have a polar OH radical. This is due to difference in electro-negativity of hydrogen and oxygen. All the molecules in alcohols are connected by hydrogen bonding as in water. Based on these differences some emulsifiers which have a capacity to connect the polar molecule of alcohol and non polar molecule of diesel. The emulsifier should be such that it can easily dissolve alcohol and water as well in it. The molecule of emulsifier should contain a polar radical that can be connected with alcohol molecule by hydrogen bonding and a non-polar edge that can be connected with diesel by Vander Wal forces. The emulsifiers having above characteristics were tested for formation of stable microemulsions, as follows.

1. Dioxane (a cyclic ether $C_4H_8O_2$)
2. 2-Ethyl-1-Hexanol ($C_8H_{18}O$)
3. n Butanol ($C_4H_{10}O$)

As we tested on dioxane it was noted that a large quantity, nearly 40 to 60 percent, emulsifier was required for formation of a successful microemulsion. Due to very high cost of dioxane (nearly 800/- per litre) the idea of using dioxane was abandoned.

With 2-E-1-H and butyl alcohol as emulsifiers different microemulsions of ethanol, diesel and 2-E-1-H as well as ethanol, diesel and butyl alcohol were prepared. In principle, an emulsifier should have a large carbon chain along with a polar edge. n-Pentanol, n-Hexanol and n-Heptanol may prove better over n-Butanol. With this in mind, tests on 2-E-1-H were conducted which have both the advantages of long carbon chain as well as low cost.

3.2 Ethanol and Ethanol Proof

Ethanol ($\text{CH}_3\text{CH}_2\text{OH}$), an oxygenated organic carbon compound, is also known as ethyl alcohol. It is a small chain high octane alcohol with molecular weight as 46.07 and contains 34.78 percent oxygen. The concentration of ethanol is expressed as degree proof which represents twice the concentration of ethanol. A 200° proof ethanol, anhydrous or absolute ethanol, has 100 percent concentration of ethanol. Ethanol proof of 180°, 184°, 188°, 190°, 194°, 196°, 198° were prepared from absolute ethanol by adding distilled water to it in required amount. The details of different levels of ethanol proofs prepared are given in Table 3.2.

Table 3.2: Proof of ethanol used for preparing microemulsions.

S. No.	Proof of Ethanol	Water content (Distilled) % by volume	Ethanol % by volume
1	200 ^o	0	100
2	196 ^o	2%	98
3	194 ^o	3%	97
4	190 ^o	5%	95
5	188 ^o	6%	94
6	184 ^o	8%	92
7	180 ^o	10%	90

3.3 2-Ethyl-1-Hexanol

The chemical formula of 2-Ethyl-1-Hexanol is represented as $C_8H_{18}O$. Its molecular weight is 130.23 and boiling temperature ranges from 181^o-185^oC. It can be effectively used as an emulsifier for ethanol diesel blends successfully due to its miscible property with diesel and ethanol both. In this study, 2-Ethyl-1-Hexanol was procured from the local market, manufactured by Central Drug House Pvt. Ltd.- New Delhi with minimum guaranteed purity of 99%. This solvent is widely used in mercerizing of textiles. It is also used as a solvent in dyes and resin industries.

3.4 Formulation of Ethanol-2-Ethyl-1-Hexanol-Diesel microemulsions

Ethanol-diesel microemulsions were prepared using anhydrous hyl-1-Hexanol as surfactant. Various microemulsions were prepared using anhydrous and aqueous ethanol having 200^o, 194^o, 188^o and 180^o

proofs by splash blending. Initially 10 ml samples were prepared for each proof of ethanol using different proportions of Ethanol and diesel and then anhydrous 2-Ethyl-1-Hexanol was added to each samples in such a way that minimum of surfactant was required to get clear and transparent microemulsions without any sign of phase separation or haziness or creaming in the solution.

The microemulsions were prepared at room temperature varying from 28°C to 34°C. The microemulsions prepared with different proofs of Ethanol and anhydrous 2-Ethyl-1-Hexanol are shown in Table 4.2.1 to 4.2.4.

3.5 Qualitative Analysis of Microemulsions

Microemulsions may be classified as stable or unstable on the basis of visual observations. A stable microemulsion is a clear, homogeneous and transparent solution, whereas an unstable microemulsion looks turbid, non-homogeneous and opaque right since the time of its formation or with in 48 hours from the time of formation. These characteristics of the microemulsions do not change even after keeping them for a long period of time at room temperature range from 28°C to 34°C.

Microemulsions found stable after hundred days from the time of their preparation were tested under varied temperature of 0°, 1°, 2°, 3°, 4°, 5°, 10°, 15°, 20°, 25°, 30°, 35°, 40° and 45°C to observe the wide range temperature stability. The stability test was conducted by exposing the microemulsion samples for 24 hours at selected temperature in a Saveer

Biotech make walk in temperature control chamber designed to operate in 0-50°C temperature range.

Initially the temperature control chamber was set on 45°C and the samples were kept for 24 hours at that temperature to observe their stability by visual inspection. After that, the temperature control chamber was maintained at 40°C, 35°C, 30°C, 25°C, 20°C, 15°C, 10°C, 5°C, 4°C, 3°C, 2°C, 1°C and 0°C. The samples were kept 24 hours at each selected temperature to observe the stability/unstability/haziness or occurrence of phase separation, if any, in the microemulsions. (Table 4.3.1 to 4.3.4)

3.6 Measurements of Fuel Properties

According to standards of Bureau of India, New Delhi fuel properties of diesel and stable microemulsion were measured.

3.6.1 Relative density and API gravity

By using 50 ml capacity pycnometers (plate 3.6.1), the relative density of the fuel was measured. The empty pycnometers were weighted on an Adair Dutt make, MJ 500 series electronic balance of 0-500g range having readability of 0.001g. The measurements were made with the pycnometers filled with fuel samples at 15°C temperature as per IS: 1448 [P:32]:1992. The samples were kept in a Saveer Biotech make walk-in-temperature control chamber, where these were

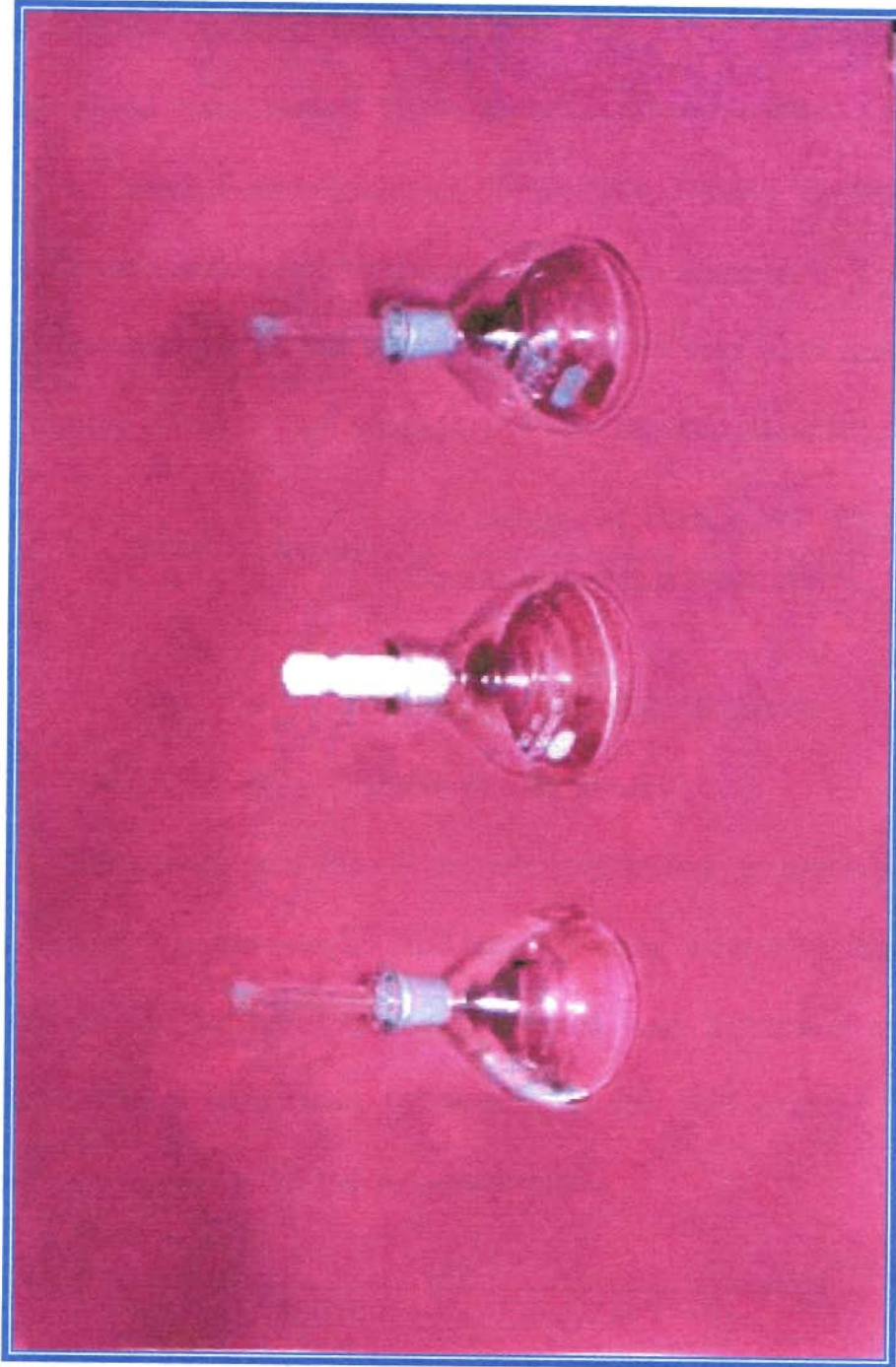


PLATE 3.6.1 PYKNOMETERS

maintained at 15°C. The temperature of fuel was measured by mercury thermometer of 0-100°C range. To get the weight of the fuel samples, the weight of the empty pyknometer was subtracted from the weight of the sample filled pyknometer. Three replications were taken for each sample and their mean was calculated. To get the density of fuel sample, this value (mass), is divided by the volume of fuel sample.

The density of distilled water at 15°C was also measured to get the relative density. The formula used for relative density is,

$$\text{Relative Density} = \frac{\text{Density of fuels at } 15^{\circ}\text{C} (P_f)}{\text{Density of distilled water at } 15^{\circ}\text{C} (P_w)}$$

where,

$$P_w = \text{density of water, } 1.0205 \text{ gm/cc}$$

$$P_f = \text{density of fuel, gm/cc.}$$

The gravity of a fuel is usually expressed in degrees API and the API (American Petroleum Institute) gravity was also calculated. API gravity is an indicator of heat content and lightness of a fuel. The relation which was used to determine the API gravity of diesel and microemulsions fuel in the experiments is,

$$\text{API gravity} = \frac{141.5}{\text{Relative density of fuel at } 15^{\circ}\text{C}} - 131.5$$

In the API scale water has a gravity of 10 and liquids lighter than water have gravity above 10. Thus lighter the fuel, the higher the API gravity.



PLATE 3.6.2 REDWOOD VISCOMETER

3.6.2 Kinematic viscosity

The viscosity of a liquid is described as its internal friction and is termed as the resistance it offers to motion of a foreign body through it or the motion of it against a foreign body. Atomization of fuel is effected by the viscosity; It affects the atomization of fuel in combustion chambers. The Kinematic viscosity of fuels was determined by Red Wood Viscometer No. 1 at 38°C as shown in Plate 3.6.2. As per IP 70/62 issued by Institute of Petroleum, London, this apparatus works on the principle of measuring the time of gravity flow in seconds of a fixed volume (50 ml.) of fluid through a specified hole in an agate piece. The cup fitted with agate jet at the bottom was surrounded by water jacket having an immersion heater. The cup was filled with fuel to a specified level indicated by a pointer in the cup. The water was heated to 38°C. The agate jet was open and closed by metallic ball. To collect the falling liquid, a standard 50 ml. measuring cylinder was kept below the agate jet. Each test was replicated five times. Kinematic viscosity was taken in terms of Red wood seconds. Kinematic viscosity was calculated using the empirical relation (**Nakra and Chaudhary, 1985**) given below.

where

$$\nu = At - \frac{B}{t}$$

ν = Kinematic viscosity centistokes = mm²/s

t = Time efflux, seconds (or degrees for Engler Viscometer).

A and B are constants applicable to the type of viscometer.

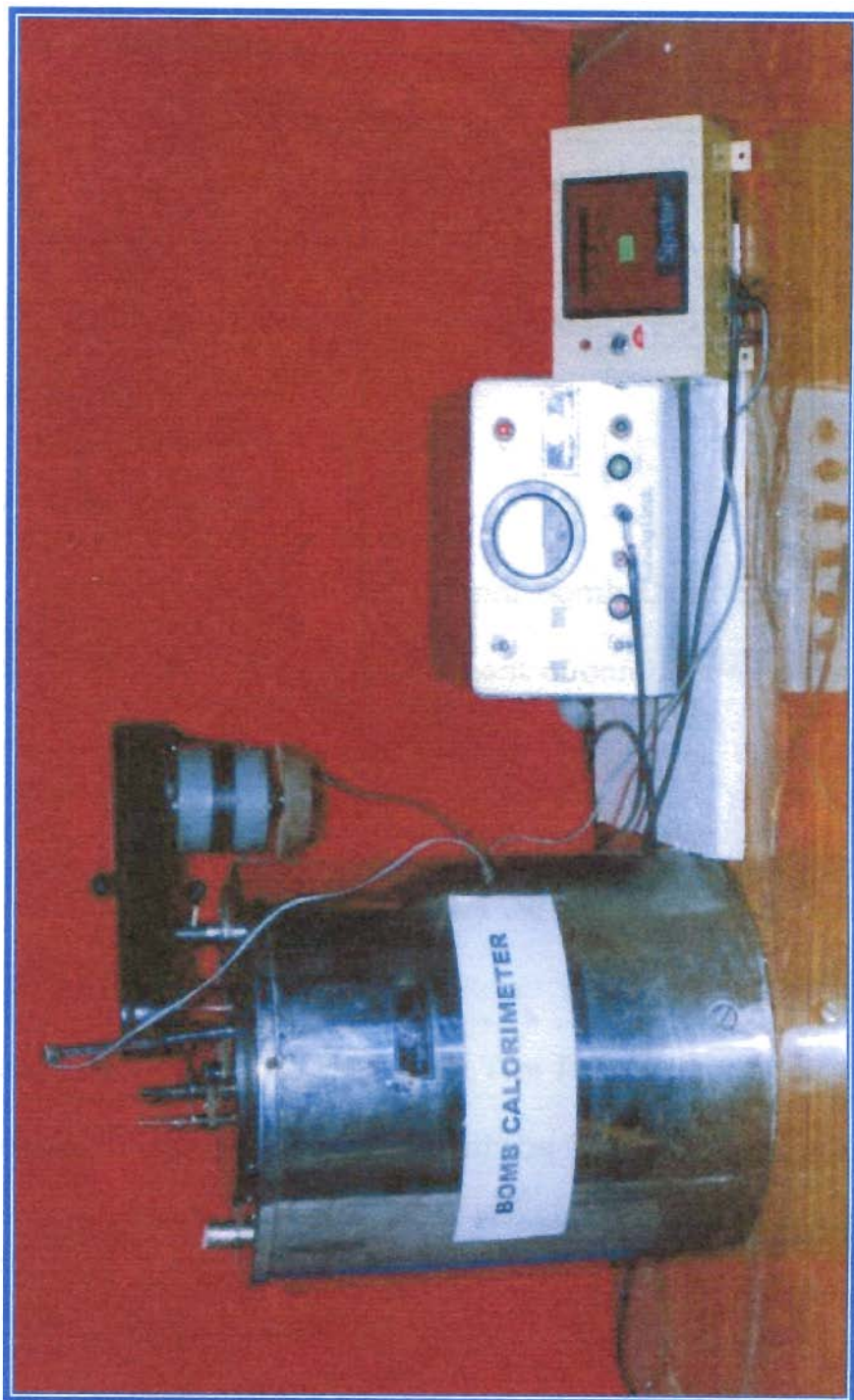


PLATE 3.6.3 ISOTHERMAL BOMB CALORIMETER

Accepted value of A and B for different viscometers

Viscometer type	A	B
Red wood viscometer	0.26	172
Say bolt viscometer	0.22	180
Engler viscometer	1.42	374

Kinematic viscosity is defined as the ratio of dynamic viscosity to the density of the liquid and is expressed in centi stoke equivalent to $1 \text{ mm}^2/\text{second}$.

3.6.3 Calorific value

With the help of an Isothermal Bomb Calorimeter (Plate 3.6.3) as per IS: 1448 [P:6]: 1984 the gross heat of combustion was determined. 1 gram or 1 ml fuel sample was ignited electrically in a bomb calorimeter in presence of pure oxygen at the pressure of 25-30 pounds. The rise in temperatures was noted for every 15 seconds. The water equivalent (effective heat capacity of the system) was determined using pure and dry benzoic acid as the test fuel. The following equation was used to determine the heat of combustion of the fuel sample

$$H_c = \frac{W_c \Delta T}{M_s}$$

where,

H_c = Heat of combustion of the fuel sample, cal/g.

W_c = Water equivalent of the calorimeter assembly, (2883.32 cal/°C)

ΔT = Rise in temperature, °C

M_s = Mass of sample burnt, gm.



PLATE 3.6.4 PENSKY MARTENS APPARATUS

3.6.4 Flash and fire point

The flash and fire point of a fuel are indicator of its volatility. Flash point is the lowest temperature at which the fuel gives off enough vapours and ignites for a moment giving visible flash. Fire point is an extension of flash point in a way that it reflects the condition, at which vapours burn continuously at least for 5 seconds. Flash point is generally lower than fire point by 5-8°C. Pensky Martens apparatus was used to determine flash and fire points. This apparatus has a fuel cup 5.5 cm. deep and having 5 cm. diameters. There is an air bath to maintain the temperature with the help of an electric heater and voltage regulator arrangement for heating the fuel in the cup. The fuel to be tested is placed in the cup up to the mark in the cup. The fuel is then heated with the help of heater by heating air bath and is stirred continuously at a slow rate. The rate of temperature rise of fuel is maintained at 5°C per minute approximately. With the help of a closure, flame through L.G. cylinder is introduced for a moment, at every 1°C temperature rise. The temperature at which a flash appears in the form of light and sound is recorded as flash point. The process is continued until fuel vapour catches fire and sustains for minimum of five seconds. The temperature at which ignition takes place is taken as the fire point of the fuel.

3.6.5 Cloud and pour point

In a low temperature zone, the flow of gasoline, aviation turbine fuel and automotive diesel fuel ordinarily do not have much of a problem as to either viscosity or solidification. The first sign of problem would be an undesirable high viscosity as the temperature falls. The next would be the temperature at which a haze or wax or cloud separate and the last would be the lowest temperature (pour point) at which the oil would flow under specified conditions.

The cloud point is the temperature at which a solid material, usually paraffin waxes and similar compounds in case of petroleum liquid begins to separate when the sample is cooled under carefully controlled conditions.

The pour point is the lowest temperature at which the liquid will flow in a specific way when cooled under likewise controlled conditions or it is the temperature at which no motion of the fuel sample is observed for 5 seconds on tilting the tube on horizontal position. As per IS: 1448 [P:10]: 1970 the cloud and pour point of fuel have been determined. The apparatus consists of 12 cm high glass tube having 3 cm diameter. An air jacket filled by a freezing mixture of crushed ice and sodium chloride crystal encloses these tubes. The glass tube is filled by the fuel sample. For every 1°C interval of temperature fall, the glass tube is taken out from the jacket and is inspected for cloud point. The

cloud point is that one at which a haze is first seen at the bottom of the sample.

For the cloud point the sample is pre-warmed to 48°C and then cooled to 35°C in air but the apparatus and procedure are same. The cooled sample is then placed in the apparatus. At each 1°C interval, the fuel samples (upto 54 mm. mark) treated to above stated conditions are withdrawn from cooling bath.

The pour point was taken to be the temperature 1°C above the temperature at which no motion of the fuel sample was observed for five seconds on tilting the tube to a horizontal position. These replications were made for each fuel sample.

3.6.6 Stability tests of microemulsions

For stability tests of microemulsions the following parameters are further studied after a period of 100 days.

- Temperature Stability
- Sedimentation or creaming
- Phase Separation

3.6.6.1 Temperature stability

The stable microemulsion and diesel were tested for temperature stability after a period of 100 days in the temperature range of 0° to 45°C. All microemulsions along with diesel were kept for 18 hrs at each of the

temperatures of 45°C, 40°C, 35°C, 30°C, 25°C, 20°C, 15°C, 10°C, 5°C, 4°C, 3°C, 2°C, 1°C, 0°C in a Saveer Biotech make walk in temperature control chamber. Stability in terms of miscibility, phase separation, sedimentation or creaming of the microemulsions was then studied.

3.6.6.2 Sedimentation or creaming

This test was carried out after the expiry of hundred days from the date of preparation of microemulsions which were kept at room temperature during that period. None of the microemulsified fuels showed sedimentation of heavier particles or creaming of lighter particles, there by indicating stability of microemulsions in terms of clarity and transparency. This indicated that even after a period of six months the physical structure of microemulsion remained unchanged.

3.6.6.3 Phase separation

There was no sign of phase separation in the microemulsions even after six month of their preparation. During long duration stability test all the microemulsions showed clear and stable solution without phase separation.

3.6.7 Selection of fuel type

As test fuels, the stable microemulsions as shown in table were selected. The performance of a diesel engine on the selected microemulsions was studied and also compared with diesel.

Table 3.6.7: Selection of fuels (microemulsions)

SL No.	Fuel type		Fuel constituents			Diesel
	°Proof	Microemulsion	Ethanol	2 Ethyl 1 Hexanol	Diesel	Replacement %
1	200 ^o	2EH/2E1H/D 10/06/84	10	06	84	16%
2	200 ^o	2EH/2E1H/D 40/18/42	40	18	42	58%
3	194 ^o	2EH/2E1H/D 10/08/82	10	08	82	18%
4	194 ^o	2EH/2E1H/D 40/18/42	40	18	42	58%
5	188 ^o	2EH/2E1H/D 10/10/80	10	10	80	20%
6	188 ^o	2EH/2E1H/D 40/24/35	40	24	35	64%
7	180 ^o	2EH/2E1H/D 10/20/70	10	20	70	30%
8	180 ^o	2EH/2E1H/D 40/25/35	40	25	35	65%
9	-	Diesel	-	-	-	-

3.6.8 Experimental set-up

The test set-up consists of the engine coupled to an eddy current dynamometer along with controller. A SAJ-froude make, EC-15 model dynamometer was used to load the engine. The experimental set-up also consisted of a SAJ-froude make, SFV-75 model electronic volumetric fuel consumption measuring unit.

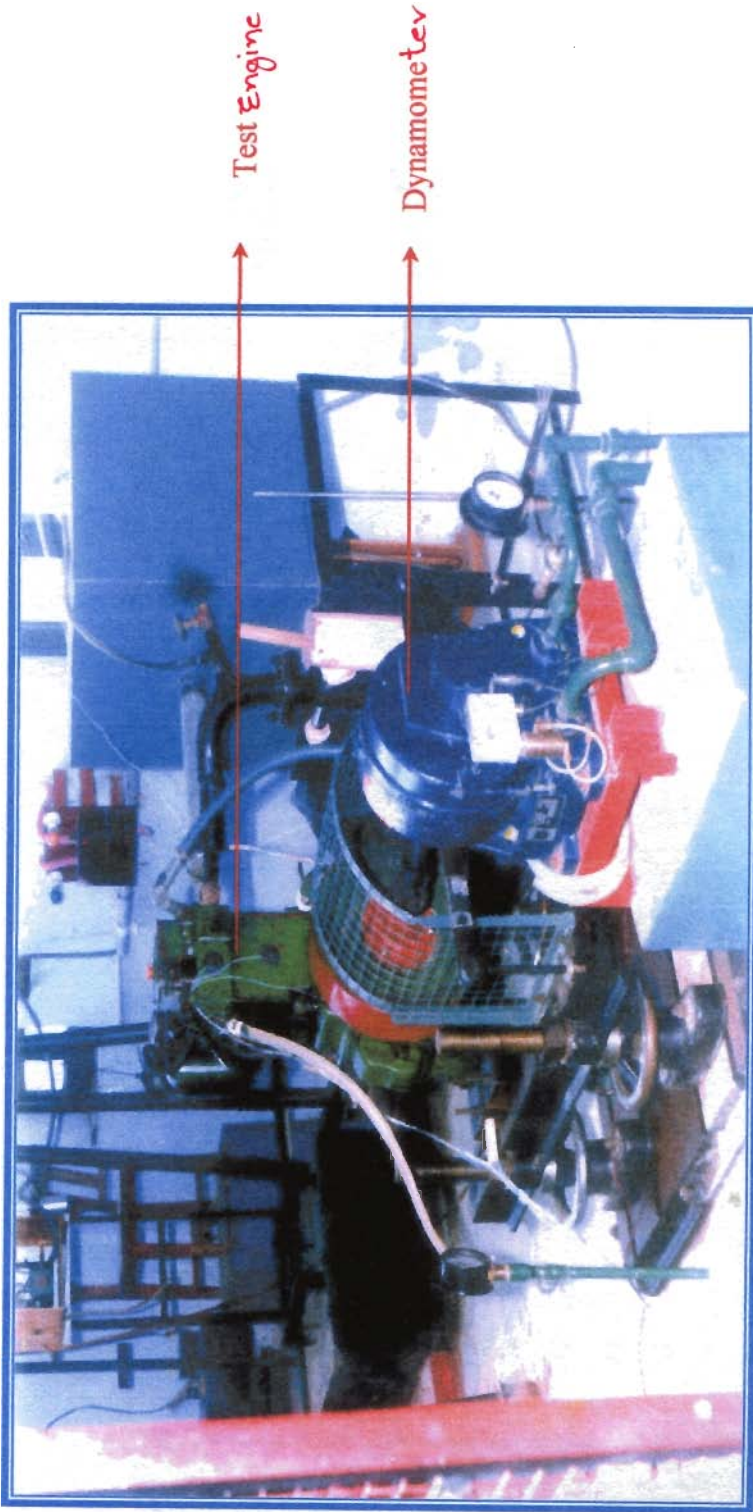


PLATE 3.6.8.1 ENGINE TEST SET-UP

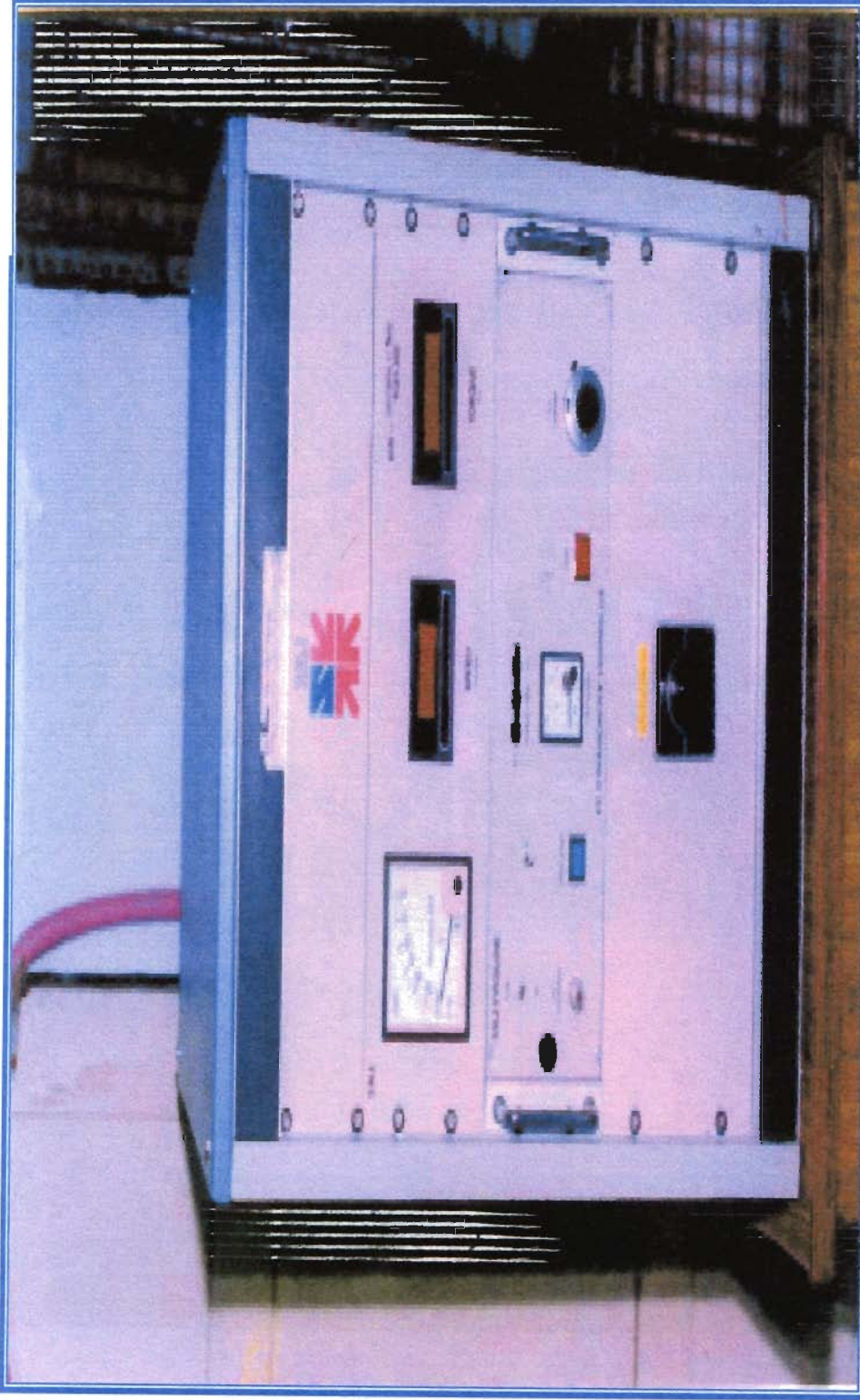


PLATE 3.6.8.2 EDDY CURRENT DYNAMOMETER CONTROLLER

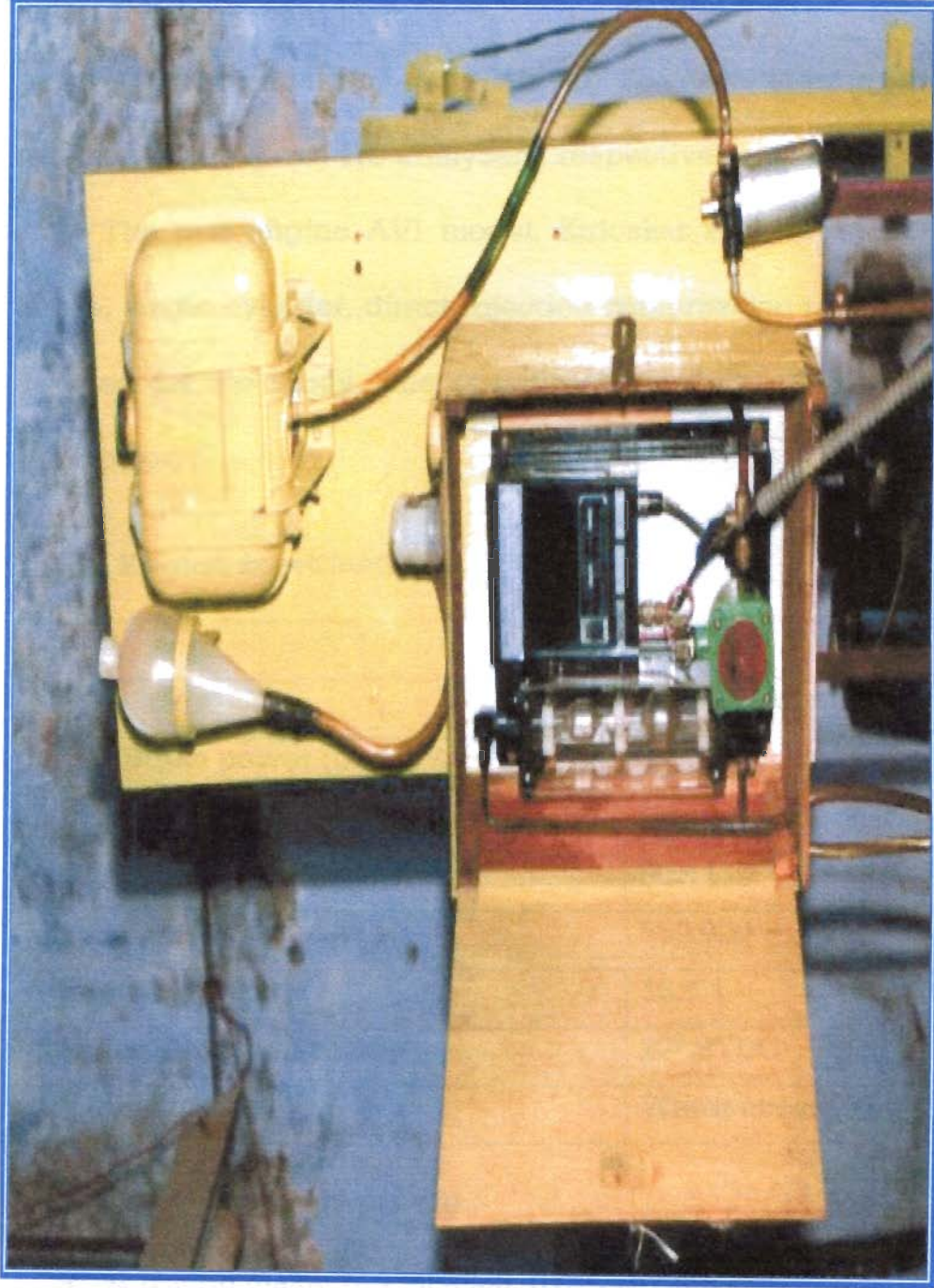


PLATE 3.6.8.3 ELECTRONIC FUEL CONSUMPTION MEASURING UNIT

The unit consists of a fuel tank, graduated glass pipette of 25, 50 and 75 ml. capacities, a solenoid valve, photo sensor assembly and timer. With the help of a steel tube, PVC gas suction pipe and an air pump exhaust emissions were drawn. The discharge of air pump was taken to NO, NO₂ and HC analyzers, respectively.

The test engine AVI model, Kirloskar make constant speed, four stroke, single cylinder, direct injection compression ignition engine was selected for the study. The specifications of the engine are shown in table below:

3.6.8.1 Engine specifications

Make	Kirloskar
Model	AVI Stationary engine
Rated Brake power (bhp/KW)	5/3.73
Number of cylinders	One
Bore × Stroke (mm × mm)	80 × 110
Displacement volume (cc)	552.920
Compression Ratio	16.5:1
Standard injection timing	27° BTDC
Cooling System	Water cooled

The mounted components are:

- A Nucon make, model 4900, hydrocarbon analyzer.
- A nucon make, model 500, Nitric oxide analyzer.
- A Nucon make model 500, Nitrogen dioxide analyzer

- Digital temperature measuring unit, having digital indicators with copper-constants thermocouple for measurement of
- Intake air temperature
- Exhaust gas temperature using chromal-alumal thermocouples.
- Engine inlet water temperature
- Engine outlet water temperature
- Engine lubricating oil temperature
- Engine crank case temperature
- Water column manometer to measure suction air pressure
- Mercury column manometer to measure exhaust tack pressure.

3.6.9 Experimental procedure

As per IS: 10000 [P:5]:1980 the performance test of the engine was conducted. By adjusting the screw given with on fuel pump, the engine was run on no load condition and at a speed of 1600 ± 10 rpm.

Using the following equation, the torque was calculated at the rated power of 3.73 KW at rated speed of $1500 \text{ rpm} \pm 10 \text{ rpm}$ under full load condition.

$$BP = \frac{N \times T}{9549.305}$$

where,

BP = Brake Power, KW

T = Engine torque, N-m

N = Engine speed, rpm.

The calculated torque was taken to be the one at 100% load on the engine as specified by the Indian Bureau standards. Then the engine speed was set to 1500 ± 10 rpm at 100% load. The engine was tested at no load, 20, 40, 60, 80, 100 and 110% load for all the selected fuels. The engine was run for at least 3 minutes under each load condition after which the data were collected. The experiment was replicated 3 times. The parameters were measured and calculations made as below.

3.6.9.1 Engine speed

During the course of experiment at different loading conditions, the engine speed (rpm) was recorded by the electronic controller unit.

3.6.9.2 Engine brake power

The following equation is used to calculate the brake power developed by the engine.

$$BP = \frac{NT}{C}$$

where,

- BP = Brake power, KW
- T = Engine torque, N-m
- N = Engine speed, rpm
- C = Dynamometer constant, 9549.305

3.6.9.3 Fuel consumption

With the help of a SAJ-froude make, SFV-75 model electronic volumetric fuel consumption measuring unit, fuel consumption was

measured. It consisted of a fuel tank, graduated glass pipette of 25, 50 and 75 ml, a solenoid valve, photo sensor assembly and timer. Timer which is provided to the unit is used to note the time taken by the fuel to pass through 25 ml. pipette.

By the relationship given below the BSFC was calculated

$$\text{BSFC} = \frac{V_{cc} \times \rho \times 3600}{\text{BP} \times t}$$

where,

BSFC = Brake specific fuel consumption, g/KWH

V_{cc} = Volume of fuel consumed, 25 cc.

ρ = Density of fuel gm/cc

BP = Brake power, KW

T = Time taken to consume 25 cc fuel, sec.

The performance of the engine on selected fuels was evaluated at the following load conditions.

- No load
- 20 percent of the rated load
- 40 percent of the rated load
- 60 percent of the rated load
- 80 percent of the rated load
- 100 percent of the rated load
- 110 percent of the rated load

Following parameters were measured during each load condition:

- Engine rpm
- Brake power, KW
- Fuel consumption, l/hr
- CO emission, percent
- UBHC emission, percent
- NO emission, ppm
- NO₂ emission, ppm
- Intake air temperature, °C
- Exhaust gas temperature, °C
- Inlet water temperature, °C
- Outlet water temperature, °C
- Engine crank case temperature, °C
- Engine lubricating oil temperature, °C
- Exhaust back pressure (mm Hg column)
- Air suction pressure (mm water column)

The brake power, brake specific fuel consumption, brake thermal efficiency and fuel consumption of the engine were calculated.

3.6.9.4 Brake thermal efficiency

At each operating condition the brake thermal efficiency of the engine was determined by the following equation

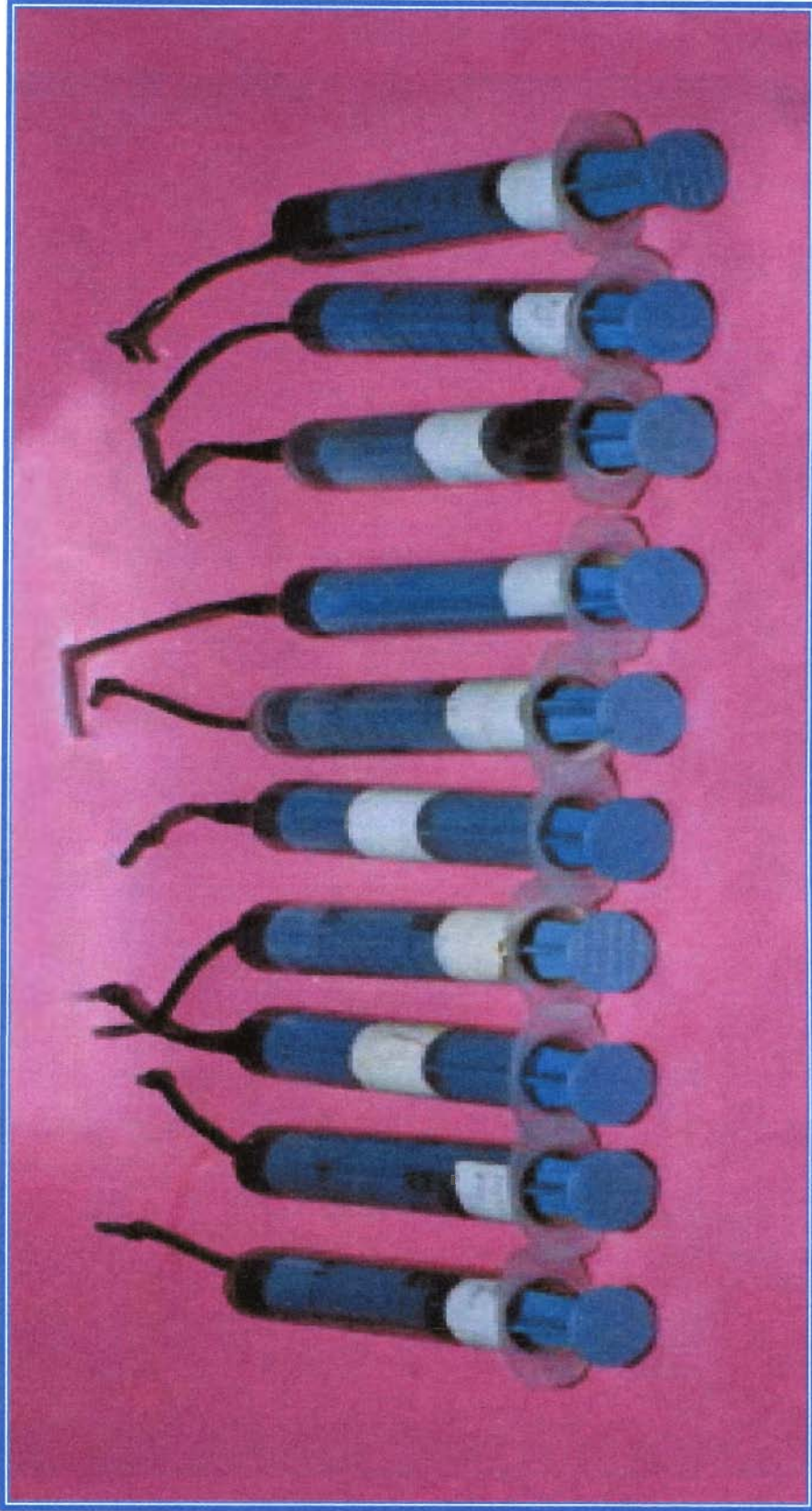


PLATE 3.6.9.6.1 DISPOSABLE SYRINGES USED FOR COLLECTION OF EXHAUST GAS SAMPLES.

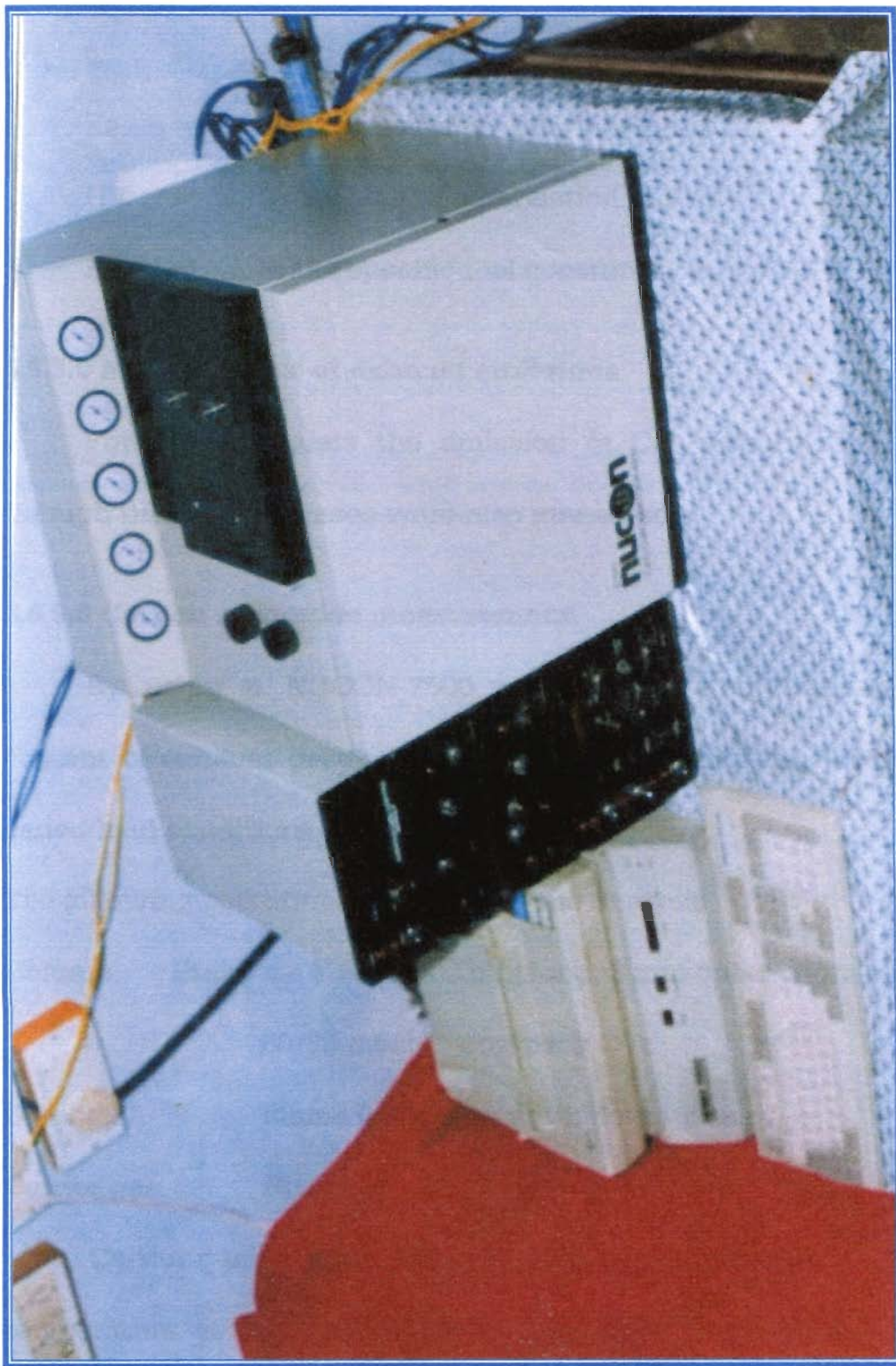


PLATE 3.6.9.6 GAS LIQUID CHROMATOGRAPH

where,

$$\eta_t = \frac{K_s}{HV \times BSFC} \times 100$$

η_t = Brake thermal efficiency

K_s = Units constant, 3600

HV = Gross heat of combustion, KJ/kg.

$BSFC$ = Brake specific fuel consumption, kg/KWh

3.6.9.5 Measurement of exhaust emissions

For different fuels the emission of CO, unburnt HC, NO, NO₂ through the exhaust gases were also measured.

3.6.9.6 Carbon monoxide measurement

By using a NUCON-7500 gas liquid chromatograph, the CO content of exhaust gases emanating from burning of selected fuels at varied load conditions was analysed.

The following conditions were set for the analysis

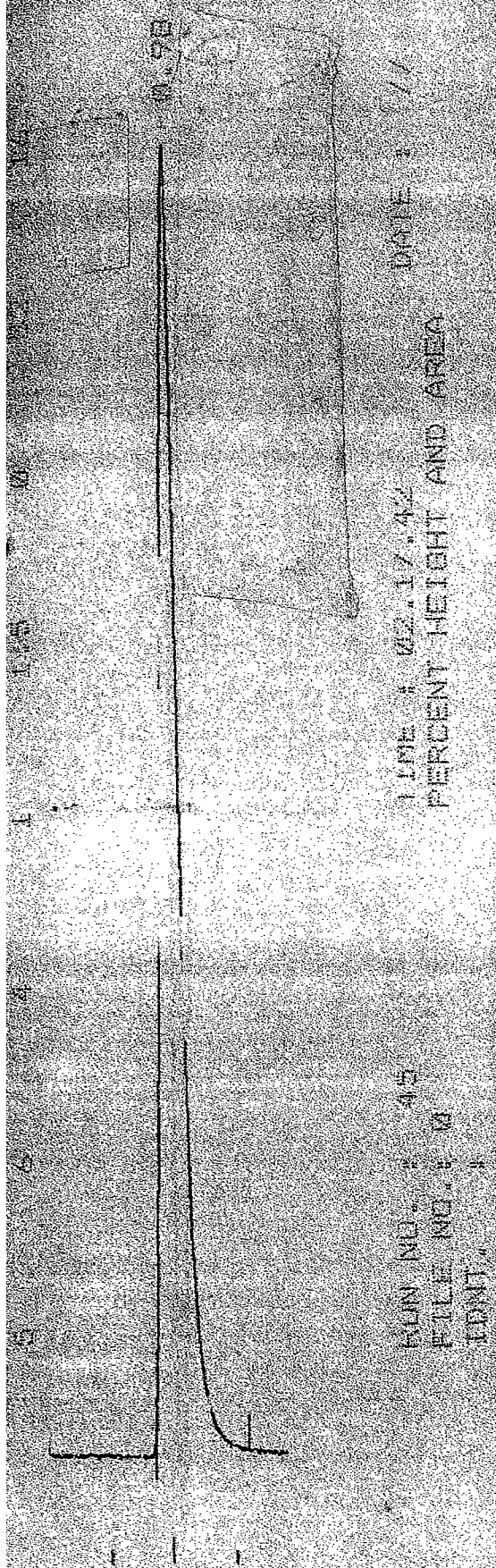
Column Stainless steel, 1800 mm long, 3 mm outer diameter,

60/80 mesh porapack Q

Detector Flame Ionization with Methanizer

Carrier gas Nitrogen

Carrier gas flow rate 12 ml/min, Oven temperature 80°C, Detector temperature 50°C, Injector temperature 50°C, Methanizer temperature 200°C.



RUN NO. : 45
 FILE NO. : 0
 UNIT : 1
 TIME : 10.98
 DATE : 11/11
 PERCENT HEIGHT AND AREA

SPN	R. TIME	HEIGHT	AREA	HTZ	AREA	TYPE	WEIGHT
1	10.98	693	175543	100.0000	100.0000	PE	0.176

TOTAL PEAKS = 1
 TOTAL HEIGHT = 693
 TOTAL AREA = 175543
 NULL FACTOR = 1.0000

Fig: 3.6.9.1: Typical elution time and peak obtained for standard CO sample from gas chromatograph.

HTREQ 5 6
 ATTN 1
 CHTSPD 1.5
 ZERO 0
 SLESTV 1.2
 DENSITY 1.6
 SENSITV 0



RUN NO.: 46
 FILE NO.: 0
 DATE: 12.19.14
 PERCENT HEIGHT AND AREA

SN	RTIME	HEIGHT	AREA	HTZ	AREA%	TYPE	AR/HT
1	0.96	28038	28038	100.0000	100.0000	EE	0.152

TOTAL PEAKS = 1
 TOTAL HEIGHT = 0
 TOTAL AREA = 28038
 MUL. FACTOR = 1.0000

01

Fig. 3.6.9.6.2: Typical elution time and peak obtained for unknown exhaust gas sample from gas chromatograph. 71

20 ml syringes were used to collect the exhaust gas sample. By injecting 1 ml standard CO, sample using a Hamilton make gas tight syringe containing 1.05 percent CO in nitrogen, the gas chromatograph was first calibrated. Thereafter, 1 ml sample from the exhaust gas sample was collected in 20ml syringe at different loads and was injected into chromatograph. The elution times total area as well as peaks obtained were noted for both test. By comparing the area of unknown sample with that of the standard sample, the amount of CO in the unknown sample was determined. Three replications were made and their average was calculated.

3.6.9.7 Unburnt hydrocarbon measurement

A NUCON make, model 4900, hydrocarbon analyzer was used for the measurement of unburnt hydrocarbon in the exhaust gas. The exhaust gas sample was fed through an air pump into the analyzer. The pump operated on 230 V, AC, drew the sample from the exhaust manifold through a 3 mm PVC tube and supplied to the analyzer. The analyzer has an electrochemical sensor which indicated the % unburnt hydrocarbon in the exhaust gas. The range of the analyzer was 0-10 percent. The measurements were made on different load conditions for each fuel.



PLATE 3.6.8.4 UNBURNT HYDROCARBON ANALYSER



PLATE 3.6.8.5 NITRIC OXIDE ANALYSER



PLATE 3.6.8.6 NITROGEN DIOXIDE ANALYSER

3.6.9.8 Nitric oxide measurement

A NUCON make, Nitric Oxide analyzer, model 500, was used to record the Nitric Oxide (in ppm) in engine exhaust gases. This analyzer has an electrochemical transducer and operates on 230 V, AC. It has a range of 0-199.9 ppm. An exhaust gas sample was drawn from the exhaust manifold through 3 mm PVC tube by an air pump operating on 230V AC and Supplied to the analyzer. The measurements were made for all the selected load conditions and selected fuels.

3.6.9.9 Nitrogen dioxide measurement

For the measurement of Nitrogen dioxide content in engine exhaust gases, a NUCON make, series 500 analyzer was used. The analyzer had a range of 0-199.9 ppm. The sample was drawn from the exhaust pipe of the engine using 3 mm PVC pipe through a pump operating on 230V, AC and fed into the chemical sensor of the analyzer. The measurements were made at different load conditions for all selected fuels.

3.7 Measurement of Exhaust Gas and Lubricating oil Temperatures

The exhaust gas and lubricating oil temperatures were measured by Cromel-Alumal thermocouples attached to digital temperature display unit. The thermocouples were inserted in the exhaust gas manifold and in the lubricating oil sump.

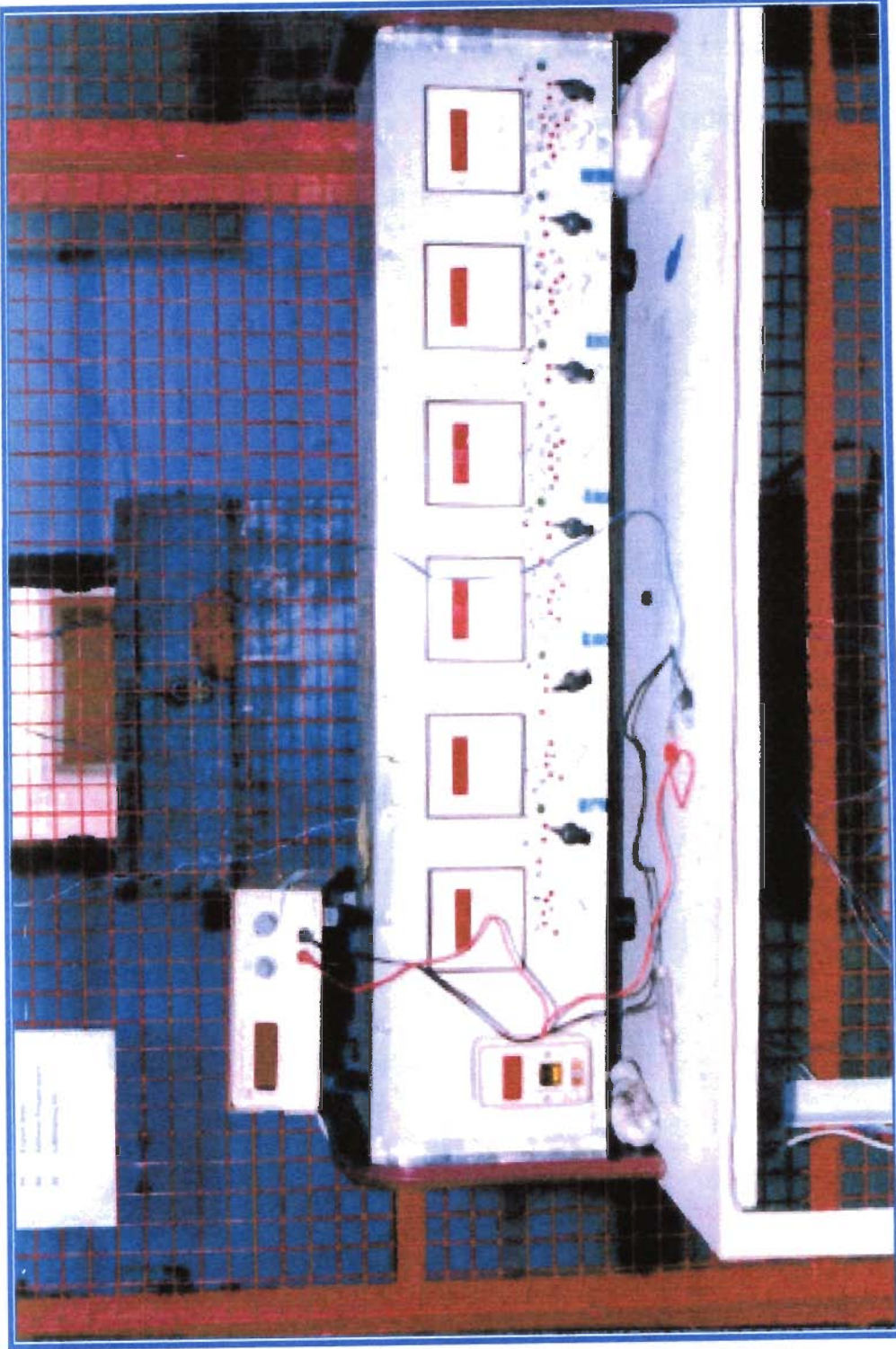


PLATE 3.6.8.7 DIGITAL TEMPERATURE MEASURING UNIT

3.8 Experimental Design

The performance test of the engine was also conducted on the reference diesel fuel and on eight stable micro emulsified fuels at seven levels of brake load. Three replication were taken at each brake load. Total number of experiments conducted to evaluate the performance test of the engine were 189.

The tests were conducted to standardize the fuel level constituents to get stable microemulsions which were prepared using anhydrous ethanol (200^o proof) and aqueous ethanol of 194^o, 188^o, 180^o proofs with 2-Ethyl-1-Hexanol as an emulsifier under a broad temperature range. In all eight microemulsions were finally selected based on the minimum and maximum diesel replacement and minimum percentage of surfactant used. The experiment was carried out on a Kirloskar make, constant speed, CI engine (model AVI), with 3.73 KW rated power at designed speed, 1500 rpm. It was installed in the Alternate energy laboratory of the department of Farm Machinery and Power Engineering of this university.

4.1 Selection of Emulsifier and Ethanol Proof

In past research, majority of the work has been done on anhydrous ethanol diesel blends or anhydrous ethanol using this as a dual/supplementary fuel in compression ignition engines. However, the commercial grade ethanol available in India is ranging from 194^o proof to 180^o proof. From anhydrous ethanol (200^o proof), adding appropriate amount of distilled water, the aqueous ethanol of 194^o, 188^o and 180^o

proofs were prepared. The ethanol proofs 200^o, 194^o, 188^o and 180^o were selected for the test purposes being stable, homogenous and without a phase separation at room temperature (28^oC to 34^oC). In this work, 2-Ethyl-1-Hexanol has been taken as one of the four emulsifiers on the ground of better miscibility and stability in the ethanol-diesel blends.

4.2 Stability of Microemulsions at Room Temperature

The stability and homogeneity was checked at room temperature which varied from 28^o to 34^oC, lasting for more than hundred days of their preparation. In few cases, the phase separation was observed even after seven or more days of their preparation. 10 ml samples of different combination of ethyl alcohol/surfactant/diesel were prepared. A total of 114 (one hundred fourteen) microemulsions using 2-Ethyl-1-Hexanol as the emulsifier, as per details in Table 4.21, 4.22, 4.23 and 4.24, were prepared using 200^o, 194^o, 188^o and 180^o proof ethanol. Out of one hundred fourteen microemulsions, seventy three were found stable after a period of hundred days. These microemulsions include twenty three of 200^o, twenty of 194^o, sixteen of 188^o and fourteen of 180^o proofs ethanol.

It is evident from the Tables 4.21, 4.22, 4.23 and 4.24 that the requirement of emulsifier, 2-Ethyl-1-Hexanol, for preparation of stable microemulsions significantly depends upon the proof of ethanol used as

Table No.4.2.1: Microemulsion prepared using 200° proof ethanol with 2E 1H and diesel.

S. No.	Fuel type	Ethanol proof	Volume of fuel prepared (ml)	Fuel Constituents (ml)			Proportion of fuel types ethanol/2E1H/diesel	Diesel replacement (%)	Stable or unstable at room temperature
				Ethanol /2E1H/ Diesel					
1	200-10/02/88	200	10	1.0	0.2	8.8	1.0:0.2:8.8	12	US
2	200-10/03/87	200	10	1.0	0.3	8.7	1.0:0.3:8.7	13	US
3	200-10/04/86	200	10	1.0	0.4	8.6	1.0:0.4:8.8	14	S
4	200-10/06/84	200	10	1.0	0.6	8.4	1.0:0.6:8.4	16	S
5	200-10/08/82	200	10	1.0	0.8	8.2	1.0:0.8:8.2	18	S
6	200-10/10/80	200	10	1.0	1.0	8.0	1.0:1.0:8.0	20	S
7	200-15/05/80	200	10	1.5	0.5	8.0	1.5:0.5:8.0	15	US
8	200-15/06/79	200	10	1.5	0.6	7.9	1.5:0.6:7.9	21	S
9	200-15/08/77	200	10	1.5	0.8	7.7	1.5:0.6:7.7	23	S
10	200-15/10/75	200	10	1.5	1.0	7.5	1.5:1.0:7.5	25	S
11	200-15/12/73	200	10	1.5	1.2	7.3	1.5:1.2:7.3	27	S
12	200-15/18/67	200	10	1.5	1.8	6.7	1.5:1.8:6.7	33	S
13	200-20/05/75	200	10	2.0	0.5	7.5	2.0:0.5:7.5	25	US
14	200-20/06/74	200	10	2.0	0.6	7.4	2.0:0.6:7.4	26	US
15	200-20/08/72	200	10	2.0	0.8	7.2	2.0:0.8:7.2	28	S
16	200-20/10/70	200	10	2.0	1.0	7.0	2.0:1.0:7.0	30	S
17	200-20/20/60	200	10	2.0	2.0	6.0	2.0:2.0:6.0	40	S
18	200-25/05/70	200	10	2.5	0.5	7.0	2.5:0.5:7.0	25	S
19	200-25/09/66	200	10	2.5	0.9	6.6	2.5:0.9:6.6	34	S
20	200-25/10/65	200	10	2.5	1.0	6.5	2.5:1.0:6.5	35	S
21	200-25/15/60	200	10	2.5	1.5	6.0	2.5:1.5:6.0	40	S
22	200-25/20/55	200	10	2.5	2.0	5.5	2.5:2.0:5.5	45	US
23	200-25/25/50	200	10	2.5	2.5	5.0	2.5:2.5:5.0	50	US
24	200-30/08/62	200	10	3.0	0.8	6.2	3.0:0.8:6.2	38	US
25	200-30/10/60	200	10	3.0	1.0	6.0	3.0:1.0:6.0	40	S
26	200-30/15/55	200	10	3.0	1.5	5.5	3.0:1.5:5.5	45	S
27	200-30/18/52	200	10	3.0	1.8	5.2	3.0:1.8:5.2	48	S
28	200-40/10/50	200	10	4.0	1.0	5.0	4.0:1.0:5.0	50	US
29	200-40/12/48	200	10	4.0	1.2	4.8	4.0:1.2:4.8	52	US
30	200-40/15/45	200	10	4.0	1.5	4.5	4.0:1.5:4.5	55	S
31	200-40/18/42	200	10	4.0	1.8	4.2	4.0:1.8:4.2	58	S
32	200-40/20/40	200	10	4.0	2.0	4.0	4.0:2.0:4.0	60	S
33	200-50/16/34	200	10	5.0	1.6	3.4	5.0:1.6:3.4	66	S
34	200-53/11/36	200	10	5.3	1.1	3.6	5.3:1.1:3.6	65	US

S - Clear and stable with no sign of phase separation
 US - Partial/distinct phase separation (Unstable)

Table 4.2.2: Microemulsion prepared using 194^o proof ethanol with 2E 1H and diesel

S. No.	Fuel type	Ethanol proof	Fuel constituent (ml)			Volume of fuel sample prepared (ml)	Proportion of fuel types ethanol/2E1H/diesel	Diesel replacement (%)	Stable or unstable At room temperature
			Ethanol / 2E1H/ Diesel						
1	194-10/05/85	194	1.0	0.5	8.5	10	1.0:0.5:8.5	15	US
2	194-10/06/84	194	1.0	0.6	8.4	10	1.0:0.6:8.4	16	US
3	194-10/07/83	194	1.0	0.7	8.3	10	1.0:0.7:8.3	17	S
4	194-10/08/82	194	1.0	0.8	8.2	10	1.0:0.8:8.2	18	S
5	194-10/10/80	194	1.0	1.0	8.0	10	1.0:1.0:8.0	20	S
6	194-15/06/79	194	1.5	0.6	7.9	10	1.5:0.6:7.9	21	US
7	194-15/07/78	194	1.5	0.7	7.8	10	1.5:0.7:7.8	22	US
8	194-15/08/77	194	1.5	0.8	7.7	10	1.5:0.8:7.7	23	US
9	194-15/10/75	194	1.5	1.0	7.5	10	1.5:1.0:7.5	25	S
10	194-15/12/73	194	1.5	1.2	7.3	10	1.5:1.2:7.3	27	S
11	194-20/06/74	194	2.0	0.6	7.4	10	2.0:0.6:7.4	26	US
12	194-20/08/72	194	2.0	0.8	7.2	10	2.0:0.8:7.2	28	US
13	194-20/10/70	194	2.0	1.0	7.0	10	2.0:1.0:7.0	30	S
14	194-20/12/68	194	2.0	1.2	6.8	10	2.0:1.2:6.8	32	S
15	194-20/15/65	194	2.0	1.5	6.5	10	2.0:1.5:6.5	35	S
16	194-25/08/67	194	2.5	0.8	6.7	10	2.5:0.8:6.7	33	US
17	194-25/10/65	194	2.5	1.0	6.5	10	2.5:1.0:6.5	35	US
18	194-25/12/63	194	2.5	1.2	6.3	10	2.5:1.2:6.3	37	S
19	194-25/13/62	194	2.5	1.3	6.2	10	2.5:1.3:6.2	38	S
20	194-25/14/61	194	2.5	1.4	6.1	10	2.5:1.4:6.1	39	S
21	194-25/15/60	194	2.5	1.5	6.0	10	2.5:1.5:6.0	40	S
22	194-25/18/57	194	2.5	1.8	5.7	10	2.5:1.8:5.7	43	S
23	194-30/10/60	194	3.0	1.0	6.0	10	3.0:1.0:6.0	40	US
24	194-30/12/58	194	3.0	1.2	5.8	10	3.0:1.2:5.8	42	US
25	194-30/14/56	194	3.0	1.4	5.6	10	3.0:1.4:5.6	44	S
26	194-30/15/55	194	3.0	1.5	5.5	10	3.0:1.5:5.5	45	S
27	194-30/18/52	194	3.0	1.8	5.2	10	3.0:1.8:5.2	48	S
28	194-40/12/48	194	4.0	1.2	4.8	10	4.0:1.2:4.8	52	S
29	194-40/15/45	194	4.0	1.5	4.5	10	4.0:1.5:4.5	55	S
30	194-40/18/42	194	4.0	1.8	4.2	10	4.0:1.8:4.2	58	US
31	194-40/20/40	194	4.0	2.0	4.0	10	4.0:2.0:4.0	60	S
32	194-50/16/34	194	5.0	1.6	3.4	10	5.0:1.6:3.4	66	US
33	194-50/20/30	194	5.0	2.0	3.0	10	5.0:2.0:3.0	70	S

S - Clear and stable with no sign of phase separation

US - Partial/distinct phase separation (Unstable)

Table 4.2.3: Micro emulsions prepared using 188^o proof ethanol with 2EH 1H and diesel

S. No.	Fuel type	Ethanol proof	Fuel constituent (ml)			Volume of fuel sample prepared (ml)	Proportion of fuel types ethanol/2E1H/diesel	Diesel replacement (%)	Stable or unstable At room temperature
			Ethanol/2-E-1-H/ Diesel						
1	188 ^o -10/01/89	188	1	0.1	8.9	10	1:0.1:8.9	11	US
2	188-10-03-87	188	1	0.3	8.7	10	1:0.3:8.7	13	US
3	188-10-05-85	188	1	0.5	8.5	10	1:0.3:8.5	15	US
4	188-10-08-82	188	1	0.8	8.2	10	1:0.8:8.2	18	US
5	188-10-10-80	188	1	1.0	8.0	10	1.0:1.0:8.0	20	S
6	188-10-12-78	188	1	1.2	7.8	10	1.0:1.2:7.8	22	S
7	188-15-02-83	188	1.5	0.2	8.3	10	1.5:0.2:8.3	17	US
8	188-15-05-80	188	1.5	0.5	8.0	10	1.5:0.5:8.0	20	US
9	188-15-08-78	188	1.5	0.8	7.8	10	1.5:0.8:7.8	23	US
10	188-15-10-75	188	1.5	1.0	7.5	10	1.5:1.0:7.5	25	US
11	188-15-12-73	188	1.5	1.2	7.3	10	1.5:1.2:7.3	27	US
12	188-15-15-70	188	1.5	1.5	7.0	10	1.5:1.5:7.0	30	S
13	188-20-15-65	188	2.0	1.5	6.5	10	2.0:1.5:6.5	35	S
14	188-20-18-62	188	2.0	1.8	6.2	10	2.0:1.8:6.2	38	S
15	188-20-20-60	188	2.0	2.0	6.0	10	2.0:2.0:6.0	40	S
16	188-20-22-58	188	2.0	2.2	5.8	10	2.0:2.2:5.8	42	S
17	188-25/15/60	188	2.5	1.5	6.0	10	2.5:1.5:6.0	40	US
18	188-25-17-58	188	2.5	1.7	5.8	10	2.5:1.7:5.8	42	S
19	188-25-18-57	188	2.5	1.8	5.7	10	2.5:1.8:5.7	43	S
20	188-25-20-55	188	2.5	2.0	5.5	10	2.5:2.0:2.0	45	S
21	188-25-22-53	188	2.5	2.2	5.3	10	2.5:2.2:5.3	47	S
22	188-30-18-52	188	3.0	1.8	5.2	10	3.0:1.8:5.2	48	S
23	188-30-20-50	188	3.0	2.0	5.0	10	3.0:2.0:5.0	50	S
24	188-30-22-48	188	3.0	2.2	4.8	10	3.0:2.2:4.8	52	S
25	188-40-20-40	188	4.0	2.0	4.0	10	4.0:2.0:4.0	60	US
26	188-40-22-38	188	4.0	2.2	3.8	10	4.0:2.2:3.8	62	S
27	188-40-24-36	188	4.0	2.4	3.6	10	4.0:2.4:3.6	64	S

S - Clear and stable with no sign of phase separation
 US - Partial/distinct phase separation (Unstable)

Table No.4.2.4: Microemulsion prepared using 180^o proof ethanol with 2E 1H and diesel.

S. No.	Fuel type	Ethanol proof	Fuel Constituent (ml)			Volume of fuel sample prepared in (ml)	Proportion of fuel types ethanol/2E1H/diesel	Diesel replacement (%)	Stable or unstable at room temperature
			Ethanol/2E1H/Diesel						
1	180-10/08/82	180	1.0	0.8	8.2	10	1.0:0.8:8.2	18	US
2	180-10/10/80	180	1.0	1.0	8.0	10	1.0:1.0:8.0	20	US
3	180-10/12/78	180	1.0	1.2	7.8	10	1.0:1.2:7.8	22	US
4	180-10/15/72	180	1.0	1.5	7.2	10	1.0:1.5:7.2	37	US
5	180-10/20/70	180	1.0	2.0	7.0	10	1.0:2.0:7.0	30	S
6	180-10/25/65	180	1.0	2.5	6.5	10	1.0:2.5:6.5	35	S
7	180-15/20/65	180	1.5	2.0	6.5	10	1.5:2.0:6.5	35	US
8	180-15/23/62	180	1.5	2.3	6.2	10	1.5:2.3:6.2	38	US
9	180-15/25/60	180	1.5	2.5	6.0	10	1.5:2.5:6.0	40	S
10	180-15/27/58	180	1.5	2.7	5.8	10	1.5:2.7:5.8	42	S
11	180-20/20/60	180	2.0	2.0	6.0	10	2.0:2.0:6.0	40	S
12	180-20/22/58	180	2.0	2.2	5.8	10	2.0:2.2:5.8	42	S
13	180-20/24/56	180	2.0	2.4	5.6	10	2.0:2.4:5.6	44	S
14	180-25/20/55	180	2.5	2.0	5.5	10	2.5:2.5:5.5	45	S
15	180-25/22/53	180	2.5	2.2	5.3	10	2.5:2.2:5.3	47	S
16	180-25/23/52	180	2.5	2.3	5.2	10	2.5:2.3:5.2	48	S
17	180-25/25/50	180	2.5	2.5	5.0	10	2.5:2.5:5.0	50	S
18	180-25/27/48	180	2.5	2.7	4.8	10	2.5:2.7:4.8	52	S
19	180-40/25/35	180	4.0	2.5	3.5	10	4.0:2.5:3.5	65	S
20	180-40/28/32	180	4.0	2.8	3.2	10	4.0:2.8:3.2	68	S

S – Clear and stable with no sign of phase separation
 US – Partial/Distinct phase separation (Unstable)

well as the diesel replacement achieved. The Tables 4.21, 4.22, 4.23 and 4.24 also indicate that with an increase in ethanol content in stable microemulsion, the requirement of 2-Ethyl-1-Hexanol also increases for a particular proof of ethanol.

The Table 4.2.1 indicates that 10 to 50 percent of anhydrous ethanol (200^o proof) in the stable microemulsion needs 4 to 16 percent 2-Ethyl-1-Hexanol at room temperature (28^o – 34^oC). These microemulsions replace diesel from 14 to 66 percent having 194^o Ethanol proof. The stable microemulsions at room temperature (28^o – 34^oC) need 7 to 20 percent of surfactant, 2-Ethyl-1-Hexanol.

Similarly, 188^o proof ethanol microemulsions require 10 to 24 percent of 2-Ethyl-1-Hexanol for the stable solution at room temperature while 180^o proof ethanol microemulsion needs 20 to 27 percent of 2-Ethyl-1-Hexanol to form stable solutions. The observations indicate that the aqueous ethanol-diesel microemulsions required a large quantity of 2-Ethyl-1-Hexanol compared to anhydrous ethanol-diesel microemulsion.

4.3 Effect of Temperature on Stability of Microemulsion

The microemulsions prepared using anhydrous and aqueous ethanol of 194^o, 188^o, 180^o proofs were found stable at room temperature for a period of 100 days and were later transferred into a confined chamber under wide temperature range 0^o, 1^o, 2^o, 3^o, 4^o, 5^o, 10^o, 15^o, 20^o, 25^o, 30^o, 35^o, 40^o and 45^oC. This stability test was conducted by placing the microemulsions for 48 hours at a selected temperature. The relative humidity was ranging from 60-72% and the phase separation was judged by visual inspection. The stability of Ethanol-2-Ethyle, 1-Hexanol and diesel micro emulsions under wide temperature range are shown in Table 4.31, 4.32, 4.33 and 4.34.

The table shows that ten microemulsions having 200^o proof ethanol stable at room temperature were also stable with no sign of phase separation ever in the temperature range of 4^oC – 45^oC.

The microemulsion 10:04:86 and 50:16:34 having 200^o ethanol proof were found stable at the selected temperature range of 15 to 45^oC. The twelve microemulsions prepared using 194^o proof Ethanol having no sign of phase separation at room temperature were also found stable in the temperature range of 5^oC – 45^oC. The eleven microemulsions having

188^o proof Ethanol were observed stable in the temperature range of 5^oC – 45^oC.

Similarly eleven microemulsions, using 180^o proof ethanol were found stable in the temperature range of 5^oC-45^oC. The microemulsions prepared using anhydrous ethanol with 10, 15, 20, 25, 30, 40 and 50 percent Ethanol and 4, 6, 8, 9, 10, 15 and 16 percent surfactant were also found unstable at and below 10^o, 20^o, 15^o, 20^o, 20^o, 10^o and 10^oC temperatures.

The microemulsions having of 194^o proof ethanol and 7, 10, 12, 12, 14 and 15 percent 2-Ethyl-1-Hexanol were seen unstable at and below 15^o, 5^o, 25^o, 25^o, 5^o and 20^oC temperatures.

Similarly, the microemulsions using 188^o proof ethanol having 10, 20, 25, 30 and 40 percent ethanol and 10, 15, 17, 18 and 20 percent 2-Ethyl-1-Hexanol surfactant were observed unstable at and below 10^o, 10^o, 20^o, 20^o and 35^oC temperature. The microemulsions prepared by using 180^oC ethanol, having 15 percent ethanol and 25 percent surfactant was found unstable at and below 10^oC temperature.

Table 4.3.1: Stability test on deferent microemulsions (ethanol/2-Ethyl-1-Hexanol/diesel) at deferent temperature

Microemulsion prepared using ethanol with 2E 1H and diesel															
200° proof	45°	40°	35°	30°	25°	20°	15°	10°	5°	4°	3°	2°	1°	0°	
10/04/86	S	S	S	S	S	S	S	US	US	US	US	US	US	US	
10/06/84	S	S	S	S	S	S	S	S	S	S	S	HS	HS	HS	
10/08/82	S	S	S	S	S	S	S	S	S	S	S	HS	HS	HS	
10/10/80	S	S	S	S	S	S	S	S	S	S	S	HS	HS	HS	
15/06/79	S	S	S	S	S	US	US	US	US	US	US	US	US	US	
15/08/75	S	S	S	S	S	S	S	S	HS	US	US	US	US	US	
15/10/75	S	S	S	S	S	S	S	S	S	S	S	S	SC	HS	
20/08/72	S	S	S	S	S	HS	US	US	US	US	US	US	US	US	
20/10/70	S	S	S	S	S	S	S	S	S	S	S	S	HS	HS	
20/15/65	S	S	S	S	S	S	S	S	S	S	S	S	HS	HS	
25/05/70	S	S	S	S	S	US	US	US	US	US	US	US	US	US	
25/09/66	S	S	S	S	S	HS	US	US	US	US	US	US	US	US	
25/10/65	S	S	S	S	S	S	S	S	S	HS	HS	HS	HS	HS	
25/15/60	S	S	S	S	S	S	S	S	S	HS	HS	HS	HS	HS	
30/10/60	S	S	S	S	S	HS	US	US	US	US	US	US	US	US	
30/15/55	S	S	S	S	S	S	S	S	S	S	S	HS	HS	HS	
30/18/52	S	S	S	S	S	S	S	S	S	S	S	HS	HS	HS	
40/15/45	S	S	S	S	S	S	S	US	US	US	US	US	US	US	
40/18/42	S	S	S	S	S	S	S	S	S	S	HS	HS	HS	HS	
40/20/40	S	S	S	S	S	S	S	S	S	S	HS	HS	HS	HS	
50/16/34	S	S	S	S	S	S	S	HS	US	US	US	US	US	US	
53/11/36	S	S	S	S	HS	US	US	US	US	US	US	US	US	US	

S - Clear and stable with nso sign of phase separation
 HS - Hazy with no phase separation
 US - Partial/distinct phase separation (Unstable)

Table 4.3.2: Stability test on different microemulsions (ethanol/2-Ethyl-1-Hexanol/diesel) at different temperature

Microemulsion prepared using ethanol with 2E 1H and diesel														
194° proof	45°	40°	35°	30°	25°	20°	15°	10°	5°	4°	3°	2°	1°	0°
10/07/83	S	S	S	S	S	S	US	US	US	US	US	US	US	US
10/08/82	S	S	S	S	S	S	S	S	S	S	S	HS	HS	HS
10/10/80	S	S	S	S	S	S	S	S	S	S	S	HS	HS	HS
15/10/75	S	S	S	S	S	S	S	S	US	US	US	US	US	US
15/12/73	S	S	S	S	S	S	S	S	S	S	HS	HS	HS	HS
20/10/70	S	S	S	S	US	US	US	US	US	US	US	US	US	US
20/12/68	S	S	S	S	S	S	HS	HS	US	US	US	US	US	US
20/15/65	S	S	S	S	S	S	S	S	S	S	HS	HS	HS	HS
25/12/63	S	S	S	S	US	US	US	US	US	US	US	US	US	US
25/13/62	S	S	S	S	S	S	S	S	S	S	HS	HS	HS	HS
25/14/61	S	S	S	S	S	S	S	S	S	S	S	S	S	S
25/15/60	S	S	S	S	S	S	S	S	S	HS	HS	HS	HS	HS
25/18/57	S	S	S	S	S	S	S	S	S	S	HS	HS	HS	HS
30/10/60	S	S	S	S	S	S	US	US	US	US	US	US	US	US
30/12/58	S	S	S	S	S	S	S	US	US	US	US	US	US	US
30/14/56	S	S	S	S	S	S	S	S	US	US	US	US	US	US
30/15/55	S	S	S	S	S	S	S	S	S	S	HS	HS	HS	HS
30/18/52	S	S	S	S	S	S	S	S	S	S	HS	HS	HS	HS
40/12/48	S	S	S	S	US	US	US	US	US	US	US	US	US	US
40/15/45	S	S	S	S	S	US	US	US	US	US	US	US	US	US
40/18/42	S	S	S	S	S	S	S	S	S	S	HS	HS	HS	HS
40/20/40	S	S	S	S	S	S	S	S	S	S	HS	HS	HS	HS
50/16/34	S	S	S	S	S	S	HS	HS	HS	HS	US	US	US	US

S -- Clear and stable with no sign of phase separation
 HS -- Hazy with no phase separation
 US -- Partial/distinct phase separation (Unstable)

Table 4.3.3: Stability test on different microemulsions (ethanol/2-Ethyl-1-Hexanol / diesel) at different temperature

188° proof	45°	40°	35°	30°	25°	20°	15°	10°	5°	4°	3°	2°	1°	0°
10/10/80	S	S	S	S	S	S	HS	HS	US	US	US	US	US	US
10/12/78	S	S	S	S	S	S	S	S	S	S	HS	HS	HS	HS
15/15/70	S	S	S	S	S	S	S	S	S	S	HS	HS	HS	HS
20/15/65	S	S	S	S	S	S	S	US	US	US	US	US	US	US
20/18/62	S	S	S	S	S	S	S	S	S	HS	HS	HS	HS	HS
20/20/60	S	S	S	S	S	S	S	S	S	HS	HS	HS	HS	HS
20/22/58	S	S	S	S	S	S	S	S	S	HS	HS	HS	HS	HS
20/24/56	S	S	S	S	S	S	S	S	S	HS	HS	HS	HS	HS
25/17/58	S	S	S	S	S	US	US	US	US	US	US	US	US	US
25/18/57	S	S	S	S	S	S	US	US	US	US	US	US	US	US
25/20/55	S	S	S	S	S	S	S	S	S	HS	HS	HS	HS	HS
25/23/52	S	S	S	S	S	S	S	S	S	HS	HS	HS	HS	HS
30/18/52	S	S	S	S	S	US	US	US	US	US	US	US	US	US
30/20/50	S	S	S	S	S	S	S	US	US	US	US	US	US	US
30/22/48	S	S	S	S	S	S	S	S	S	S	HS	HS	HS	HS
40/20/40	S	S	US	US	US	US	US	US	US	US	US	US	US	US
40/22/38	S	S	S	S	S	S	US	US	US	US	US	US	US	US
40/24/36	S	S	S	S	S	S	S	S	S	HS	HS	HS	HS	HS

S - Clear and stable with no sign of phase separation
 HS - Hazy with no phase separation
 US - Partial/distinct phase separation (Unstable)

Table 4.3.4: Stability test on different microemulsions (ethanol/2-Ethyl-1-Hexanol/diesel) at different temperature

Microemulsion ethanol 2E 1H diesel														
180° proof	45°	40°	35°	30°	25°	20°	15°	10°	5°	4°	3°	2°	1°	0°
10/20/80	S	S	S	S	S	S	S	S	S	S	HS	US	US	US
15/27/58	S	S	S	S	S	S	S	S	S	S	S	HS	HS	HS
20/20/60	S	S	S	S	S	S	S	S	S	HS	HS	HS	HS	HS
20/22/58	S	S	S	S	S	S	S	S	S	HS	HS	HS	HS	HS
20/24/56	S	S	S	S	S	S	S	S	S	S	HS	HS	HS	HS
25/23/52	S	S	S	S	S	S	S	S	S	HS	HS	HS	HS	HS
25/25/50	S	S	S	S	S	S	S	S	S	S	HS	HS	HS	HS
25/27/48	S	S	S	S	S	S	S	S	S	HS	HS	HS	HS	HS
40/25/35	S	S	S	S	S	S	S	S	S	S	HS	HS	HS	HS
40/28/32	S	S	S	S	S	S	S	S	S	S	HS	HS	HS	HS

- S - Clear and stable with no sign of phase separation
 HS - Hazy with no phase separation
 US - Partial/distinct phase separation (Unstable)

4.4 Characteristic Fuel Properties of Various Fuels

The microemulsions found stable at different temperatures, with 10 to 40 percent ethanol were selected to study their characteristic fuel properties. The properties of diesel, different ethanol proofs and 2-Ethyl-1-Hexanol were also determined.

4.4.1 Relative density and API gravity

The relative density and API gravity of diesel 2-Ethyl-1-Hexanol, different proofs of Ethanol and selected ethanol, 2-Ethyl-1-Hexanol and

diesel microemulsions at 15°C are shown in Table 4.4.1. The relative density of diesel was found 0.8432 where as relative density of diesel reported by **Gupta [28]** is 0.830, as per **Goering *et al.* [27]** 0.840, as per **Chatterjee [15]** is 0.8291 and as per **Ram Chandra [12]** is 0.8440. The relative density of 2-Ethyl-1-Hexanol was found to be 0.8055. The relative density of 200°, 194°, 188° and 180° proof ethanol was found as 0.7702, 0.7923, 0.7890 and 0.8110, respectively. **Ram Chandra [13]** has reported the relative density of 200°, 190°, 180° proofs ethanol as 0.7923, 0.8113 and 0.8265 whereas **Wakman *et al.* [62]** has reported the relative density of 200° and 180° proof ethanol as 0.780 and 0.810, respectively. **Chatterjee [15]** has reported the relative density of 200° and 180° proofs ethanol as 0.8047 and 0.8284. Thus, the observed relative densities of diesel, different ethanol proofs was found to be in line with the findings reported by earlier scientists.

The Table 4.4.1 also shows the relative density of ten microemulsions that are 200° [10:06:84]; 200°[10:08:82]; 200° [10:10:80]; 200° [40:18:42]; 194° [10:08:82]; 194° [40:18:42]; 188° [10:10:80]; 188° [40:24:36]; 180° [10:20:70]; and 180° [40:25:35] which was found to be 0.8300, 0.8275, 0.8236, 0.8055, 0.8319, 0.8084, 0.8177, 0.7991, 0.8187 and 0.8123, respectively. The microemulsions having lower proof of ethanol had lower relative density due to higher 2E-1H content in the proof.

Table 4.4.1: Relative density and API gravity of different fuels and microemulsions.

Sl. No.	Fuel Type	Relative density	Percentage different than diesel	API gravity	Percentage different than diesel
1.	Diesel	0.8432	-	36.31	-
2.	2E-1H	0.8055	-4.5	41.17	+13.4
Ethanol proof					
3.	200 ^o	0.7702	-8.7	52.22	+43.8
4.	196 ^o	0.7818	-7.3	49.49	+36.3
5.	194 ^o	0.7923	-6.0	47.09	+29.7
6.	188 ^o	0.7976	-5.4	45.91	+26.4
7.	184 ^o	0.8021	-4.9	44.91	+23.7
8.	180 ^o	0.8045	-4.6	44.39	+22.3
Microemulsions					
9.	200 ^o [10:06:84]	0.8300	-1.6	38.98	+7.35
10.	200 ^o [10:08:82]	0.8275	-1.9	39.50	+8.79
11.	200 ^o [10:10:80]	0.8236	-2.3	40.31	+11.01
12.	200 ^o [40:18:42]	0.8055	-4.5	44.17	+21.65
13.	194 ^o [10:08:82]	0.8319	-1.3	40.10	+10.44
14.	194 ^o [40:18:42]	0.8084	-4.13	43.54	+19.91
15.	188 ^o [10:10:80]	0.8177	-3.02	41.55	+14.43
16.	188 ^o [40:24:36]	0.7991	-5.23	45.57	+25.50
17.	180 ^o [10:20:70]	0.8187	-2.91	41.34	+13.85
18.	180 ^o [40:25:35]	0.8123	-3.67	42.70	+17.60

The observations in Table 4.4.1 show that microemulsions containing higher proof of ethanol as well as higher percentage of ethanol have higher API gravity compared to the microemulsions having lower proof of ethanol and containing lower percentage of ethanol. API gravity of all microemulsions indicate that all are lighter than diesel.

4.4.2 Kinematic viscosity

The kinematic viscosity at 38°C of diesel, 2-Ethyl-1-Hexanol and selected microemulsions, ethanol; 2-Ethyl-1-Hexanol and diesel fuels were obtained in the terms of Redwood seconds and centistokes which are tabulated in Table No 4.4.2. The kinematic viscosity of diesel was found to be 32.7 Redwood Seconds or 3.24 CS_t.

The kinematic viscosity of diesel fuel at 38°C temperature as per IS: 1460 – 1998 ranges between 30.5 to 44.5 Redwood Seconds. The kinematic viscosity of 2-Ethyl-1-Hexanol was obtained as 28.8 Redwood Seconds. The kinematic viscosity of Ethanol having 200°, 194°, 188° and 180° proofs were found to be 27.8, 28.2, 28.7 and 29.0 Redwood seconds, respectively.

Kinematic viscosity of seventeen microemulsions of 200° [10:06:84]; 200° [10:08:82]; 200° [10:10:80]; 200° [25:10:65]; 200° [40:18:42]; 194° [10:08:82]; 194° [10:10:80]; 194° [24:14:61]; 194° [40:18:42]; 188° [10:10:80]; 188° [10:12:78]; 188° [25:20:65]; 188° [40:24:36]; 180° [10:20:70]; 180°

[10:25:65]; 180° [25:23:52] and 180° [40:25:35] proofs was found as 30.7, 30.1, 30.44, 29.05, 28.4, 30.01, 30.06, 29.75, 28.6, 30.4, 30.6, 28.95, 28.0, 29.36, 29.88, 29.53 and 28.43 Red wood seconds, respectively.

The kinematic viscosity of microemulsions was found to be 6 to 13 percent lower than that of diesel.

Table 4.4.2: Kinematic viscosity of different fuels

Sl. No.	Name of the fuel	Kinematic viscosity average (Redwood seconds)	Kinematic viscosity percentage lower than diesel
1.	Diesel	32.7 or 3.24 cSt	-
2.	2-Ethyl-1-Hexanol	28.8	11.9
3.	Ethanol 200°	27.8	15.0
4.	Ethanol 194°	28.2	13.8
5.	Ethanol 188°	28.7	12.2
6.	Ethanol 180°	29.0	11.3
Microemulsions			
7.	200° [10:06:84]	30.7	6.1
8.	200° [10:08:82]	30.1	0.8
9.	200° [10:10:80]	30.44	6.9
10.	200° [25:10:62]	29.05	11.2
11.	200° [40:18:42]	28.4	13.1
12.	194° [10:08:82]	30.01	8.2
13.	194° [10:10:80]	30.06	8.1
14.	194° [24:14:61]	29.75	9.0
15.	194° [40:18:42]	28.6	12.5
16.	188° [10:10:80]	30.4	7.0
17.	188° [10:12:78]	30.6	6.4
18.	188° [25:20:65]	28.95	11.5
19.	188° [40:24:36]	28.0	14.4
20.	180° [10:20:70]	29.36	10.2
21.	180° [10:25:65]	29.88	8.6
22.	180° [25:23:52]	29.53	9.7
23.	180° [40:25:35]	28.43	13.1

4.4.3 Gross heat of combustion

The gross heat of combustion of different fuels are shown in Table 4.4.3. The Table 4.4.3 shows that the gross heat of combustion of diesel is 52.56 MJ/kg. The gross heat of combustion of diesel was reported as 44.96 MJ/kg, 43.64 MJ/kg and 45.12 MJ/kg by **Hansen *et al.* [29]**, **Ajav [2]** and **Chatterjee [15]**, respectively where as **Ram Chandra [13]** has reported as 46.85 MJ/kg. The gross heat of combustion of 2-Ethyl-1-Hexanol was found to be 45.48 MJ/kg which is slightly lower than the diesel. The gross heat of combustion of 200^o, 194^o, 188^o and 184^o proofs ethanol was obtained as 29.76 MJ/kg, 28.883 MJ/kg, 27.89 MJ/kg and 26.599 MJ/kg, respectively.

Gross heat of combustion of 200^o and 180^o proofs ethanol was reported by **Wakman *et al.* [62]** as 31.53 MJ/kg and 28.63 MJ/kg and **Chatterjee [15]** reported the gross heat of combustion of 200^o, 180^o proofs ethanol as 31.15 and 30.29 MJ/kg, respectively. The gross heat of combustion of 200^o, 190^o and 180^o proofs ethanol have been reported by **Ram Chandra [13]** as 30.73, 29.33 and 26.51 MJ/kg, respectively.

The Table 4.4.3 also shows that the observed gross heat of combustion of microemulsions 200^o [10:06:84]; 200^o [10:08:82]; 200^o [10:10:80]; 200^o [25:10:65]; 200^o [40:18:42]; 194^o [10:08:82]; 194^o [10:10:80];

Table 4.4.3: Gross heat of combustion of different fuels

Sl. No.	Fuel	Gross heat of combustion		Gross heat of combustion (percentage lower than diesel)
		K cal/kg	MJ/kg.	
1.	Diesel	12565.31	52.56	-
2.	2-Ethyl-1-Hexanol	10873.38	45.48	13.5
3.	Ethanol 200 ^o	7116.3	29.76	43.4
4.	Ethanol 194 ^o	6905.25	28.883	45.0
5.	Ethanol 188 ^o	6619.80	27.69	47.3
6.	Ethanol 184 ^o	6358.98	26.599	49.4
Microemulsions				
7.	200 ^o [10:06:84]	12074.79	50.51	3.9
8.	200 ^o [10:08:82]	12050.21	50.40	4.1
9.	200 ^o [10:10:80]	11678.18	48.85	7.1
10.	200 ^o [25:10:65]	11192.16	46.82	10.9
11.	200 ^o [40:18:42]	10978.5	45.99	12.5
12.	194 ^o [10:08:82]	11885.98	49.718	5.4
13.	194 ^o [10:10:80]	11456.42	47.919	8.8
14.	194 ^o [24:14:62]	11362.20	47.526	9.6
15.	194 ^o [40:18:42]	11833.84	45.32	13.8
16.	188 ^o [10:10:80]	11850.66	49.570	5.7
17.	188 ^o [10:12:78]	11322.56	47.361	9.9
18.	188 ^o [25:20:55]	9801.48	40.997	22.0
19.	188 ^o [40:24:36]	8697.329	36.380	30.8
20.	180 ^o [10:20:70]	9662.42	40.416	23.1
21.	180 ^o [10:25:65]	9512.657	39.790	24.3
22.	180 ^o [25:23:52]	9274.87	38.796	26.2
23.	180 ^o [40:25:35]	8242.68	34.478	34.4

194° [24:14:62]; 194° [40:18:42]; 188° [10:10:80]; 188° [10:12:78]; 188° [25:20:55]; 188° [40:24:36]; 180° [10:20:70]; 180° [10:25:65]; 180° [25:23:52] and 180° [40:25:35] proofs were 50.40, 50.51, 48.85, 46.82, 45.99, 49.718, 47.919, 47.526, 45.32, 49.570, 47.361, 40.997, 36.380, 40.416, 38.796, 39.79 and 34.478 MJ/kg, respectively. It was also observed that the microemulsions of anhydrous ethanol have gross heat of combustion close to the diesel fuel.

The gross heat of combustion of microemulsions having 200° proof ethanol was found to be lower than diesel by 4.1, 3.9, 7.05, 10.9 and 12.5 percent, respectively. Table 4.4.3 also indicates that the aqueous microemulsions of 194°, 188° and 180° proofs ethanol had lower gross heat of combustion than diesel in the range of 5 to 13.77, 5.6 to 30.7 and 23.1 to 34.4. Moreover, the observed values indicate that as the proof level of ethanol in the microemulsions decreased, there was a decrease in the gross heat of combustion. This is because of higher amount of lower proof ethanol present in the microemulsions.

4.4.4 Flash and fire point

The flash point and fire point of diesel, 2-Ethyl-1-Hexanol and different proofs of ethanol as well as different microemulsions are arranged in Table 4.4.4.

The flash and fire point of diesel was recorded as 95.5°C and 104.5°C, respectively. The flash point of diesel reported by **Goering *et al.* [27]** and **Clark *et al.* [18]** is 80°C and 78°C, respectively. **Ram Chandra [13]** reported flash and fire points of diesel as 60°C and 67.7°C. The flash and fire point of 2-Ethyl-1-Hexanol was found to be 82°C and 89°C, respectively. The flash point of 200°, 190°, 180° ethanol was found as 14.5°C, 16.4°C and 18.8°C, respectively. The fire point of the above proofs of ethanol was found as 17.5°C, 20.2°C and 24°C, respectively. The flash point of anhydrous ethanol as reported by **Cheremisinoff [16]** is 13.9°C.

Chandan [12] reported the flash point as 12.2°C, 13.5°C and 15.2°C and the fire point as 18.5°C, 19.3°C and 23.5°C for the ethanol proof of 200°, 190° and 180°, respectively.

The flash and fire point of microemulsions was found less as compared to diesel due to low flash and fire point of various ethanol proofs. The reduced flash and fire point of microemulsified fuels reflects that the greater care must be required in handling these fuels during high ambient temperature conditions.

Table 4.4.4: Flash and fire point of different fuel

Sl. No.	Fuel	Flash point (°C)	Fire point (°C)
1.	Diesel	95.5	104.5
2.	2-Ethyl-1-Hexanol	82	89
3.	Ethanol 200°	14.5	17.5
4.	Ethanol 194°	16.8	20.3
5.	Ethanol 188°	18.6	22.7
6.	Ethanol 184°	19.1	23.2
Microemulsions			
7.	200° [10:06:84]	21	26.5
8.	200° [10:08:82]	22	27
9.	200° [10:10:80]	22.5	28
10.	200° [25:10:65]	21	26
11.	200° [40:18:42]	19.7	24.6
12.	194° [10:08:82]	24	31
13.	194° [10:10:80]	25	34
14.	194° [24:14:62]	21.5	27.5
15.	194° [40:18:42]	20.5	26.5
16.	188° [10:10:80]	28.1	31.4
17.	188° [10:12:78]	29.2	32.6
18.	188° [25:20:55]	25.8	29.1
19.	188° [40:24:36]	21.9	24.0
20.	180° [10:20:70]	29	31
21.	180° [10:25:65]	31	34.5
22.	180° [25:23:52]	26	28
23.	180° [40:25:35]	22	28

4.4.5 Cloud and pour point

The cloud and pour points of diesel, 2-Ethyl-1-Hexanol, different proof of ethanol and microemulsions are listed in Table No. 4.4.5. The cloud and pour points of diesel was found as 0.5°C and -9.0°C . The cloud point of diesel as reported by **Peterson *et al.* [46]**, and **Chatterjee [15]** is -13.9°C and 3°C and the pour point as 27.8°C and 0°C , respectively. Where as **Ram Chandra [13]** reported the cloud and Pour points of diesel as 1.5°C and -7.5°C , respectively. The cloud and pour points of 2-Ethyl-1-Hexanol, 200° , 194° , 188° and 180° proofs ethanol could not be recorded at a lower temperature of -10°C .

The cloud point of six microemulsions 200° [10:06:84]; 194° [10:08:82]; 188° [10:10:80]; 188° [40:24:36]; 180° [10:20:70] and 180° [40:25:35] was recorded as -4.5°C , -3.5°C , -3.0°C , -7.5°C , -0.5°C and -7.0°C , respectively. Whereas in case of microemulsions 200° [40:18:42] and 194° [40:18:42] it could not be recorded being below -10°C . The pour point of microemulsions having 188° [10:10:80] and 180° [10:20:70] were found -10°C and -7°C , respectively. The pour point of rest six microemulsions were not observed even at -10°C .

The observed values of cloud and pour point indicate that the cloud and pour point decreases sharply as the proof of ethanol is lowered in the microemulsions.

Table 4.4.5: Cloud and pour point of different fuels

S. No.	Fuel type	Cloud point	Pour point
1	Diesel	0.5°C	-9.0°C
2	2-Ethyl-1-Hexanol	-	-
Ethanol proofs			
3	Ethanol 200°	-	-
4	Ethanol 194°	-	-
5	Ethanol 188°	-	-
6	Ethanol 180°	-	-
Microemulsions			
7	200° – 10/06/84	-4.5°C	-
8	200° – 40/18/42	-	-
9	194° – 10/08/82	-3.5°C	-
10	194° – 40/18/42	-	-
11	188° – 10/10/80	-3.0°C	-10°C
12	188° – 40/24/36	-7.5°C	-
13	180° – 10/20/70	-0.5°C	-7.0°C
14	180° – 40/25/35	-7.0°C	-

4.5 Performance of the Engine on Diesel and Selected Microemulsion Fuels.

4.5.1 Experimental procedure and observation

The performance of an engine was carried out in terms of variable parameters such as brake power, fuel consumption, brake thermal efficiency, energy input, emission of carbon monoxide, unburnt hydrocarbon, nitrogen dioxide and nitric oxide. The above parameters were observed on diesel and eight microemulsions that are 200° [10:06:84]; 200° [40:18:42]; 194° [10:08:82]; 194° [40:18:42]; 188° [10:10:80]; 188° [40:24:36]; 180° [10:20:70]; 180° [40:25:35] at zero load, 20, 40, 60, 80, 100 and 110 percent of the full load.

The above parameters were measured by conducting the tests on CI engine as per IS: 10,000 [P: 8]:1980 and the evaluated parameters are shown in Tables 4.5.2, 4.6.1, 4.6.2, 4.6.3, 4.6.4, 4.7.1, 4.7.2, 4.7.3, 4.7.4, 4.7.4.1, 4.7.5, 4.7.6 and were compared to assess the compatibility of microemulsion fuels as C.I. engine fuels.

4.5.2 Engine performance under fuel consumption test

Table 4.5.2 shows observed fuel consumption in litre/hour of the engine at different brake loads on diesel and eight selected microemulsified fuels. The graph between the fuel consumption of the engine and brake load in terms of % of full load is plotted on different

Table 4.5.2: Fuel consumption of Kirloskar AVI 5.0/3.75 (bhp/KW) engine on selected fuels

Sl. No.	Brake load (%)	Diesel	Fuel types (Alcohol-diesel microemulsion)							
			Fuel consumption (l/hr)							
			200° 10/06/84	200° 40/18/42	194° 10/08/82	194° 40/18/42	188° 10/10/80	188° 40/24/36	180° 10/20/70	180° 40/25/35
1	0	0.428	0.419	0.474	0.380	0.534	0.414	0.807	0.460	
2	20	0.564	0.553	0.626	0.539	0.699	0.561	0.943	0.569	
3	40	0.706	0.698	0.774	0.695	0.821	0.723	0.953	0.719	
4	60	0.846	0.901	0.969	0.928	1.009	0.929	0.981	0.941	
5	80	1.020	1.176	1.197	1.209	1.225	1.261	1.166	1.187	
6	100	1.231	1.408	1.340	1.430	1.496	1.497	1.343	1.380	
7	110	1.698	1.548	1.488	1.615	1.594	1.617	1.530	1.499	

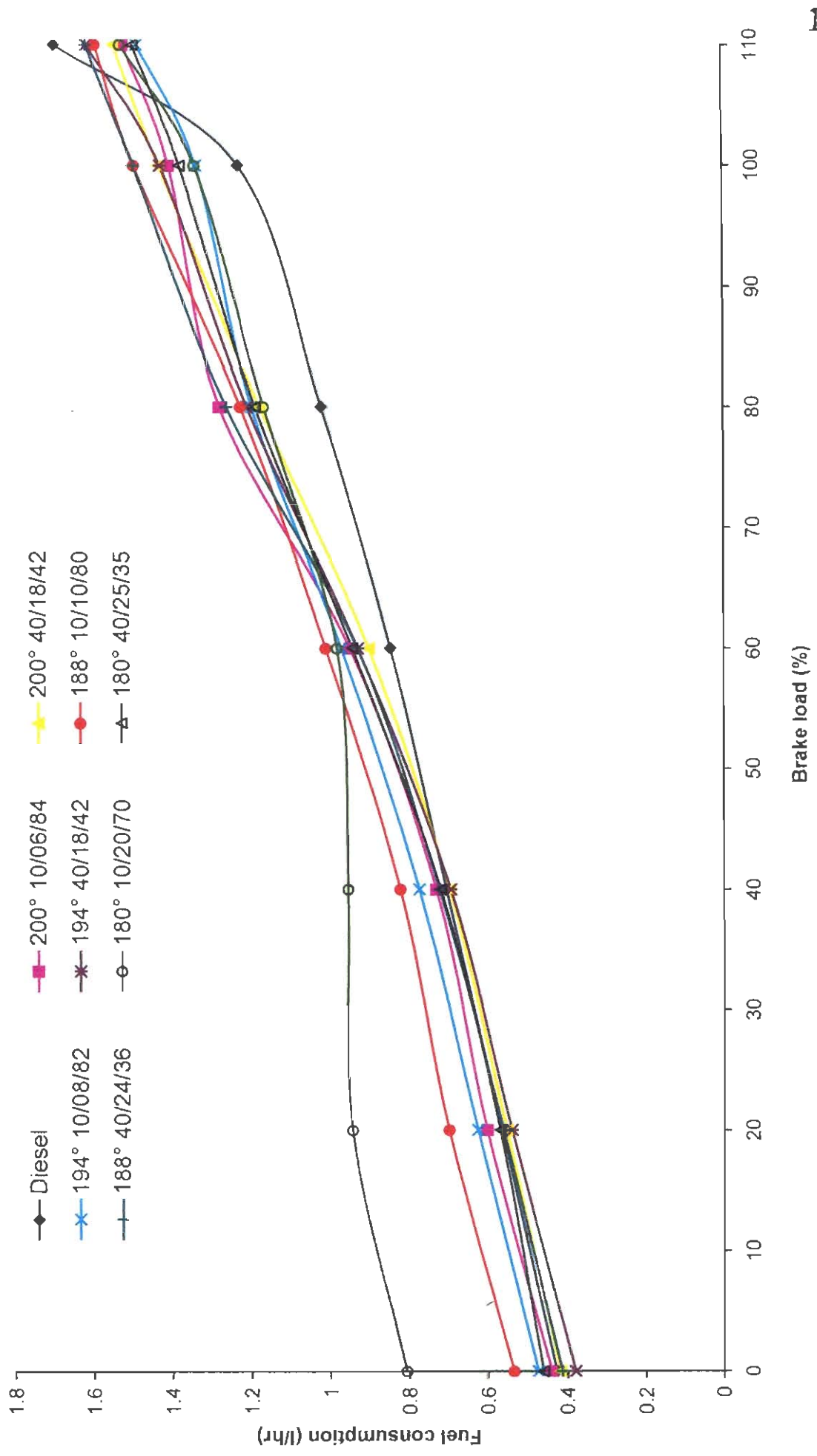


Fig 4.5.2: Fuel consumption of the engine at different brake load on diesel and microemulsions.

fuels. It is evident from the figure that the fuel consumption of the engine gradually increased with the increase of brake load and was observed maximum at 110 percent brake load condition for all fuels. It was observed that the fuel consumption of the engine at full load condition, the engine developing its rated power 3.74 KW was 1.231, 1.408, 1.433, 1.340, 1.430, 1.496, 1.497, 1.343, 1.380 litre/hour with diesel, 200° [10:06:84]; 200° [40:18:42]; 194° [10:08:82]; 194° [40:18:42]; 188° [10:10:80]; 188° [40:24:36]; 180° [10:20:70]; 180° [40:25:35] microemulsions, respectively.

It is also evident from the Fig. 4.5.2 that the fuel consumption of the engine using diesel was lowest at all the brake load conditions compared to the eight microemulsions tested. This may be due to the reason that the calorific values of the microemulsion were found 3.6 to 34.4 percent lower than that of diesel. Hansen *et al.* [29] reported that an increase in fuel consumption approximately equivalent to the reduction in energy content of Ethanol- diesel blends can be expected.

4.6 Measurement of Engine Parameters

4.6.1 Brake specific fuel consumption

The brake specific fuel consumption (BSFC) of the engine on diesel and microemulsions at different brake load is shown in table 4.6.1 and the variation of BSFC and brake load has been presented in Fig. 4.6.1.

Table 4.6.1: Brake specific fuel consumption of Kirloskar AVI 5.0/3.75 (bhp/KW) engine on selected fuels

Sl. No.	Brake load (%)	Diesel	Fuel types (Alcohol-diesel microemulsion)									
			Brake specific fuel consumption (g/KW-hr)									
			200° 10/06/84	200° 40/18/42	194° 10/08/82	194° 40/18/42	188° 10/10/80	188° 40/24/36	180° 10/20/70	180° 40/25/35		
1	No load	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	
2	20	624.91	638.17	607.06	679.82	573.19	743.57	599.29	1022.32	623.40		
3	40	397.00	395.18	380.68	427.35	370.87	440.52	385.36	518.26	394.56		
4	60	331.82	377.13	333.83	361.34	338.0	369.45	338.59	357.65	346.86		
5	80	293.86	353.05	327.26	338.61	335.37	336.93	347.87	323.29	327.88		
6	100	284.49	318.21	316.33	305.47	318.24	333.21	326.02	299.63	304.69		
7	110	364.12	316.45	341.63	309.40	327.75	335.77	322.58	312.74	313.38		

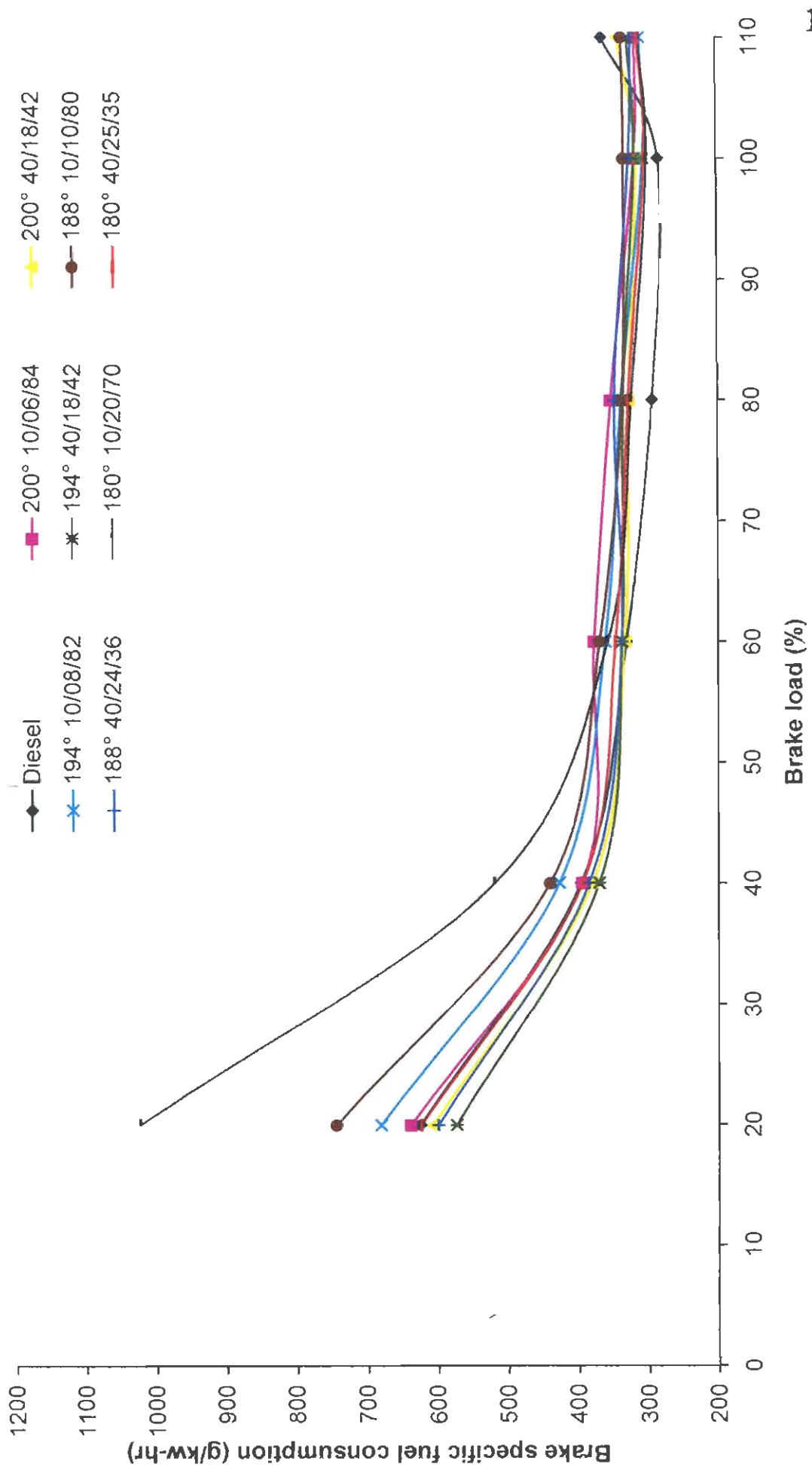


Fig 4.6.1: Brake specific fuel consumption of the engine at different brake load on diesel and microemulsions. 108

The brake specific fuel consumption of the engine on diesel at rated load (engine developing 3.73 KW at full load) was found to be 0.285 kg/KWh and on microemulsions 200° [10:06:84]; 200° [40:18:42]; 194° [10:08:82]; 194° [40:18:42]; 188° [10:10:80]; 188° [40:24:36]; 180° [10:20:70] and 180° [40:25:35] as 0.318, 0.316, 0.305, 0.318, 0.333, 0.326, 0.299 and 0.305 kg/KWh, respectively. Brake specific fuel consumption increased with the increased ethanol in the microemulsions as reported by **Chaplin and Janius [14]**. **Goering *et al.* [27]** indicated in their study that higher brake specific fuel consumption for ethanol blends may be expected because of their less calorific values compared to diesel. It is evident from the Fig. 4.6.1 that BSFC of the engine gradually decreased with the increase in brake load due to the fact that brake power of the engine increased with the break load. It was further observed that at 20 percent brake load, the BSFC of the engine was 0.625 kg/KWh on diesel and on 200° [10:06:84]; 200° [40:18:42]; 194° [10:08:82]; 194° [40:18:42]; 188° [10:10:80]; 188° [40:24:36]; 180° [10:20:70] and 180° [40:25:35] microemulsions was 0.638, 0.607, 0.680, 0.573, 0.744, 0.599, 1.022 and 0.623 kg/KWh. The highest BSFC of the engine was found as 1.022 kg/KWh on 180° [10:20:70] microemulsion fuel at the brake load of 20 percent. The figure also shows that the drop in the brake specific fuel consumption of the engine was at the higher rate upto 80 percent brake load. Less change in the BSFC of the engine was observed between 80 percent and 110

Table 4.6.2: Brake thermal efficiency of Kirloskar AVI 5.0/3.75 (bhp/KW) engine on selected fuels

Sl. No.	Brake load (%)	Diesel	Fuel types (Ethanol-diesel microemulsion)								
			Brake thermal efficiency (%) η_t								
			200° 10/06/84	200° 40/18/42	194° 10/08/82	194° 40/18/42	188° 10/10/80	188° 40/24/36	180° 10/20/70	180° 40/25/35	
1	0	0	0	0	0	0	0	0	0	0	
2	20	10.95	11.18	12.90	10.64	13.85	13.12	16.50	16.50	8.704	16.73
3	40	17.24	18.06	16.93	21.40	16.47	25.65	25.65	25.65	17.17	26.44
4	60	20.62	18.92	20.02	23.48	19.64	29.20	29.20	29.20	24.88	30.07
5	80	23.29	20.21	21.36	23.66	21.53	28.42	28.42	28.42	27.52	31.81
6	100	24.05	22.42	23.68	25.10	21.77	30.32	30.32	30.32	29.70	34.24
7	110	18.79	22.55	23.38	24.21	21.61	30.65	30.65	30.65	28.45	33.29

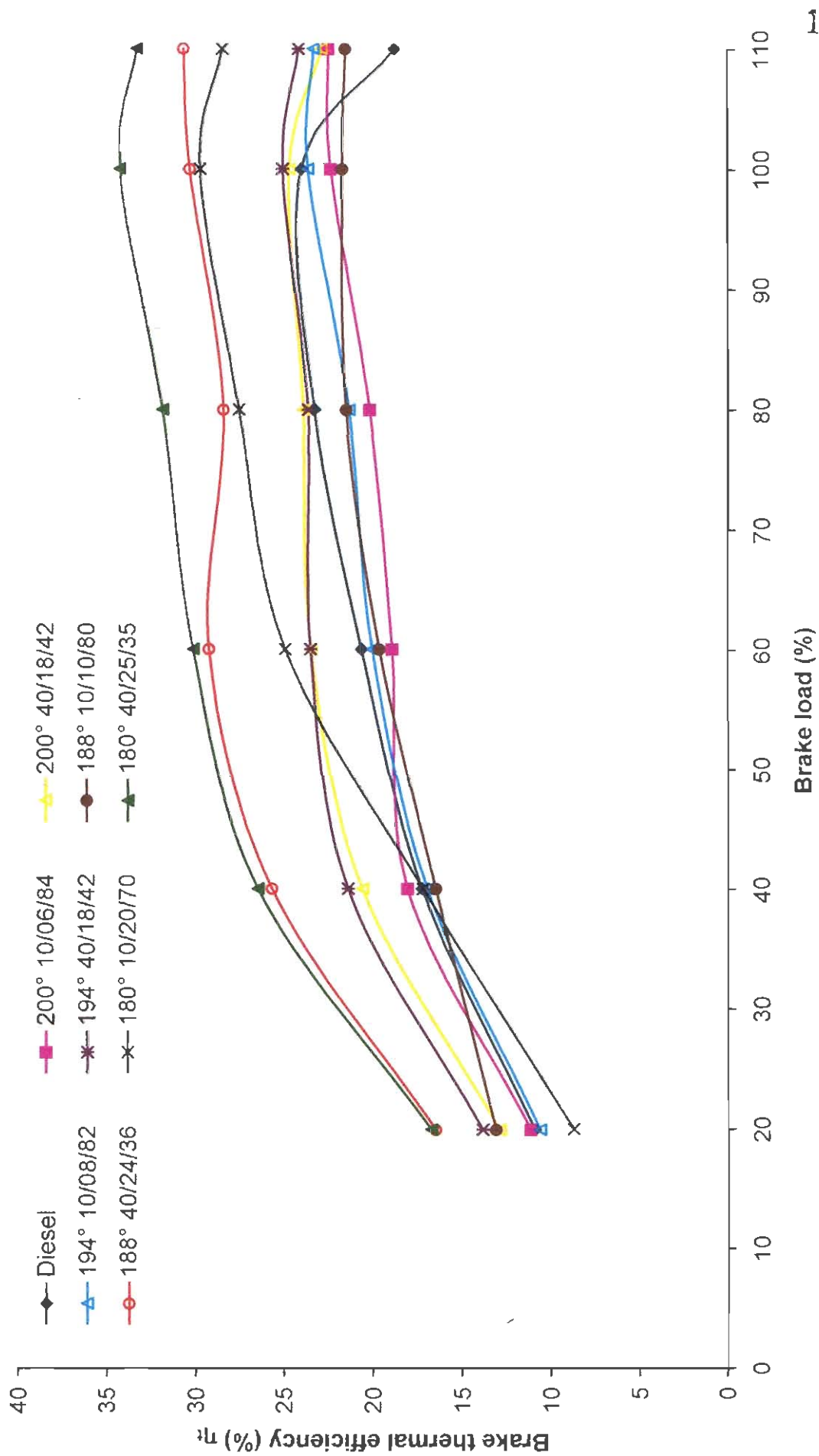


Fig 4.6.2: Brake thermal efficiency of the engine at different brake load on diesel and microemulsions.

percent brake loads. This is due to the reason that increase in brake power of the engine from 80 percent to 110 percent load was less as compared to increase in brake power between no load and 80 percent brake load. The analysis of the above results on BSFC indicates that at full load condition when engine developed its maximum power, the BSFC of the engine on 200° [10:06:84]; 200° [40:18:42]; 194° [10:08:82]; 194° [40:18:42]; 188° [10:10:80]; 188° [40:24:36]; 180° [10:20:70]; 180° [40:25:35] microemulsion fuels was 11.6, 10.9, 7.0, 11.6, 16.8, 14.4, 5.3 and 7.0 percent higher than that of diesel.

4.6.2 Brake thermal efficiency

The brake thermal efficiency of the engine on diesel and microemulsions is presented in Table 4.6.2. In Fig. 4.6.2 graph is plotted between brake thermal efficiency and brake load percentage for various fuels. The brake thermal efficiency on diesel at full load was found to be 24.1 percent when the engine develops 3.73 KW.

The brake thermal efficiency of the engine on 200° [10:06:84]; 200° [40:18:42]; 194° [10:08:82]; 194° [40:18:42]; 188° [10:10:80]; 188° [40:24:36]; 180° [10:20:70] and 180° [40:25:35] microemulsions at rated load was found 22.4, 24.8, 23.7, 25.1, 21.8, 30.3, 29.7 and 34.2 percent, respectively. It was observed that on an average, brake thermal efficiency on aqueous microemulsions was higher than that of diesel. This may be due to high heat of vapourization of alcohols which results into excessive cylinder

Table: 4.6.3: Brake power developed by Kirloskar AVI 5.0/3.75 (bhp/KW) engine selected fuels

S.No.	Brake load (%)	Fuel types (Alcohol -diesel micro emulsion)																																					
		Diesel						200° 10/06/84				200° 40/18/42				194° 10/08/82				194° 40/18/42				188° 10/10/80				188° 40/24/36				180° 10/20/70				180° 40/25/35			
		Engine speed (rpm)	Brake powder (kw)	Engine speed (rpm)	Brake powder (kw)	Engine speed (rpm)	Brake powder (kw)	Engine speed (rpm)	Brake powder (kw)	Engine speed (rpm)	Brake powder (kw)	Engine speed (rpm)	Brake powder (kw)	Engine speed (rpm)	Brake powder (kw)	Engine speed (rpm)	Brake powder (kw)	Engine speed (rpm)	Brake powder (kw)	Engine speed (rpm)	Brake powder (kw)	Engine speed (rpm)	Brake powder (kw)	Engine speed (rpm)	Brake powder (kw)	Engine speed (rpm)	Brake powder (kw)	Engine speed (rpm)	Brake powder (kw)										
1	0	1597	0	1614	0	1559	0	1588	0	1591	0	1588	0	1626	0	1582	0	1584	0	1570	0	1570	0	1570	0	1570	0	1570	0										
2	20	1562	0.78	1606	0.80	1549	0.77	1563	0.78	1573	0.78	1563	0.78	1578	0.79	1535	0.76	1551	0.71	1522	0.76	1522	0.76	1522	0.76	1522	0.76	1522	0.76										
3	40	1541	1.53	1575	1.57	1516	1.51	1554	1.55	1545	1.54	1554	1.55	1564	1.56	1539	1.53	1545	1.54	1518	1.51	1518	1.51	1518	1.51	1518	1.51	1518	1.51										
4	60	1530	2.28	1551	2.31	1487	2.22	1517	2.26	1526	2.28	1517	2.26	1527	2.28	1499	2.24	1535	2.29	1508	2.25	1508	2.25	1508	2.25	1508	2.25	1508	2.25										
5	80	1502	2.99	1541	3.07	1485	2.96	1494	2.97	1509	3.00	1494	2.97	1525	3.03	1485	2.96	1515	3.01	1509	3.00	1509	3.00	1509	3.00	1509	3.00	1509	3.00										
6	100	1498	3.72	1508	3.75	1498	3.72	1500	3.73	1498	3.72	1500	3.73	1507	3.75	1506	3.74	1506	3.74	1510	3.75	1510	3.75	1510	3.75	1510	3.75	1510	3.75										
7	110	1467	4.01	1490	4.08	1440	3.94	1486	4.07	1493	4.08	1486	4.07	1448	3.96	1494	4.09	1494	4.09	1450	3.97	1450	3.97	1450	3.97	1450	3.97	1450	3.97										

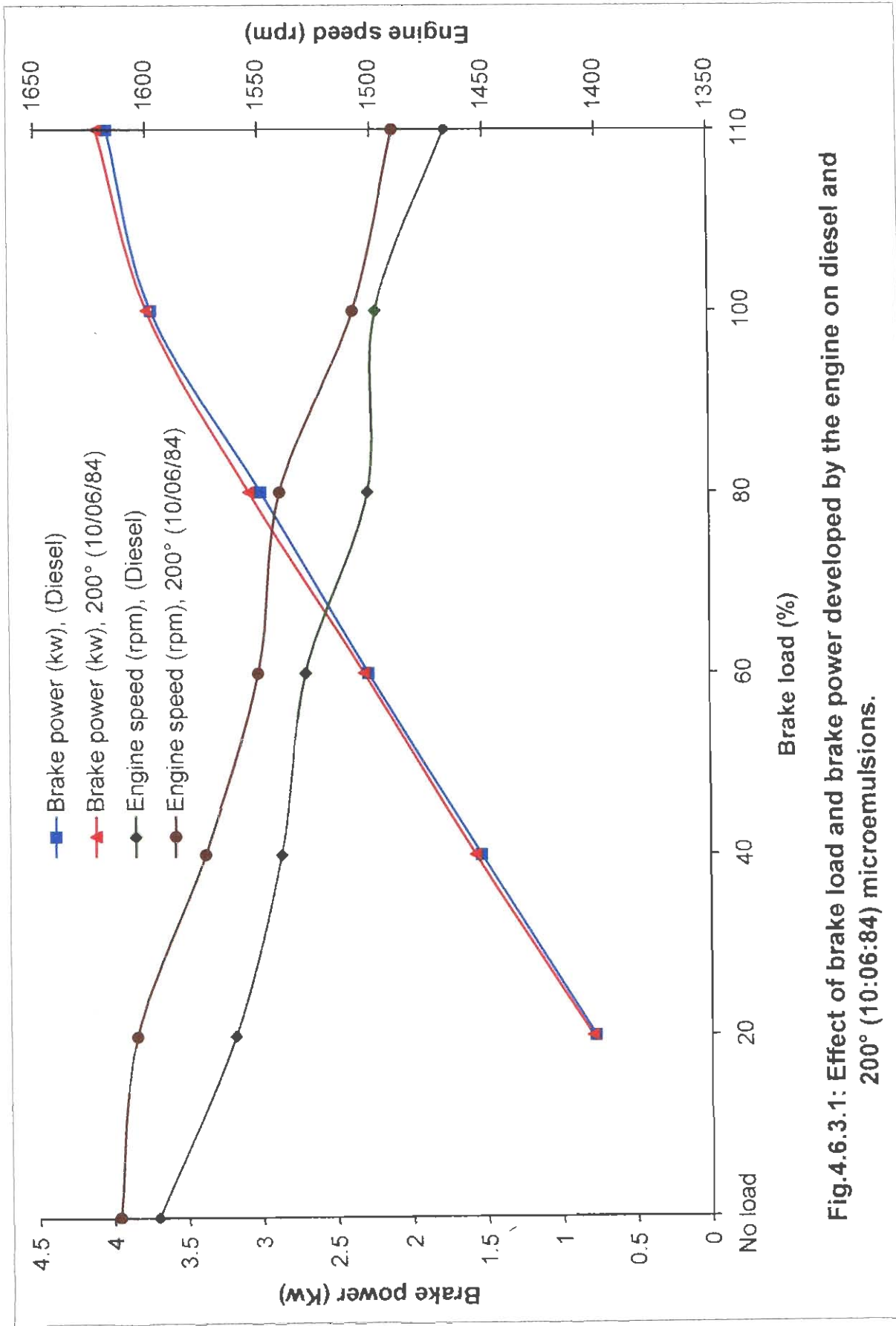


Fig.4.6.3.1: Effect of brake load and brake power developed by the engine on diesel and 200° (10:06:84) microemulsions.

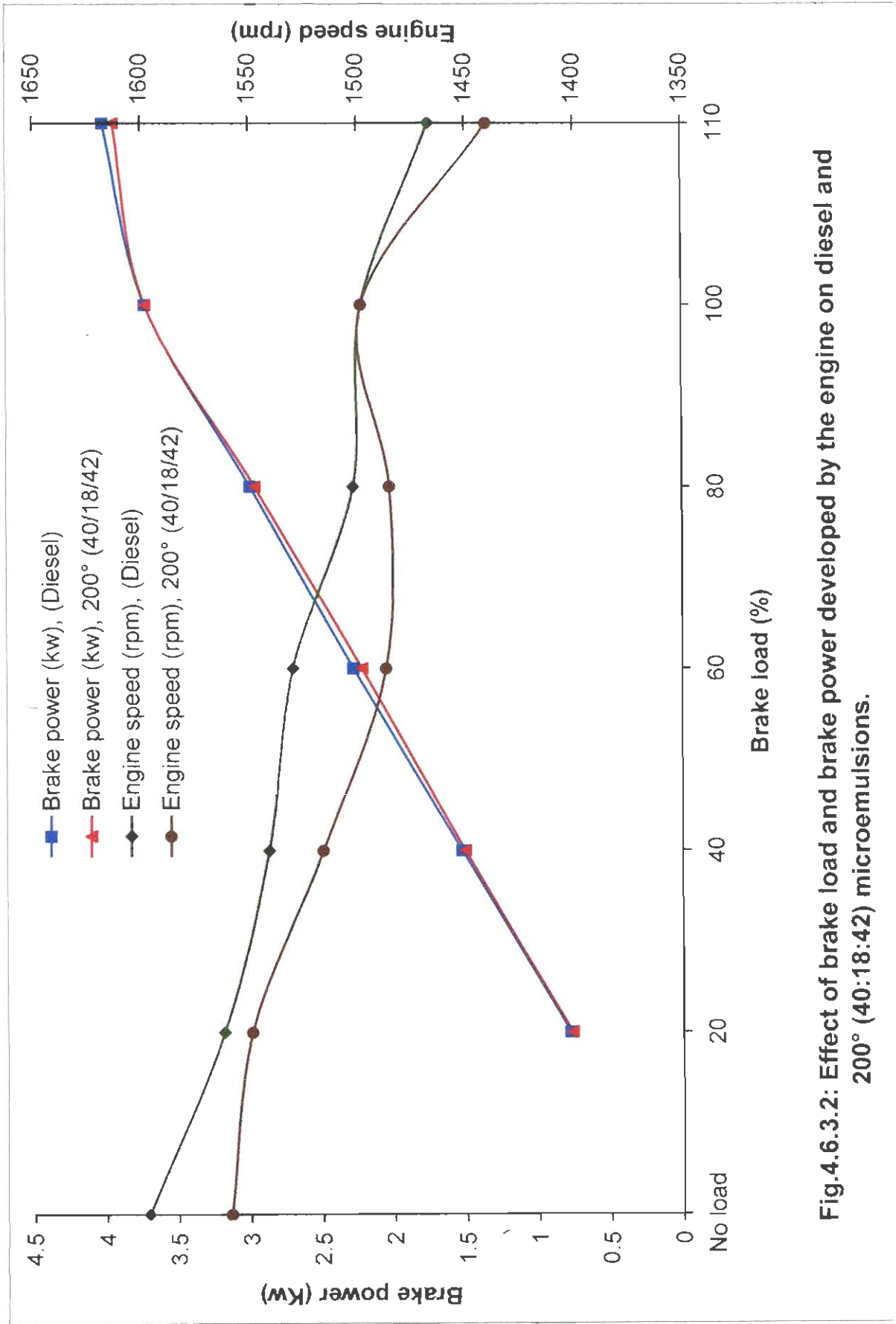


Fig.4.6.3.2: Effect of brake load and brake power developed by the engine on diesel and 200° (40:18:42) microemulsions.

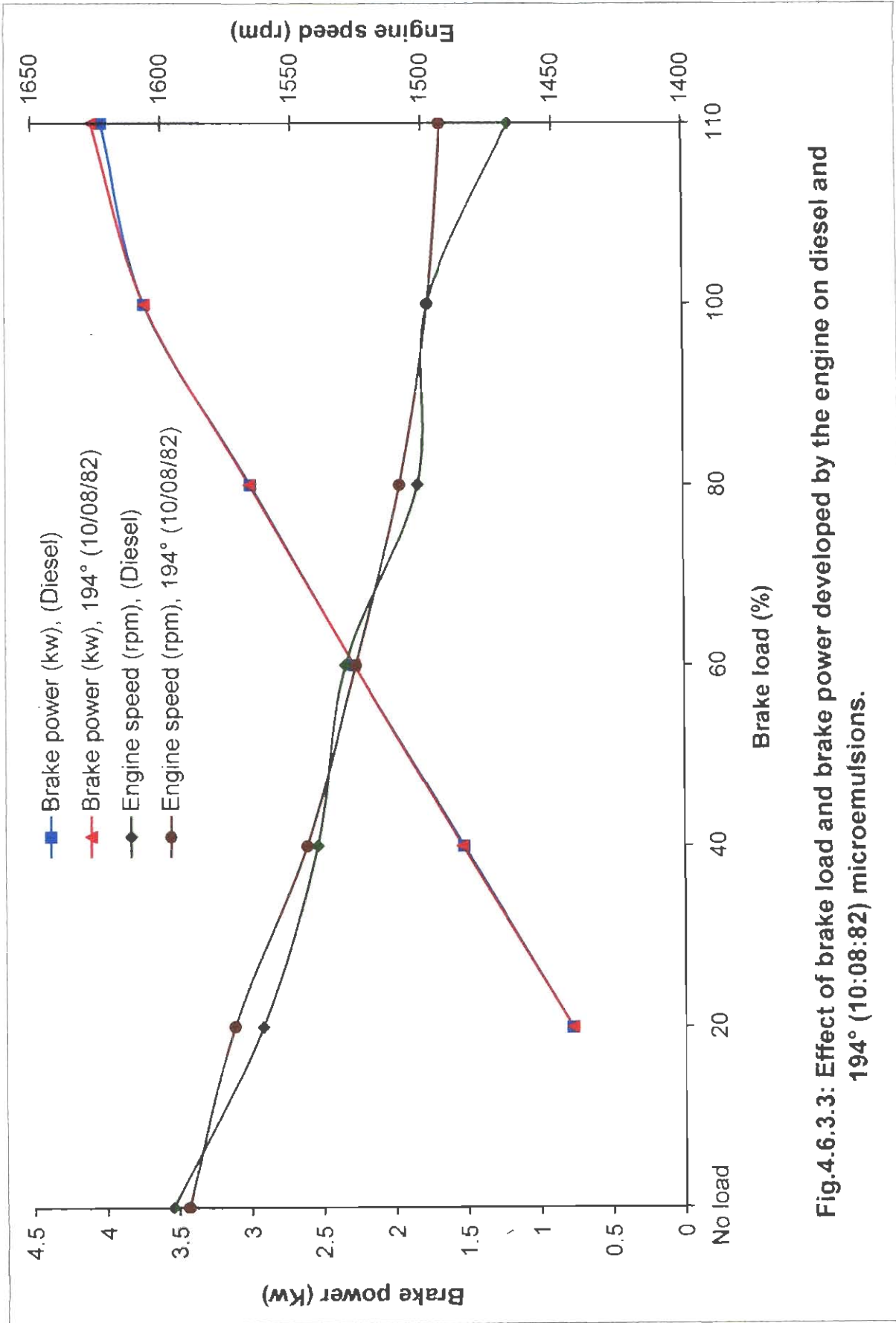


Fig.4.6.3.3: Effect of brake load and brake power developed by the engine on diesel and 194° (10:08:82) microemulsions.

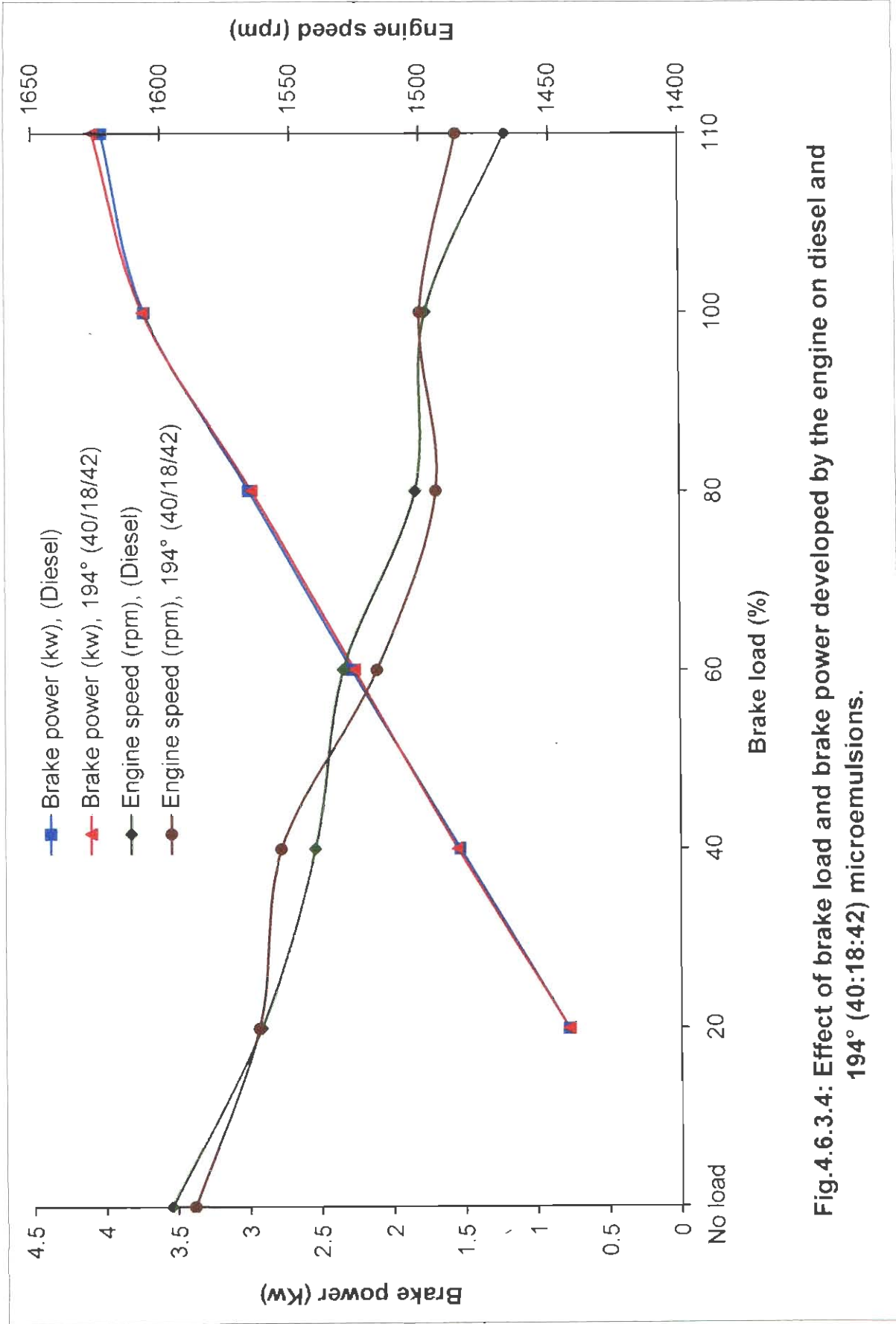


Fig.4.6.3.4: Effect of brake load and brake power developed by the engine on diesel and 194° (40:18:42) microemulsions.

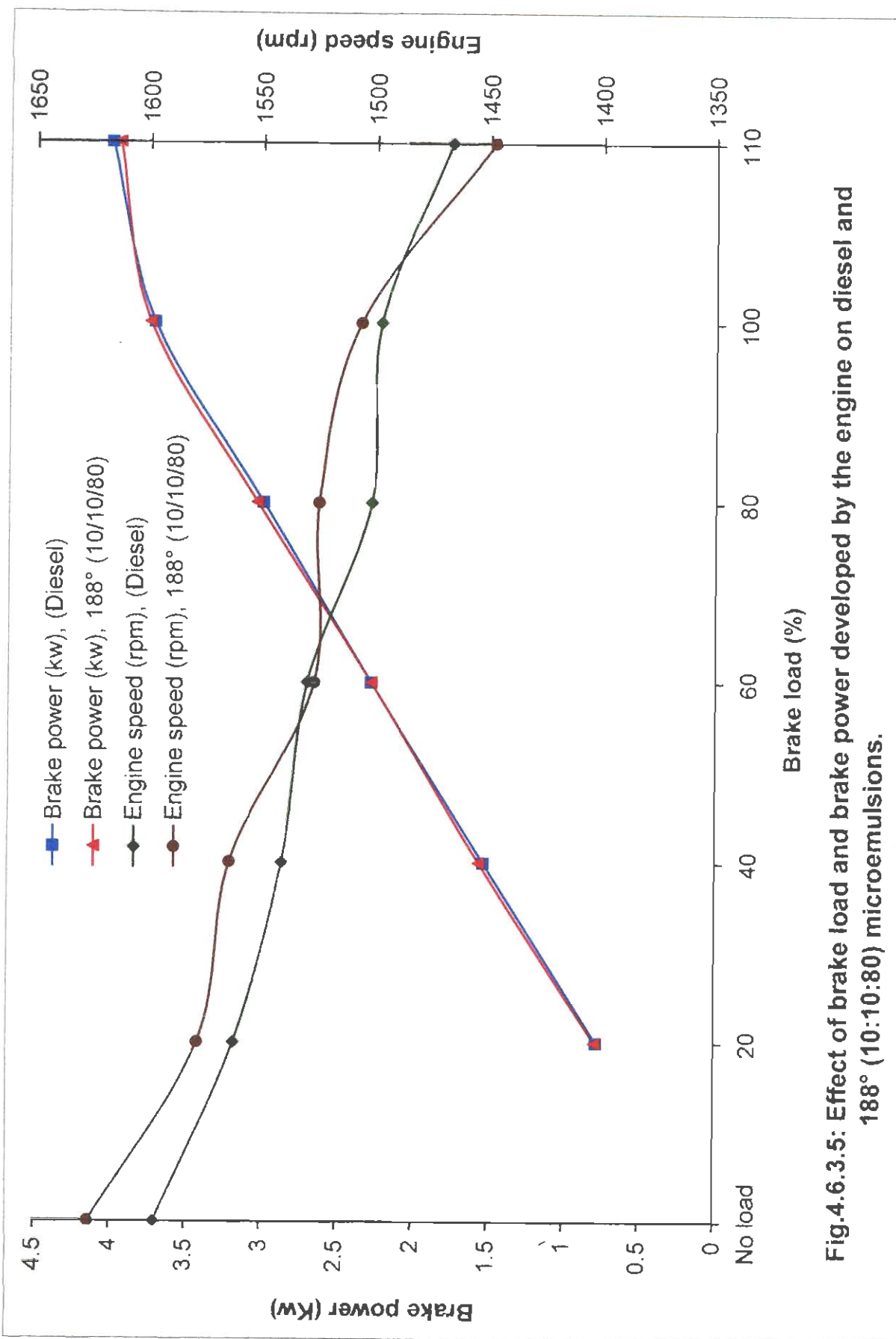


Fig.4.6.3.5: Effect of brake load and brake power developed by the engine on diesel and 188° (10:10:80) microemulsions.

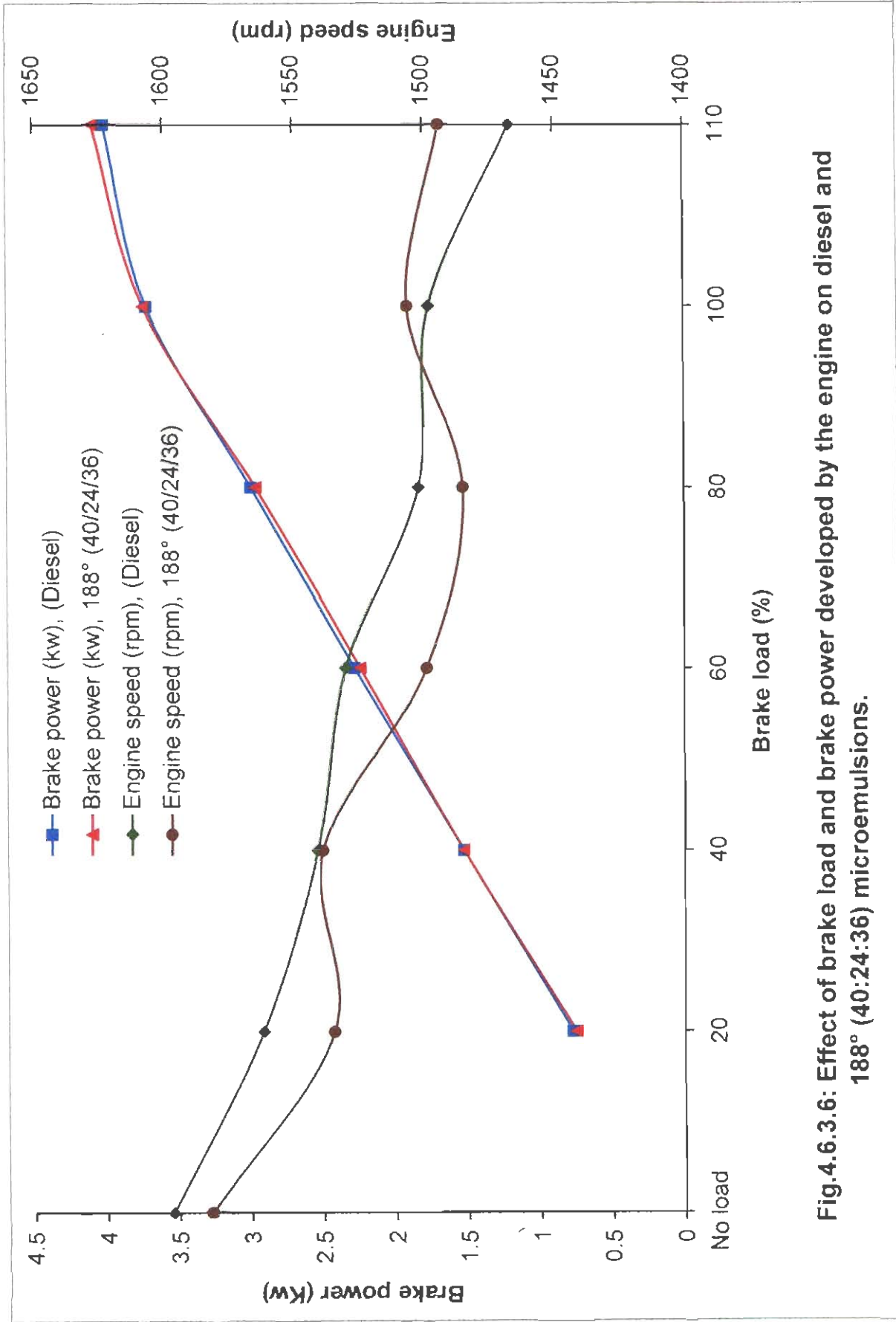


Fig.4.6.3.6: Effect of brake load and brake power developed by the engine on diesel and 188° (40:24:36) microemulsions.

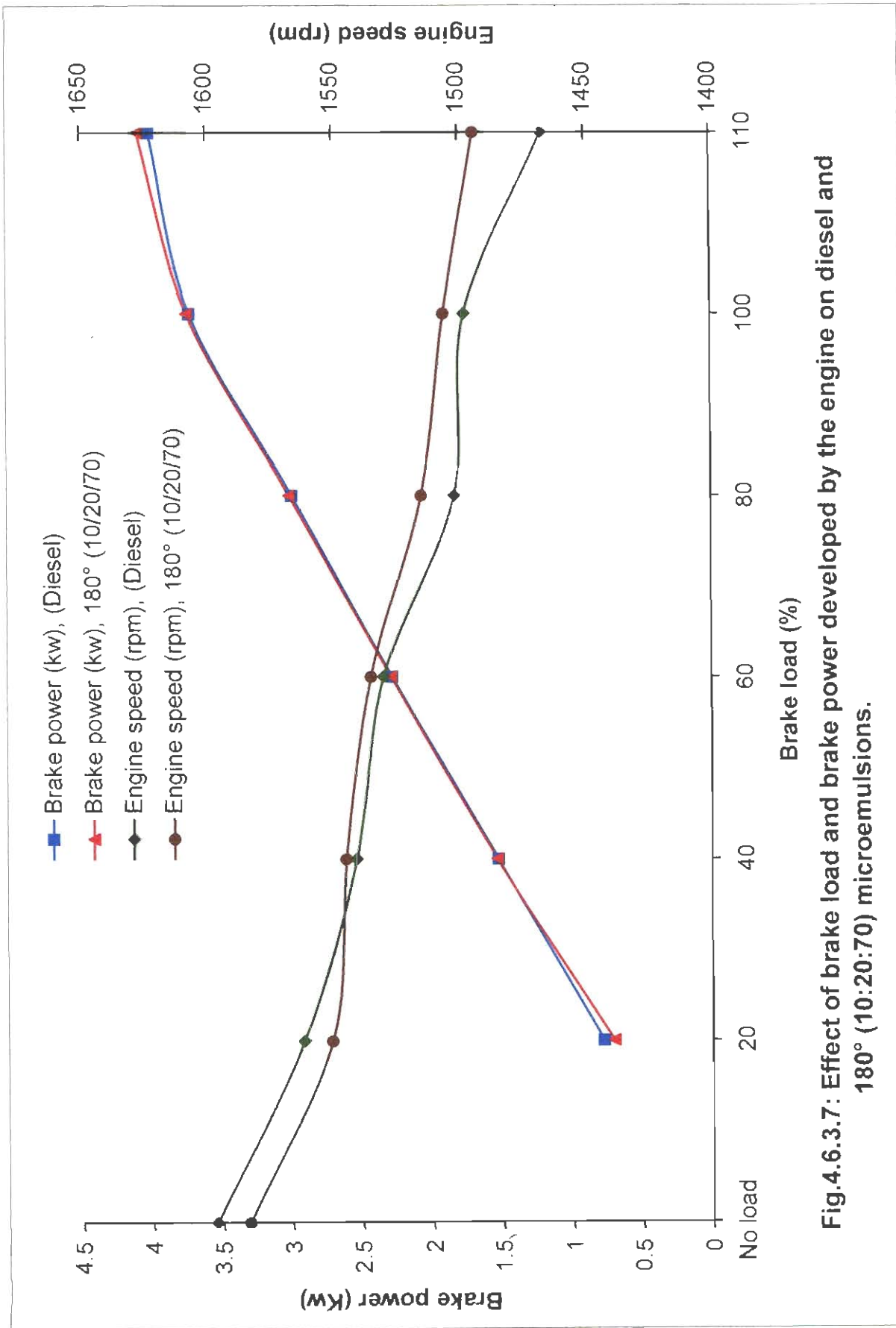


Fig.4.6.3.7: Effect of brake load and brake power developed by the engine on diesel and 180° (10:20:70) microemulsions.

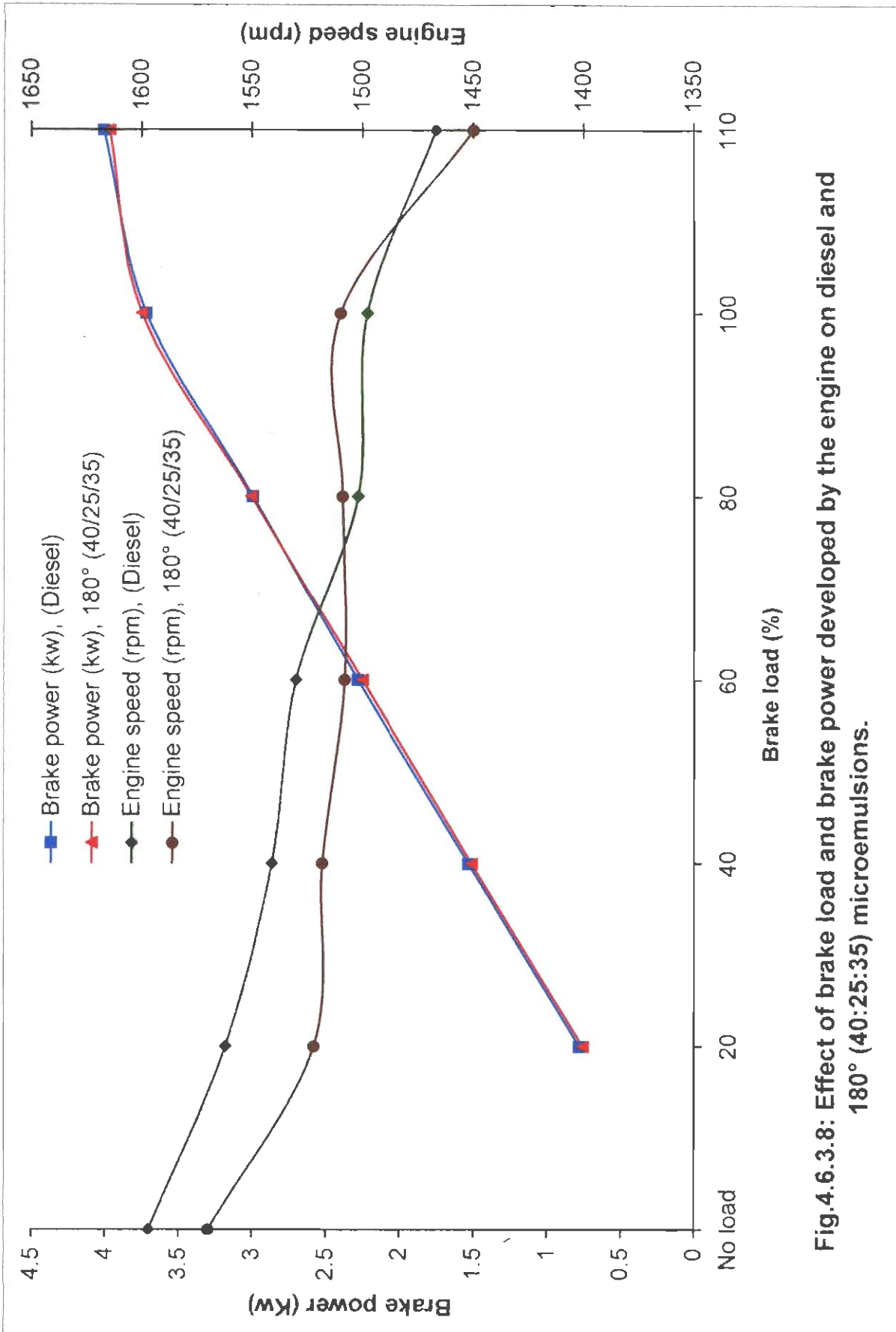


Fig.4.6.3.8: Effect of brake load and brake power developed by the engine on diesel and 180° (40:25:35) microemulsions.

cooling and therefore, increased brake thermal efficiency at high loads, **Chaplin and Janius [14]**. The maximum brake thermal efficiency was found as 34.24 percent on 180° proof [40:25:35] as compared to other microemulsions.

It is also evident from the table 4.6.2 that the thermal efficiency of the engine increases with the increase of 2-Ethyl-1-Hexanol in the microemulsions. It may therefore, be concluded that 2-Ethyl-1-Hexanol increases the thermal efficiency on account of its better vapourization which offer more time for mixing and consequently better air utilization.

4.6.3 Brake power

The brake power developed by the engine on selected fuels at zero load, 20, 40, 60, 80, 100 and 110 percent brake loads and at corresponding engine speed are shown in Table 4.6.3 and relationship between brake power and engine speed at different load conditions is presented in Fig. 4.6.3.1 to Fig. 4.6.3.8. It is evident from the table 4.6.3 that the engine develops 3.72 KW brake power at 1498 rpm on diesel. The rated engine brake power as per manufacturer is 3.73 KW at 1500 rpm. Table 4.6.3 also shows that the engine developed 3.75, 3.72, 3.72, 3.73, 3.75, 3.74, 3.75, 3.75 KW brake power at the full load conditions on 200° [10:06:84]; 200° [40:18:42]; 194° [10:08:82]; 194° [40:18:42]; 188° [10:10:80]; 188° [40:24:36]; 180° [10:20:70] and 180° [40:25:35] microemulsions, respectively. The observed engine speed at above

brake power was 1508, 1498, 1498, 1500, 1507, 1506, 1506 and 1510 rpm, respectively. All microemulsions showed higher or equivalent brake power and engine speed at rated load than diesel. This may be due to diesel replacement from (16% to 65%) by ethanol and 2-Ethyl-1-Hexanol in the microemulsions. The engine speed at full and 110 % of the rated load was found slightly higher on microemulsions than that on diesel and this may have resulted in marginal higher brake power on microemulsions than diesel.

The results are consistent with the findings of **Meiring *et al.* [40]** which states that the power reduction in lighter load region occurs due to reduced heat content of microemulsions and increase in ignition delay with alcohol when light loads are encountered. The combustion efficiency of microemulsions improves and ignition delay is reduced at higher load conditions.

Based on results on brake power developed by the engine on diesel and different microemulsions it can be said that the microemulsions tested have similar power producing capabilities as diesel though the amount of diesel replacement of microemulsions varied from 16 to 65 percent.

4.6.4 Energy input

Energy input in (MJ/hour) to the engine using diesel and microemulsions at different brake load is shown in Table 4.6.4 and the

Table 4.6.4: Energy input to the engine at different brake load on selected fuels

Sl. No.	Brake load (%)	Diesel	Fuel type (Alcohol-diesel microemulsion)							
			Energy input (MJ/hour)							
			200° 10/06/84	200° 40/18/42	194° 10/08/82	194° 40/18/42	188° 10/10/80	188° 40/24/36	180° 10/20/70	180° 40/25/35
1	0	19.40	15.85	20.06	14.24	22.14	16.00	27.31	13.18	
2	20	25.56	20.92	24.90	20.20	28.98	16.68	31.91	16.30	
3	40	32.0	26.40	32.76	26.04	34.04	21.50	32.25	20.59	
4	60	38.34	34.08	41.02	34.77	41.88	27.62	33.20	26.95	
5	80	42.23	44.49	50.67	45.30	50.79	37.49	39.46	34.0	
6	100	52.79	54.21	56.72	53.58	62.02	44.51	45.44	39.52	
7	110	76.96	58.56	62.99	60.52	66.08	48.08	51.77	42.93	

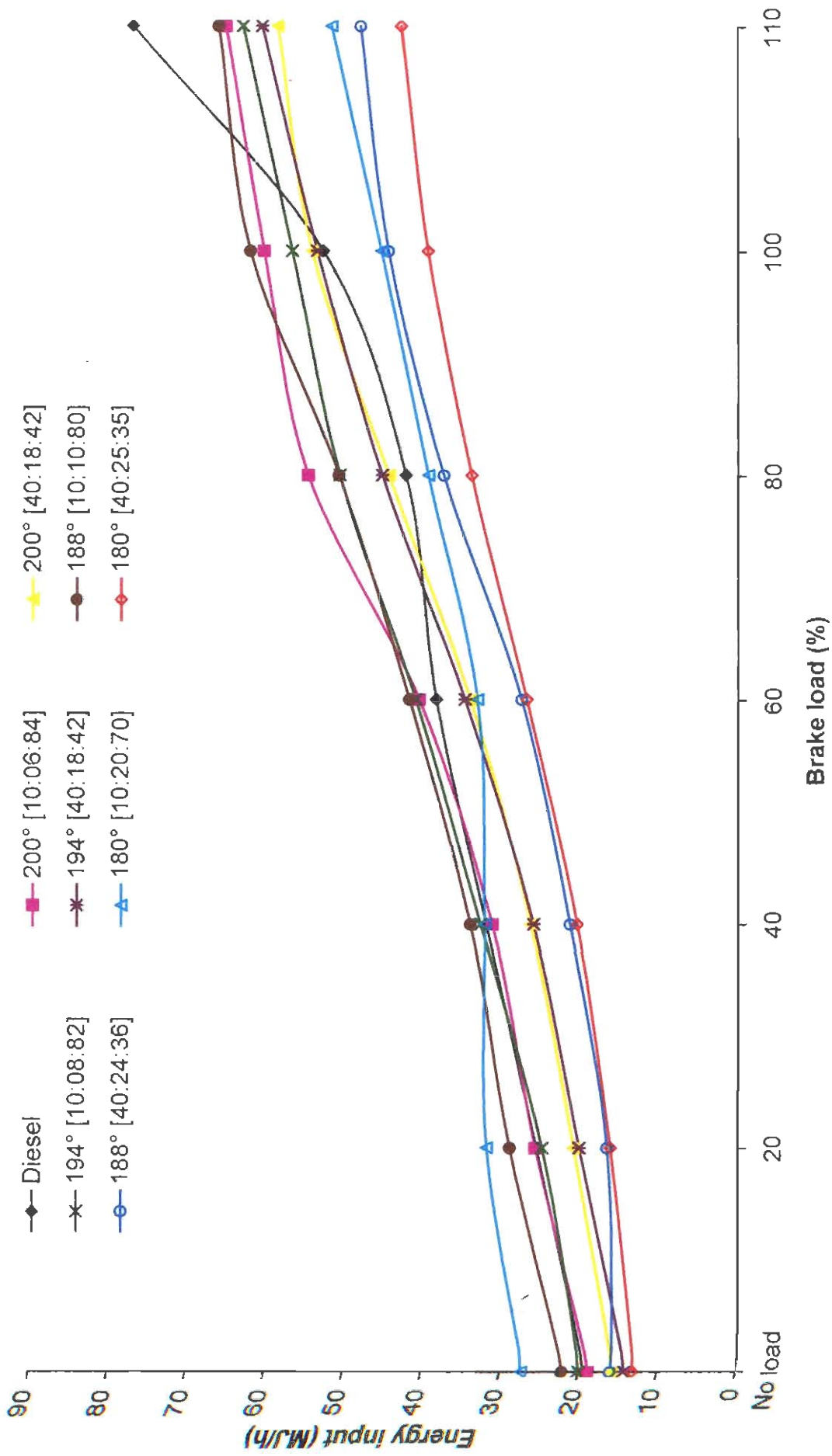


Fig. 4.6.4: Energy input to the engine at the different brake load on selected fuels.

relationship between energy input and brake load for the selected fuels is presented in Fig. 4.6.4. The figure shows that the fuel energy input to the engine increased with an increase of brake load and was highest at 110 percent brake load conditions. The input fuel energy at rated load on diesel, 200° [10:06:84]; 200° [40:18:42]; 194° [10:08:82]; 194° [40:18:42]; 188° [10:10:80]; 188° [40:24:36]; 180° [10:20:70] and 180° [40:25:35] microemulsions was observed as 52.79, 60.24, 54.21, 56.72, 53.82, 62.02, 44.51, 45.44 and 39.52 (MJ/hr), respectively.

The Table 4.6.4 shows that the maximum energy input at rated load was observed as 62.02 MJ/hr with 188° [10:10:70] microemulsion. This may be due to high fuel consumption of this microemulsified fuel. The lowest input fuel energy was found as 39.52 MJ/hr on 180° [40:25:35] microemulsion at rated engine load at which engine develops 3.754 KW power. This may be because of low heat content of this microemulsion.

4.7 Exhaust Emission and Lubricating Oil Temperature Measurement

The carbon monoxide CO, unburnt hydrocarbon (UBHC), nitrogen dioxide (NO₂) and nitric oxide (NO) from the engine at different brake loads on diesel and eight selected microemulsions were measured during the test.

4.7.1 Carbon monoxide emission

The carbon monoxide (CO) emission from the engine on diesel and ethanol- 2-Ethyl-1-Hexanol- diesel microemulsions at full brake load

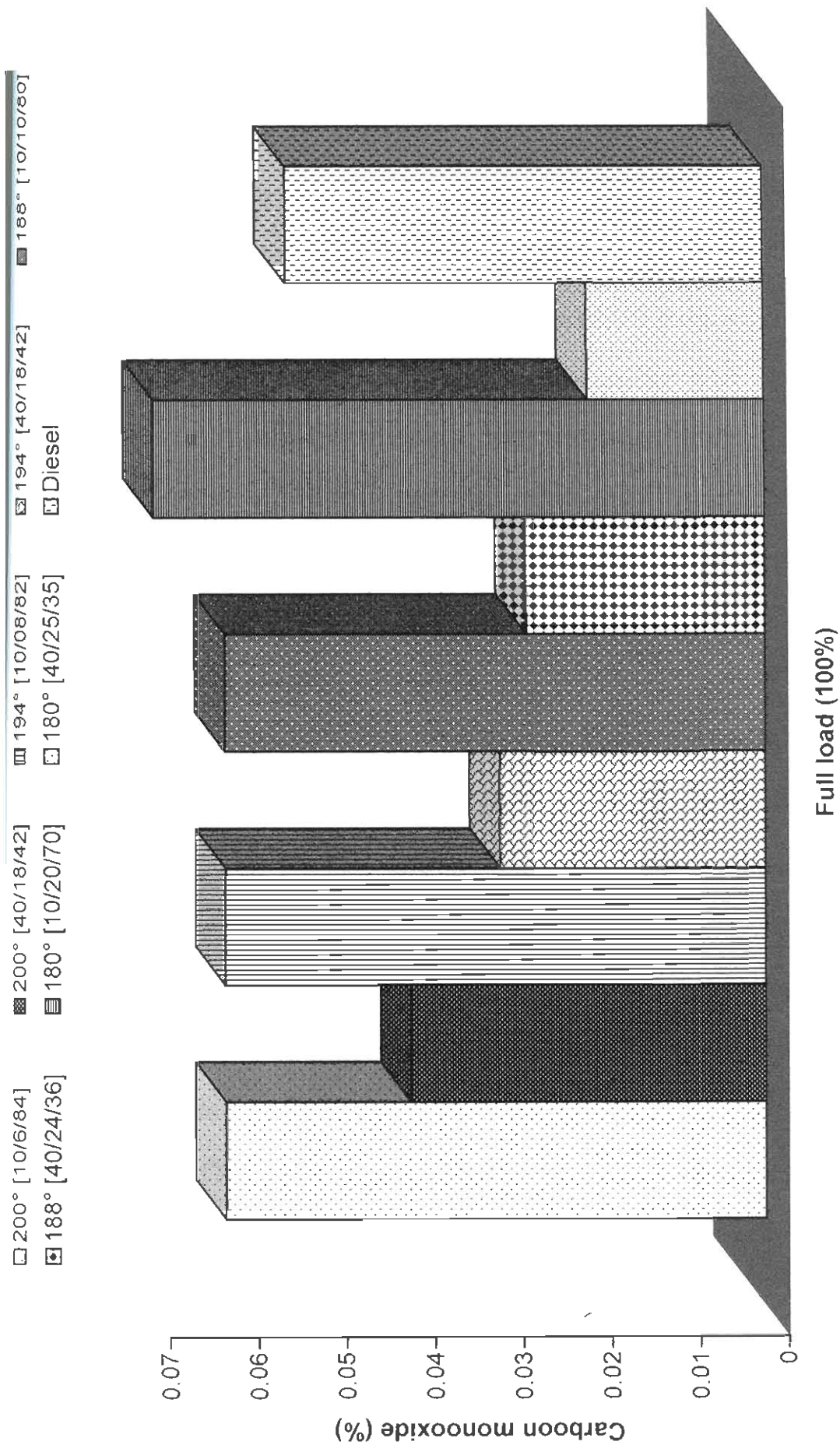


Fig 4.7.1: Carbon monoxide emission from the engine on diesel and different microemulsions at full break load condition

condition is shown in Table 4.7.1. The variation in emission of CO from the exhaust gases of the test engine at full load for selected fuels is presented in Fig. 4.7.1.

The table indicates that the emission of CO from engine on diesel was in the range of 0.054 to 0.058 percent at full load. The range of emission of CO on 200° [10:06:84]; 200° [40:18:42]; 194° [10:08:82]; 194° [40:18:42]; 188° [10:10:80]; 188° [40:24:36]; 180° [10:20:70] and 180° [40:25:35] microemulsions was found to be 0.061 - 0.064; 0.040 - 0.042; 0.061 - 0.065; 0.030 - 0.033; 0.060 - 0.062; 0.066 - 0.069; 0.026 - 0.028; 0.020 to 0.022 at full load, respectively.

From the results it is evident that at rated load when the engine developed rated power (3.73 KW), the emission of CO from the engine while running on highest amount of Ethanol microemulsion on 200° [40:18:42], 194° [40:18:42], 188° [40:24:36] and 180° [40:25:35] were recorded lower in the range of 0.041, 0.032, 0.027, 0.021 than diesel (in the range of 0.056). This is because of the presence of highest amount of Ethanol in the microemulsions. The above findings are in the line with **Boruff *et al.* [11]** and **Ecklund [20]** who have reported that CO emission is less in alcohol blended fuels due to the presence of oxygen molecules in alcohol which oxidizes CO to carbon dioxide.

Table 4.7.1: Carbon monoxide emission from 3.73 KW Kirloskar AVI engine at full load on selected fuel types.

Sl. No.	Brake load (%)	Fuel type			
		$^{\circ}$ Proof	Type of microemulsion	Ratio of the constituents	Carbon monoxide (%)
1	Full load 100%	200 $^{\circ}$	EH/2E1H/D	10/06/84	0.061
2	Full load 100%	200 $^{\circ}$	EH/2E1H/D	40/18/42	0.040
3	Full load 100%	194 $^{\circ}$	EH/2E1H/D	10/08/82	0.061
4	Full load 100%	194 $^{\circ}$	EH/2E1H/D	40/18/42	0.030
5	Full load 100%	188 $^{\circ}$	EH/2E1H/D	10/10/80	0.061
6	Full load 100%	188 $^{\circ}$	EH/2E1H/D	40/24/36	0.027
7	Full load 100%	180 $^{\circ}$	EH/2E1H/D	10/20/70	0.069
8	Full load 100%	180 $^{\circ}$	EH/2E1H/D	40/25/35	0.020
9	Full load 100%	-	Diesel	-	0.054

4.7.2 Unburnt hydrocarbon emission

The UBHC emission in the exhaust gas of the engine on diesel and different microemulsions is shown in Fig. 4.7.2. The change in UBHC emission in percent from the engine at varying load conditions on different fuels is presented in Fig. 4.7.2. The emission of UBHC from the exhaust of the engine on diesel was observed to vary from. 0.025 to 0.07 percent between no load to 110 percent brake load. It was also observed

Table 4.7.2: Unburnt hydrocarbon emission from Kirloskar AVI 5.0 HP engine on selected fuels

Sl. No.	Brake load (%)	Diesel	Fuel types (Ethanol-diesel microemulsion)								
			Unburnt hydrocarbon (%)								
			200° 10/06/84	200° 40/18/42	194° 10/08/82	194° 40/18/42	188° 10/10/80	188° 40/24/36	180° 10/20/70	180° 40/25/35	
1	0	0.030	0.057	0.09	0.08	0.07	0.06	0.06	0.06	0.05	0.04
2	20	0.025	0.017	0.085	0.07	0.06	0.06	0.06	0.06	0.05	0.04
3	40	0.03	0.033	0.07	0.06	0.06	0.06	0.05	0.04	0.04	0.03
4	60	0.07	0.037	0.04	0.024	0.026	0.026	0.021	0.029	0.03	0.026
5	80	0.06	0.023	0.06	0.023	0.026	0.026	0.022	0.032	0.024	0.024
6	100	0.07	0.057	0.06	0.024	0.024	0.024	0.026	0.024	0.024	0.023
7	110	0.07	0.037	0.03	0.028	0.026	0.026	0.018	0.019	0.029	0.017

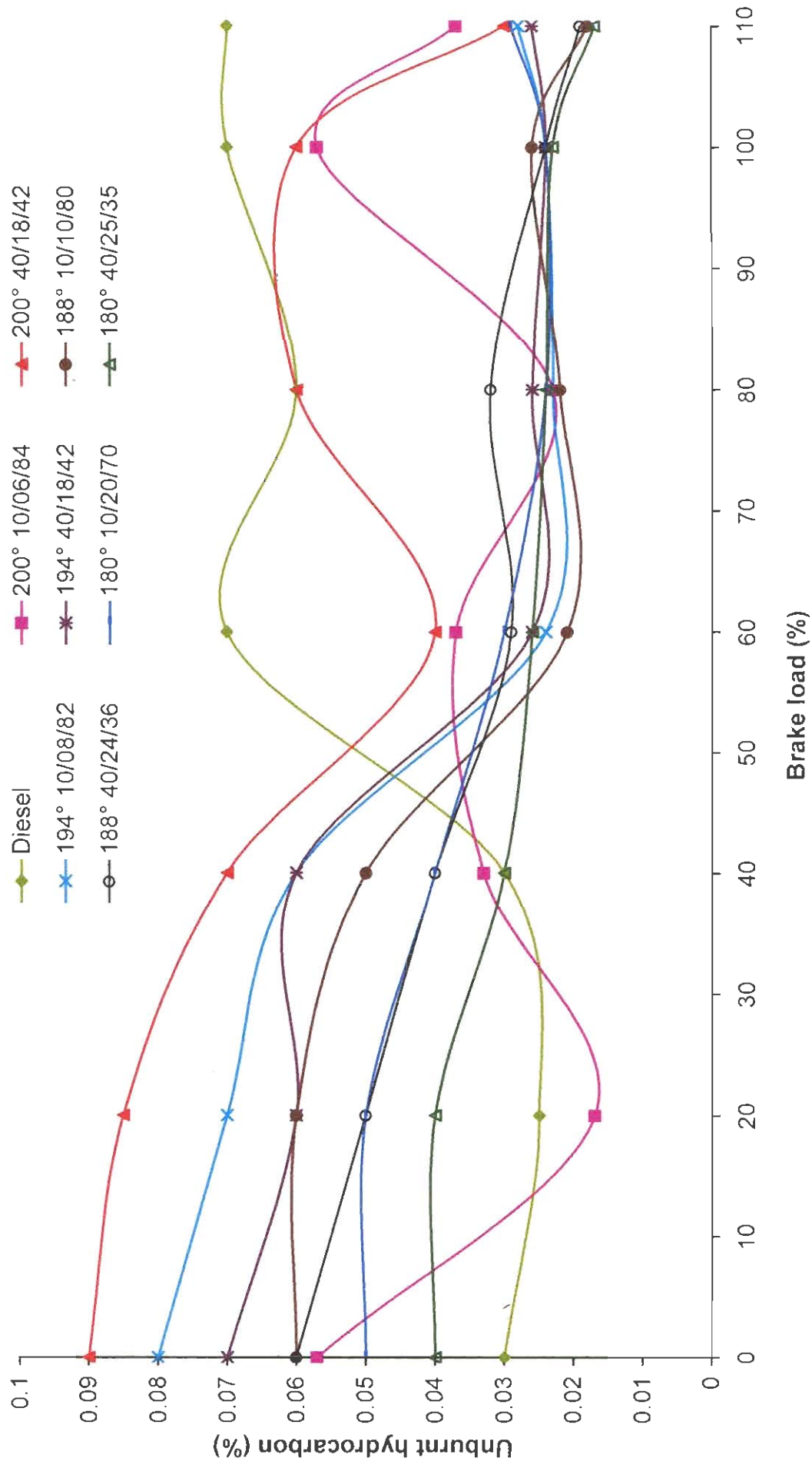


Fig. 4.7.2: The UHBC emission in the exhaust gas of the engine on diesel and different microemulsions.

Table 4.7.3: Nitric oxide emission from Kirloskar, AVI 5.0/3.75 (bhp/KW) engine on selected fuels

Sl. No.	Brake load (%)	Diesel	Fuel types (Alcohol-diesel microemulsion)								
			Nitric oxide emission (ppm)								
			200° 10/06/84	200° 40/18/42	194° 10/08/82	194° 40/18/42	188° 10/10/80	188° 40/24/36	180° 10/20/70	180° 40/25/35	
1	0	28	13	18	24	24	24	6	2	10	32
2	20	65	14	35	31	33	33	10	9	15	38
3	40	79	21	40	39	40	40	12	11	18	40
4	60	106	31	52	42	45	45	25	20	30	48
5	80	124	45	66	51	50	50	36	25	33	60
6	100	140	56	72	55	61	61	38	28	35	66
7	110	124	82	85	63	72	72	43	42	42	83

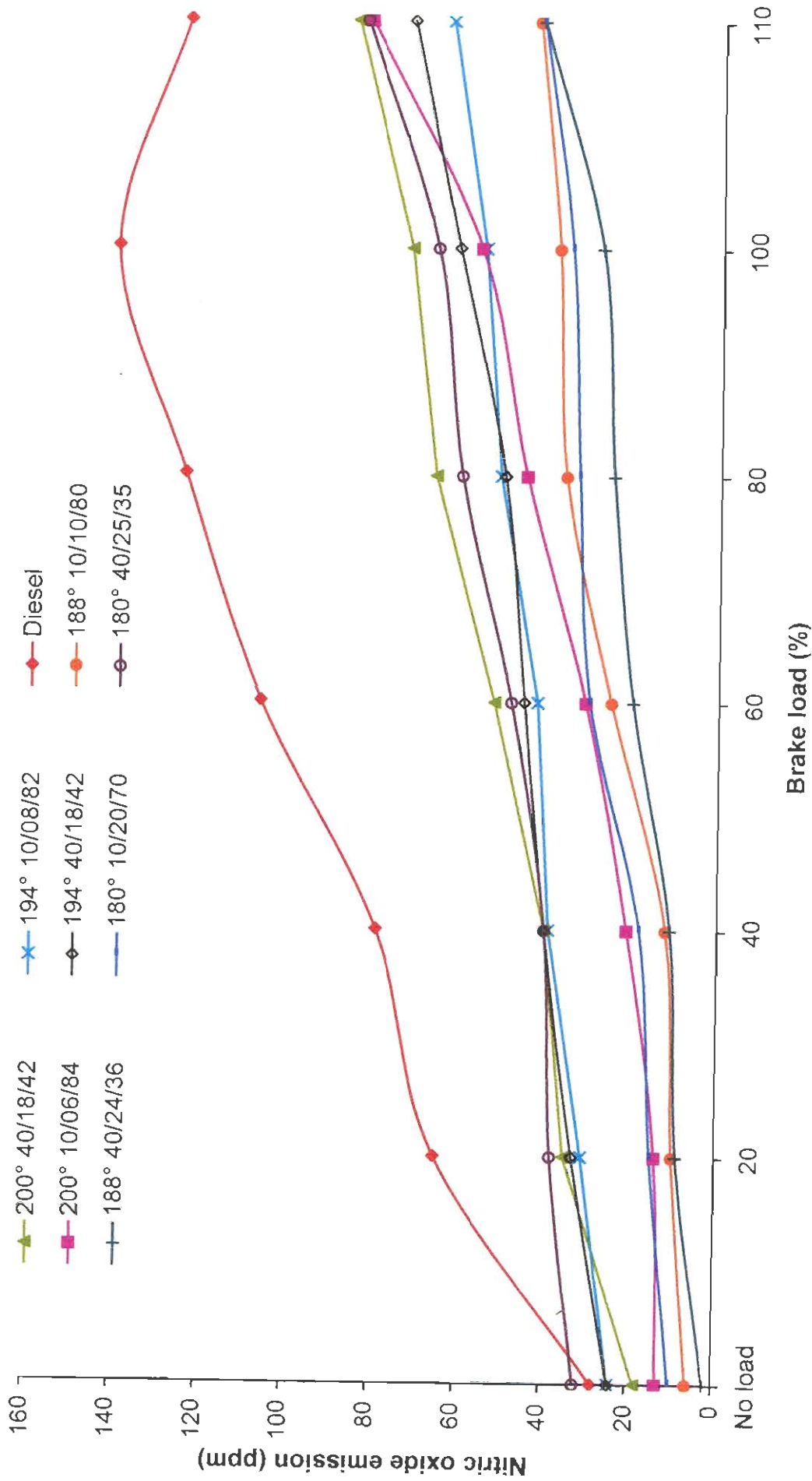


Fig. 4.7.3: Emission of nitric oxide (NO) in the exhaust of the engine on diesel and various selected microemulsion fuels.

that the emission of UBHC on diesel is almost same to be as 0.030 percent upto 60 percent of the brake load and then, increases to 0.07 percent upto 110 percent brake load.

It is evident from the result that the emission of UBHC from the exhaust of the engine when operating on 200° [10:06:84]; 200° [40:18:42]; 194° [10:08:82]; 194° [40:18:42]; 188° [10:10:80]; 188° [40:24:36]; 180° [10:20:70] and 180° [40:25:35] microemulsions was observed to vary in the range of 0.017 – 0.057; 0.03 – 0.09; 0.023 – 0.08; 0.024 – 0.07; 0.018 – 0.06; 0.019 – 0.06; 0.024 – 0.05 and 0.023 – 0.04 percent, respectively.

4.7.3 Emission of nitric oxide

The emission of nitric oxide (NO) in the exhaust of the engine operating on diesel and selected blended fuels is recorded in Table 4.7.3 and variation of NO in different fuels is shown in Fig. 4.7.3. The variation of diesel was reported in the range of 28-140 ppm between no load to 110 percent load. The level of NO emission from the engine running on 200° [10:06:84]; 200° [40:18:42]; 194° [10:08:82]; 194° [40:18:42]; 188° [10:10:80]; 188° [40:24:36]; 180° [10:20:70] and 180° [40:25:35] microemulsion fuels was found to vary in the range of 13 – 82; 18 – 85; 24 – 63; 24 – 72; 6 – 43; 2 – 42; 10 – 42 and 32 – 83 ppm, respectively between no load to 110 percent brake load.

It is evident from the Fig. 4.7.3 and Table 4.7.3 that the emission of NO from the exhaust of the engine was found lower on microemulsions

Table 4.7.4: Nitrogen dioxide emission from Kirloskar AVI 5.0/3.75 (bhp/KW) engine on selected fuels

Sl. No.	Brake load (%)	Diesel	Fuel types (Alcohol-diesel microemulsion)							
			Nitrogen dioxide (ppm)							
			200° 10/06/84	200° 40/18/42	194° 10/08/82	194° 40/18/42	188° 10/10/80	188° 40/24/36	180° 10/20/70	180° 40/25/35
1	0	2.2	1.2	1.4	1.0	1.0	1.1	1.9	1.4	1.2
2	20	2.3	1.3	1.5	1.0	1.0	1.2	2.5	1.4	1.3
3	40	2.4	1.4	1.8	1.2	1.2	1.4	2.9	1.5	1.4
4	60	2.5	1.5	1.9	1.3	1.3	1.6	3.1	1.6	1.6
5	80	3.8	1.7	2.1	1.5	1.4	2.0	3.6	1.9	2.1
6	100	4.6	1.9	2.2	1.8	1.7	2.6	3.7	2.0	2.3
7	110	4.3	2.0	1.9	2.0	1.07	2.2	4.0	2.1	2.9

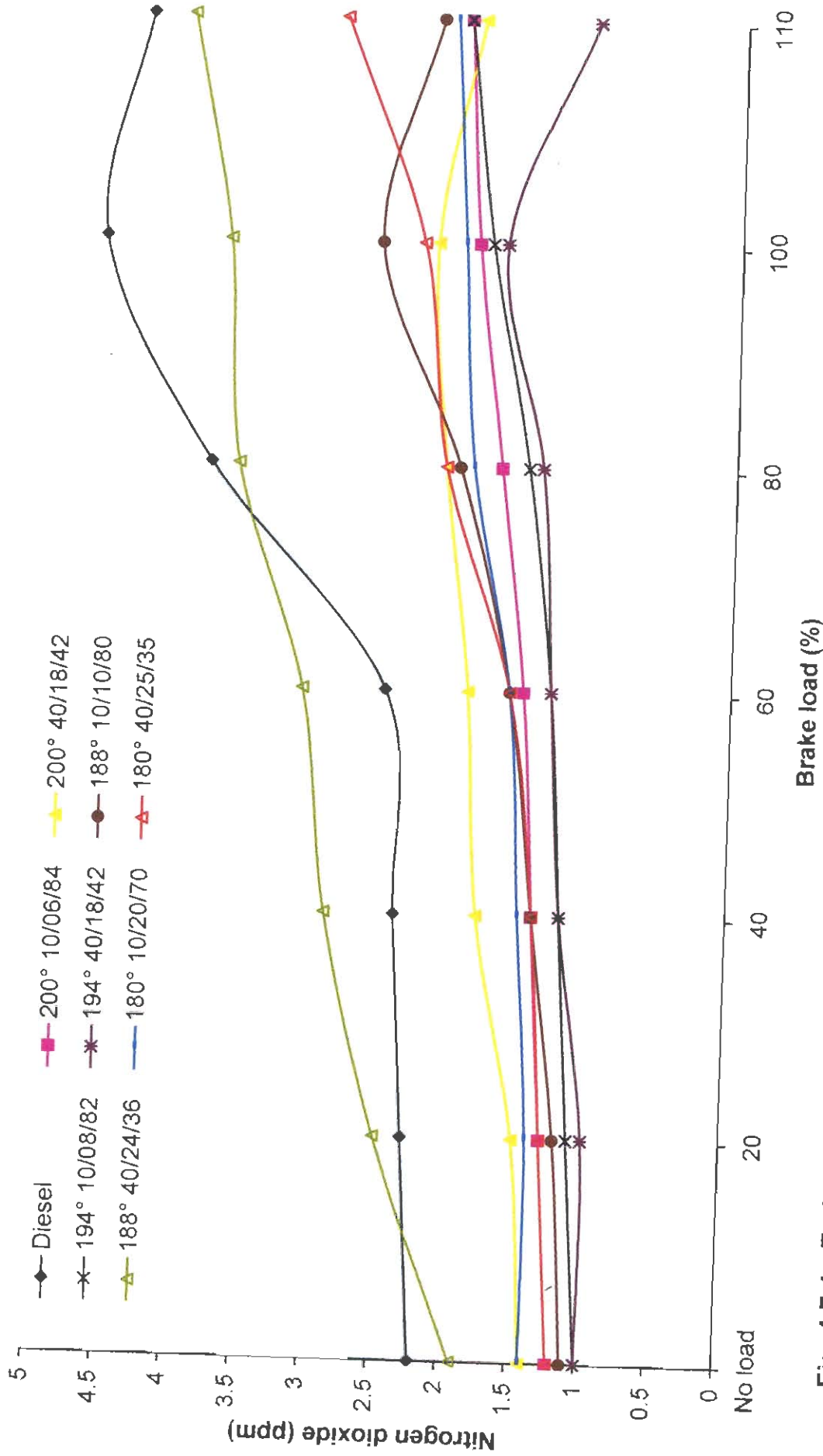


Fig. 4.7.4: Emission of nitrogen dioxide (NO₂) from the exhaust of the engine on diesel and different microemulsions.

than the diesel fuel between all brake loads. Table 4.7.3 also indicates that the emission of NO from the engine running on 188° proof was lower at almost all brake load conditions compared to any fuel. This is due to presence of water in ethanol and proportion of 2-Ethyl-1-Hexanol in the microemulsion.

4.7.4 Emission of nitrogen dioxide

The emission of nitrogen dioxide (NO₂) from the exhaust of the engine running on diesel and selected microemulsions is shown in Table 4.7.4 and variation in NO₂ in ppm at different brake load is presented in Fig. 4.7.4. The emission of nitrogen dioxide from exhaust of the engine on diesel was found to be in the range of 2.2 to 4.3 between no load to 110 percent brake load. The level of NO₂ emission from the engine on 200° [10:06:84]; 200° [40:18:42]; 194° [10:08:82]; 194° [40:18:42]; 188° [10:10:80]; 188° [40:24:36]; 180° [10:20:70] and 180° [40:25:35] microemulsions was found to vary from 1.2 - 2.0; 1.4 - 1.9; 1.0 - 2.0; 1.0 - 1.07; 1.1 - 2.2; 1.9 - 4.0; 1.4 - 2.1 and 1.2 to 2.9 ppm, respectively between no load to 110 percent brake loads.

It is evident from the figure that the emission of NO₂ from the engine was found almost lower on all microemulsions than the diesel under no load to 110 percent load. This indicates that with ethanol and 2-Ethyl-1-Hexanol in the microemulsion, the emission of NO₂ has been reduced. **Ecklund [20]** indicated that the presence of alcohol in a fuel

Table 4.7.4.1: (NO)_x emission from Kirloskar AVI 56 hp/3.75 KW engine on selected fuels

Sl. No.	Brake load (%)	Diesel	Fuel type (Alcohol – diesel microemulsion)							
			NO _x (ppm)							
			200° 10/06/84	200° 40/18/42	194° 10/08/82	194° 40/18/42	188° 10/10/80	188° 40/24/36	180° 10/20/70	180° 40/25/35
1	0	30.2	14.2	19.4	25.0	25	7.1	3.9	11.4	33.2
2	20	67.3	15.3	36.5	32.1	34	11.2	11.5	16.4	39.3
3	40	81.4	22.4	41.8	40.2	41.2	13.4	13.9	19.5	41.4
4	60	108.5	30.5	53.9	43.3	46.3	26.6	23.1	31.6	49.6
5	80	127.8	46.7	68.1	52.5	51.4	38.0	28.6	34.9	62.1
6	100	144.6	57.9	74.2	56.8	62.7	40.6	31.6	37.0	68.3
7	110	128.3	84.0	86.9	65.0	72.1	45.2	46.0	44.1	85.9

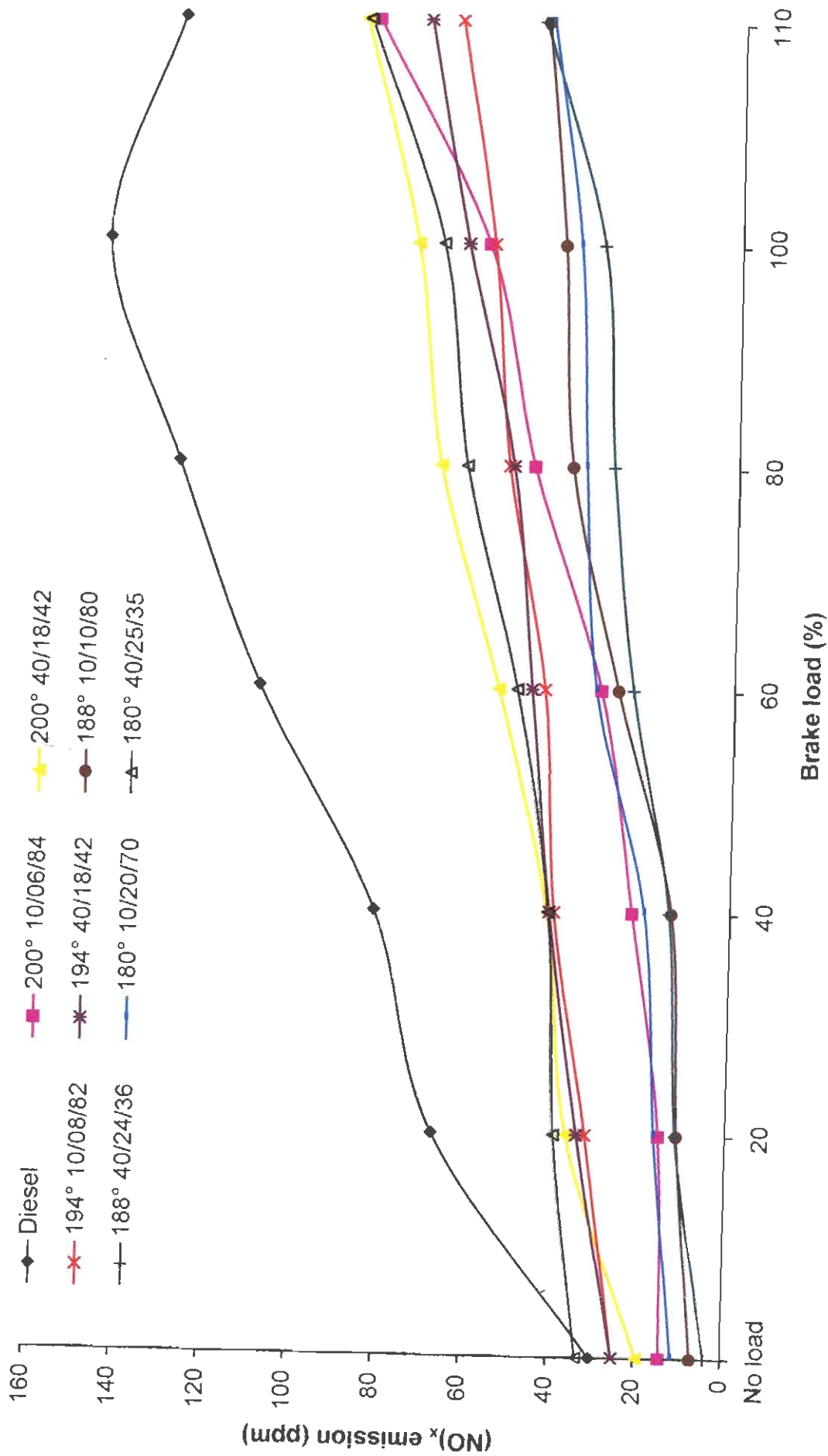


Fig. 4.7.4.1: Emission of (NO)_x from the exhaust of the engine on diesel and different microemulsions.

increases ignition delay and causes higher peak combustion temperature due to higher peak cylinder pressure, causing in increased emission of NO_x from the engine. However, in the present study a reverse trend was noticed which could be due to use of 2-Ethyl-1-Hexanol as a surfactant which might have helped in reducing NO_x emission from the engine. The $(\text{NO})_x$ emission of the engine on selected fuels at different brake loads is presented in Table 4.7.4.

4.7.5 Exhaust gas temperature

The observations were made on exhaust gas temperature when the engine was running on diesel and different selected fuels at different brake load conditions ranging from no load to 110 percent brake load. Table 4.7.5 shows the observed exhaust gas temperature of the engine on diesel and eight selected microemulsions. The change in exhaust gas temperature at different brake loads is shown in Fig. 4.7.5. It was found that the exhaust gas temperature of the engine on diesel was in the range of 177°C – 532.8°C between no load to 110 percent loads. Table 4.7.5 indicates that the exhaust gas temperature of the engine was increased with an increase of brake load for all fuels.

It is also evident that the exhaust gas temperature of the engine on all microemulsions was observed higher than diesel. The increased exhaust gas temperature of the engine on microemulsions was due to

Table 4.7.5: Exhaust gas temperature of Kirloskar AVI 5.0/3.75 (bhp/KW) engine on selected fuels

Sl. No.	Brake load (%)	Diesel	Fuel types (Alcohol-diesel microemulsion)							
			Exhaust gas temperature (°C)							
			200° 10/06/84	200° 40/18/42	194° 10/08/82	194° 40/18/42	188° 10/10/80	188° 40/24/36	180° 10/20/70	180° 40/25/35
1	0	177	214	212	244	260	227	315	246	337
2	20	222.5	232.3	245.7	273	290.4	240	340.8	270	377.4
3	40	304	298	302	321.7	342	302.8	397	292.4	428
4	60	334	345	357.5	387	408.6	399.2	467	348	501
5	80	399	355.6	428	448	498	468	518	417	572
6	100	495	452	502	567	573	513.6	540.4	498	617.8
7	110	532.8	547	577	592.8	595	570	592	567.6	660

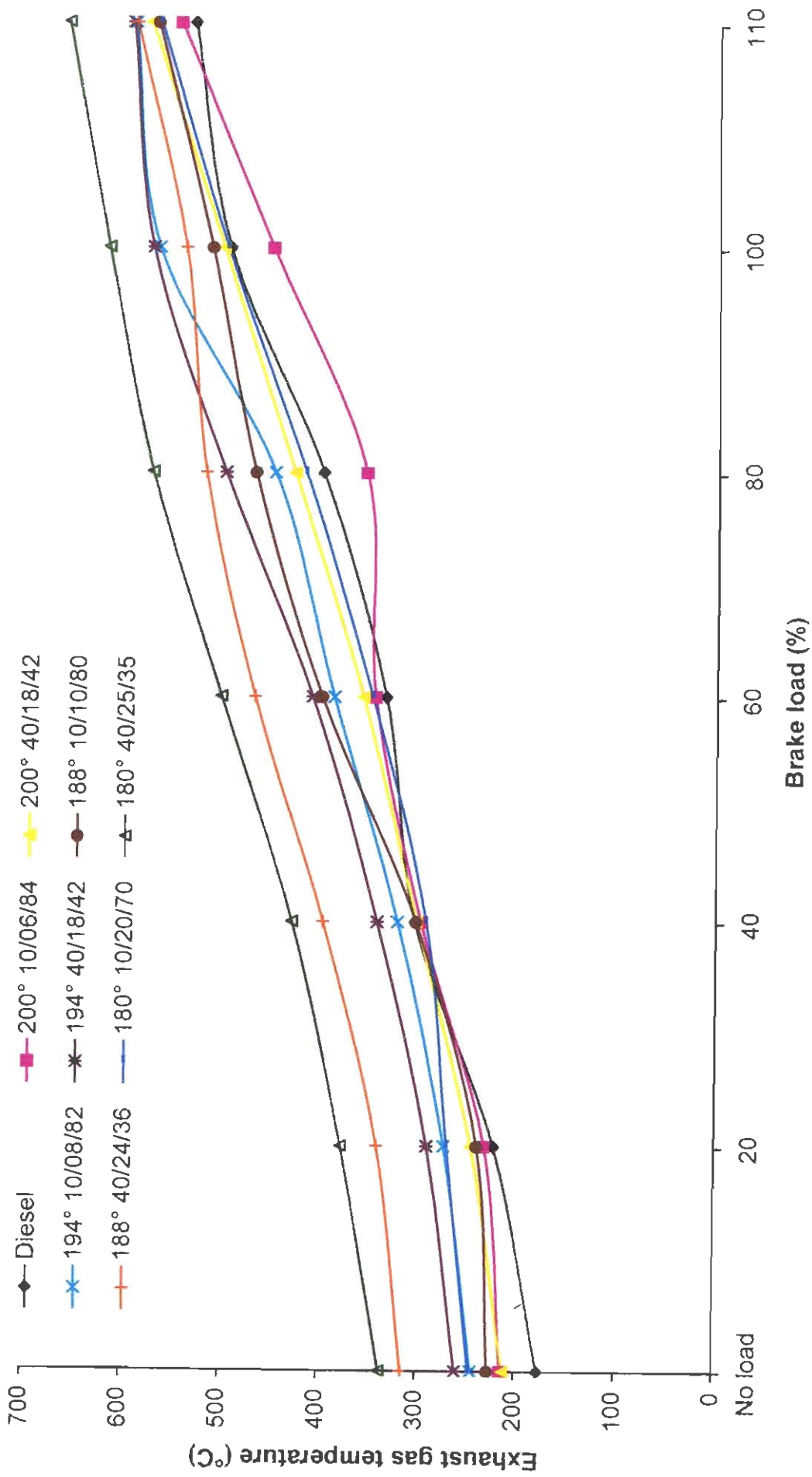


Fig. 4.7.5: Exhaust gas temperature of the engine running on diesel and different microemulsions at different brake load.

increase in peak cylinder pressure resulting in higher peak combustion temperature as reported by **Ecklund [20]**.

It was observed that at full load conditions, the exhaust gas temperature on diesel and 200° [10:06:84]; 200° [40:18:42]; 194° [10:08:82]; 194° [40:18:42]; 188° [10:10:80]; 188° [40:24:36]; 180° [10:20:70] and 180° [40:25:35] microemulsions were 495°C, 452°C, 502°C, 567°C, 573°C, 513.6°C, 540.4°C, 498°C and 617.8°C, respectively.

4.7.6 Lubricating oil temperature

Lubricating oil temperatures of the engine while running on diesel and selected fuels are shown in Table 4.7.6 and the variation in lubricating oil temperatures for different fuels at different brake loads is presented in Fig. 4.7.6. It is observed from the Table 4.7.6 that the lubricating oil temperature on diesel at NO load, 20, 40, 60, 80, 100 and 110 percent brake loads was recorded as 58°C, 59.3°C, 60°C, 62°C, 63°C, 64.5°C and 66.3°C, respectively. It was seen that the lubricating oil temperature increased with an increase of brake load for all fuels.

It was also found that the engine lubricating oil temperature on microemulsions, 200° [10:06:84]; 200° [40:18:42]; 194° [10:08:82]; 194° [40:18:42]; 188° [10:10:80]; 188° [40:24:36]; 180° [10:20:70] and 180° [40:25:35] varied in the range of 50 – 71.1; 55 – 72.0; 53.0 – 70.0; 58 – 70; 48.0 – 64.6; 63 – 69.3°C; 62 – 68.2 and 46 – 67, respectively between no

Table 4.7.6: Lubricating oil temperature of Kirloskar AVI 5.0/3.75 (bhp/KW) engine on selected fuels.

Sl. No.	Brake load (%)	Diesel	Fuel types (Alcohol-diesel microemulsion)							
			Exhaust gas temperature (°C)							
			200° 10/06/84	200° 40/18/42	194° 10/08/82	194° 40/18/42	188° 10/10/80	188° 40/24/36	180° 10/20/70	180° 40/25/35
1	0	58	55	53	58	48	63	62	46	
2	20	59.3	64	59	65	51	64	63	54	
3	40	60	66	61.2	66	53	64	64	55	
4	60	62	67	64	66	55	65	65	58	
5	80	63	69	65.3	67	58	66	66.3	61.3	
6	100	64.5	71.3	68	68.6	61	67	67.6	63	
7	110	66.3	72.0	70	70	64.6	69.3	68.2	67	

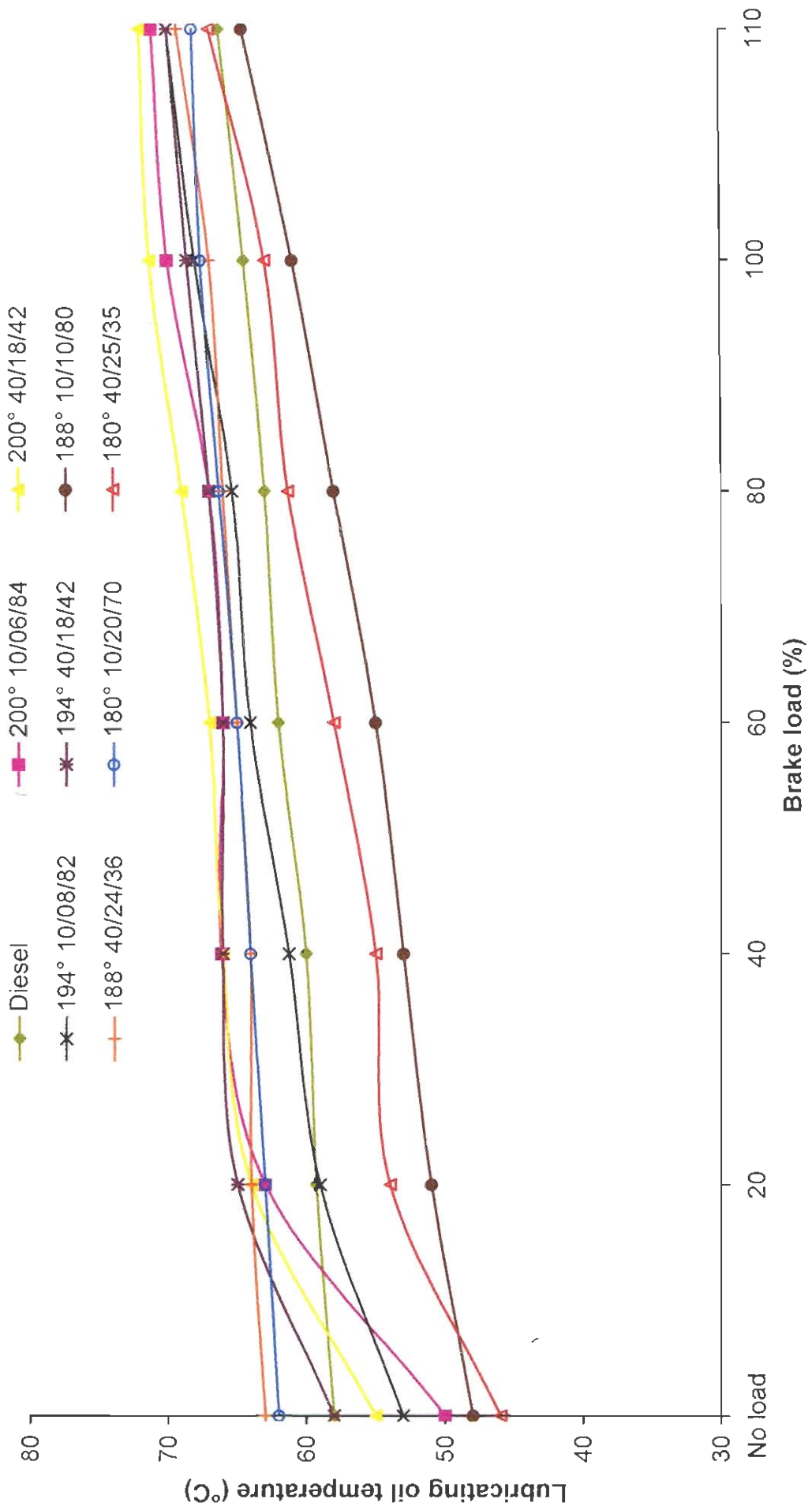


Fig. 4.7.6: Lubricating oil temperature of the engine running on diesel and various microemulsions at different brake load.

load to 110 percent loads. It was also observed from the figure that the trend of the lubricating oil temperature on microemulsion fuels is almost similar to that on diesel oil. However, a decreased engine oil temperature trend was observed on microemulsion fuels. This is due to fact that the ethanol has higher latent heat of vapourization and ethanol burns with lower flame temperature. **Owen and Caley [45]** than diesel and thus, it cools the crown of the piston after injection of the fuel into the combustion chamber. The decreased engine oil temperature maintains proper lubricity and reduces consumption of the engine oil in the sump of the engine.

To standardize the level of constituents to achieve stable microemulsions of anhydrous and aqueous alcohols with diesel oil using 2-Ethyl-1-Hexanol as an emulsifier, several experiments were conducted for the research study. The stability of different microemulsions in terms of phase separation and their homogeneity was observed at room temperature (28° – 34°C) and at 0°, 1°, 2°, 3°, 4°, 5°, 10°, 15°, 20°, 25°, 30°, 35°, 40° and 45°C temperatures, respectively.

The 200° [10:06:84]; 200° [40:18:42]; 194° [10:08:82]; 194° [40:18:42]; 188° [10:10:80]; 188° [40:24:36]; 180° [10:20:70] and 180° [40:25:35] proof microemulsions were found to be stable under the temperature range of 0° to 45°C and were selected for study of fuel properties and performance tests on C.I. engine. The identified microemulsions were chosen on the basis of optimum diesel replacement with ethanol and minimum amount of emulsifier required.

A stationary 3.73 KW (5.0 bhp) constant speed, compression ignition engine was tested for performance on diesel fuel and eight selected blended fuels out of 43 samples as per IS: 10,000 [P: 5] 1980 code. The engine performance in respect of brake power, fuel consumption, brake specific fuel consumption, thermal efficiency and

emission of CO, UBHC, NO_x, temperature of exhaust gas and lubricating oil was evaluated. Based on the study, following conclusions are drawn:-

(I) All seventy two ethanol-diesel-2-Ethyl-1-Hexanol microemulsions, using 200^o, 194^o, 188^o and 180^o proofs Ethanol and 2-Ethyl-1-Hexanol surfactant were found stable and homogeneous even after one hundred days of their preparation at room temperature (28^o – 34^oC). The requirement of emulsifier for the preparation of stable microemulsions significantly depends upon the proof of ethanol used as well as the amount of diesel replacement.

Out of seventy two, sixty microemulsions were found clear and stable with no sign of phase separation in the temperature range of 20^o – 45^oC. In the temperature range of 5^o – 15^oC, some microemulsions showed clarity, some were hazy and others with partial separation and distinct phase separation. Out of sixty, forty three microemulsions were found stable and homogeneous even at very low temperature of the order of 0^oC.

(i) The ethanol-2-Ethyl-1-Hexanol-diesel microemulsions prepared using 200^o proof ethanol and designated as 200^o [10:06:84]; 200^o [10:08:82]; 200^o [10:10:80]; 200^o [15:10:75]; 200^o [20:10:70]; 200^o [20:15:65]; 200^o [30:15:55]; 200^o [30:18:52]; 200^o [40:18:42] and 200^o [40:20:40] were found stable at the selected temperature range

(0° – 45°C). This indicates that microemulsions having the level of anhydrous ethanol ranging between 10 to 40 percent would require 2-Ethyl-1-Hexanol emulsifier in the range of 6 to 20 percent. The replacement of diesel is then possible between 16 to 60 percent with such microemulsions.

(ii) The microemulsions using 194° proof ethanol and demarcated as 194° [10:08:82]; 194° [10:10:80]; 194° [15:12:73]; 194° [20:15:65]; 194° [25:13:62]; 194° [25:14:61]; 194° [25:18:53]; 194° [30:15:55]; 194° [30:18:52]; 194° [40:18:42]; 194° [40:20:40] were found stable and homogeneous at the selected temperature conditions. The above microemulsions require 2-Ethyl-1-Hexanol as surfactant ranging from 8 to 20 percent while the diesel replacement between 18 to 60 percent is possible with such microemulsions.

(iii) The microemulsions using 188° proof ethanol and designated as 188° [10:10:80]; 188° [10:12:78]; 188° [10:15:70]; 188° [20:18:62]; 188° [20:20:60]; 188° [20:22:58]; 188° [20:24:56]; 188° [25:20:55]; 188° [25:23:52] and 188° [40:24:36] were found stable and homogeneous at the selected temperature range. The above microemulsions require 2-Ethyl-1-Hexanol as surfactant ranging from 10 to 24 percent while the diesel replacement between 20 to 64 percent may be possible with such microemulsions.

(iv) The microemulsions using 180° proof ethanol and indicated as 180° [10:20:70]; 180° [10:25:65]; 180° [15:27:58]; 180° [20:20:60]; 180° [20:22:58]; 180° [20:24:56]; 180° [25:23:52]; 180° [25:25:50]; 180° [25:27:48]; 180° [40:25:35] and 180° [40:28:32] were found stable and homogenous at the selected temperature range. These microemulsions require 2-Ethyl-1-Hexanol as surfactant ranging from 20 to 28 percent while the diesel replacement between 30 to 68 percent may be possible.

(II) The relative density of ethanol-2-Ethyl-1-Hexanol diesel microemulsions was found to increase with decrease in ethanol proof, decreases with increased percentage of ethanol and also decreases with the increased percentage of 2-Ethyl-1-Hexanol.

(i) The relative density of diesel was found to be 0.8432 and 200°, 194°, 188°, 180° proofs ethanol and 2-Ethyl-1-Hexanol were observed as 0.7702, 0.7923, 0.7926, 0.8045 and 0.8055, respectively.

(ii) The relative density of 200° [10:06:84]; 200° [10:08:82]; 200° [10:10:80]; 200° [40:18:42]; 194° [10:08:82]; 194° [10:10:80]; 194° [40:18:42]; 188° [10:10:80]; 188° [10:12:78]; 188° [40:24:36]; 180° [10:20:70]; 180° [10:25:65] and 180° [40:25:35] microemulsions was found to be 0.8300, 0.8275, 0.8236, 0.8055, 0.8319, 0.8280, 0.8138, 0.8345, 0.8310, 0.8155, 0.8355, 0.8335 and 0.829, respectively.

(III) The kinematic viscosity of ethanol-2-Ethyl-1-Hexanol-diesel microemulsions was found to decrease with an increase in level of ethanol in the microemulsion. The kinematic viscosity was found to increase with decrease in ethanol proof.

(i) The kinematic viscosity of diesel, 2-Ethyl-1-Hexanol and that of 200^o, 198^o, 196^o, 194^o, 190^o, 188^o, 184^o and 180^o proof ethanol was found to be 32.7, 27.8, 27.9, 28.0, 28.15, 28.23, 28.5, 28.95, 29.33 and 29.67 Red wood seconds, respectively.

(ii) The kinematic viscosity of 200^o [10:06:84]; 200^o [10:08:82]; 200^o [10:10:80]; 200^o [25:10:65]; 200^o [40:18:42]; 194^o [10:08:82]; 194^o [10:10:80]; 194^o [24:14:61]; 194^o [40:18:42]; 188^o [10:10:80]; 188^o [10:12:78]; 188^o [25:20:65]; 188^o [40:24:36]; 180^o [10:20:70]; 180^o [10:25:65]; 180^o [25:23:52] and 180^o [40:25:35] ethanol-2-Ethyl-1-Hexanol-diesel microemulsions was found to be 30.7, 30.5, 30.44, 29.05, 28.4, 30.06, 30.01, 29.75, 28.6, 30.6, 30.4, 28.95, 28.0, 29.88, 29.53 and 29.36 Redwood seconds.

(IV) The gross heat of combustion of different proofs of ethanol and microemulsions of ethanol-2-Ethyl-1-Hexanol diesel was found to decrease with decrease in proof level of ethanol. The gross heat of combustion of different microemulsions was observed to decrease with increase in the level of ethanol as well as surfactant 2-Ethyl-1-Hexanol in the microemulsions.

- (i) The gross heat of combustion of diesel was found to be 52.56 MJ/kg and that of 200^o, 194^o, 188^o, 180^o and 2-Ethyl-1-Hexanol it was found to be 29.767, 28.883, 27.690, 26.399 and 45.482 MJ/kg, respectively.
- (ii) The gross heat of combustion of 200^o [10:06:84]; 200^o [10:08:82]; 200^o [10:10:80]; 200^o [25:10:65]; 200^o [40:18:42]; 194^o [10:08:82]; 194^o [10:10:80]; 194^o [24:14:61]; 194^o [40:18:42]; 188^o [10:10:80]; 188^o [10:12:78]; 188^o [25:20:55]; 188^o [40:24:36]; 180^o [10:20:70]; 180^o [10:25:65]; 180^o [25:23:52]; 180^o [40:25:35] microemulsions (ethanol-2-Ethyl-1-Hexanol-diesel) was found to be 50.51; 49.86; 48.85; 46.82; 45.99; 49.718; 47.919; 47.526; 45.32; 49.570; 47.361; 40.997; 36.380; 40.416; 39.790; 38.796 and 34.478, respectively.
- (iii) The gross heat of combustion of ethanol-2-Ethyl-1-Hexanol-diesel microemulsions was found to be 3.9 to 34.4 % lower than that of diesel.
- (V) The flash and fire points of different proofs of ethanol and microemulsions were found to increase with decrease in the proof level of ethanol.
- (i) The flash and fire point of diesel were found to be 95.25^oC and 104.3^oC, respectively.
- (ii) The flash point of 200^o, 194^o, 188^o, 180^o proof Ethanol and 2-Ethyl-1-Hexanol was found to be 14.5^oC, 16.8^oC, 18.6^oC, 19.5^oC and 81.5^oC,

respectively whereas the fire point of 200^o, 194^o, 188^o, 180^o proof ethanol and 2-Ethyl-1-Hexanol was found to be 17.5^oC, 20.3^oC, 22.7^oC, 24.7^oC and 89.0^oC, respectively.

(iii) The flash points of 200^o [10:06:84]; 200^o [10:08:80]; 200^o [25:10:65]; 200^o [40:18:42]; 194^o [10:08:82]; 194^o [10:10:80]; 194^o [24:14:61]; 194^o [40:18:42]; 188^o [10:10:80]; 188^o [10:12:78]; 188^o [25:20:65]; 188^o [40:24:36]; 180^o [10:20:70]; 180^o [10:25:65]; 180^o [25:23:52] and 180^o [40:25:35] ethanol-2-Ethyl-1-Hexanol diesel microemulsions were found to be as 21^o, 22^o, 21^o, 19.7^o, 24^o, 25^o, 21.5^o, 20.5^o, 28.1^o, 29.2^o, 25.8^o, 21.9^o, 29.0^o, 31^o, 26.0^o and 22^oC, respectively. The fire points of above microemulsions were found to be as 26.5^o, 27^o, 26^o, 24.6^o, 31^o, 34^o, 27.5^o, 26.5^o, 31.4^o, 32.6^o, 29.1^o, 24.0^o, 31^o, 34.5^o, 28.5^o and 28.0^oC respectively.

(VI) The cloud and pour point of ethanol- 2-Ethyl-1-Hexanol diesel microemulsions were found to decrease with an increase in the proof level of ethanol and found to increase with reduced level of aqueous ethanol in the microemulsion.

(i) The cloud and pour points of diesel were found to be 0.5 and 9.0^oC.
(ii) The cloud and pour points of all microemulsions were found to be below 0^oC and below -10^oC, respectively.

(VII) The brake power of the engine was found to increase with an increase in brake load while testing with all microemulsified fuels.

- (i) The engine was found to develop its rated power of 3.72 KW on diesel at the engine speed, 1500 rpm at full load.
- (ii) The brake power developed by the engine at full load on 200° [10:06:84]; 200° [40:18:42]; 194° [10:08:82]; 194° [40:18:42]; 188° [10:10:80]; 188° [40:24:36]; 180° [10:20:70] and 180° [40:25:35] ethanol-2-Ethyl-1-Hexanol microemulsion fuels was found to be 3.75, 3.72, 3.72, 3.73, 3.74, 3.74 and 3.75 KW, respectively.
- (iii) The microemulsions of ethanol-2-Ethyl-1-Hexanol diesel were found to have the similar power producing capabilities as diesel under each load conditions.

(VIII) The fuel consumption of the engine on all microemulsified fuels tested, showed an increase with an increase in the brake load and was found to be maximum at 110% brake load.

- (i) The fuel consumption of the engine on diesel at rated load was observed to be 1.231 l/hr.
- (ii) The fuel consumptions of the engine at full load on 200° [10:06:84]; 200° [40:18:42]; 194° [10:08:82]; 194° [40:18:42]; 188° [10:10:80]; 188° [40:24:36]; 180° [10:20:70] and 180° [40:25:35] were observed as 1.408, 1.433, 1.340, 1.430, 1.496, 1.497, 1.343 and 1.380 l/hr, respectively.

- (iii) The fuel consumption of the engine was found to be slightly higher at all brake loads in case of microemulsions selected for experimental investigations compared to diesel.
- (IX) The brake specific fuel consumption (BSFC) of the engine was observed to decrease with an increase in the brake load and was found to be maximum at 20 % brake load conditions on all microemulsions.
- (i) The brake fuel consumption of the engine at rated load condition, engine developing its rated power was 624.91, 638.17, 607.06, 679.82, 573.19, 743.57, 599.29, 1022.32 and 623.40 (gm/KW-hr) on diesel, 200° [10:06:84]; 200° [40:18:42]; 194° [10:08:82]; 194° [40:18:42]; 188° [10:10:80]; 188° [40:24:36]; 180° [10:20:70] and 180° [40:25:35] proofs microemulsions, respectively.
- (ii) At rated load condition, the BSFC of the engine on 188° [10:10:80] microemulsified fuel was observed 1.4 percent higher than that on diesel fuel.
- (X) The brake thermal efficiency of the engine on all microemulsified fuels was found to increase with an increase in the brake load and was observed to be maximum at 100 percent brake load.
- (i) The brake thermal efficiency of the engine on diesel was found as 24.05 % at full brake load.

- (ii) The brake thermal efficiencies of the engine on 200° [10:06:84]; 200° [40:18:42]; 194° [10:08:82]; 194° [40:18:42]; 188° [10:10:80]; 188° [40:24:36]; 180° [10:20:70] and 180° [40:25:35] microemulsions were observed as 22.42, 24.76, 23.68, 25.10, 21.77, 30.32, 29.70 and 34.24 percentage, respectively.
- (iii) The maximum brake thermal efficiency was observed 34.24% on 180° [40:25:35] microemulsion at rated load condition.
- (iv) The brake thermal efficiency was observed to decrease at overload conditions in diesel and all microemulsions.
- (XI) The emission of unburnt hydrocarbons (UBHC) from the engine at rated load condition was found to be lower on all the microemulsions compared to diesel.
- (i) The UBHC emission on diesel was observed to vary from 0.025 to 0.07 ppm percent between no load to 110 percent load, conditions.
- (ii) The UBHC emission on microemulsified fuels was observed to vary from 0.015 to 0.09 ppm and was observed maximum 0.09 ppm on 200° [40:18:42] fuel at no load condition.
- (XII) The emission of nitric oxide (NO) was found to increase with an increase in brake load on all microemulsified fuels tested.
- (i) The NO emission was observed to vary from 28 to 140 ppm on diesel.

(ii) The emission of NO on 200° [10:06:84]; 200° [40:18:42]; 194° [10:08:82]; 194° [40:18:42]; 188° [10:10:80]; 188° [40:24:36]; 180° [10:20:70] and 180° [40:25:35] microemulsions was found to vary from 13 to 82, 18 to 85, 24 to 63, 24 to 72, 6 to 43, 2 to 42, 10 to 42 and 32 to 83 ppm, respectively.

(iii) The range of emission of NO range on all microemulsions was observed lower compared to diesel. All microemulsions showed lower NO emission than diesel at rated load condition.

(XIII) The emission of nitrogen dioxide (NO₂) was observed to increase with an increase in brake load under all microemulsified fuels tested.

(i) The emission of nitrogen dioxide (NO₂) on diesel was found 144.6 ppm at rated load condition and varying between 30.2 ppm to 144.6 ppm between no load to 110 percent brake load, conditions.

(ii) The emission of nitrogen dioxide (NO₂) on 200° [10:06:84]; 200° [40:18:42]; 194° [10:08:82]; 194° [40:18:42]; 188° [10:10:80]; 188° [40:24:36]; 180° [10:20:70] and 180° [40:25:35] microemulsions was found to vary from 14.2 to 84.0; 19.4 to 86.9; 25.0 to 65.0; 25.0 to 72.1; 7.1 to 45.2; 3.9 to 46.0; 11.4 to 44.1 and 33.2 to 85.9 ppm, respectively.

(iii) All microemulsions showed much lower nitrogen dioxide emission (NO₂) as compared to diesel at all brake load conditions.

(XIV) The $(NO)_x$ emission from the engine was observed lower on all microemulsions than diesel under no load to 110 percent brake load conditions.

(XV) The fuel energy input to the engine was found to increase with increase in brake load. It was also observed lowest at no brake load condition and highest at 110 percent brake load on all microemulsified fuels tested.

(XVI) The exhaust gas temperature of the engine on all microemulsions, was higher compared to diesel. The exhaust gas temperature of the engine was observed to increase with an increase in brake load on all fuels.

(i) The temperature of exhaust gas on diesel was found to vary from 177°C to 532.8°C between no load and 110 percent over load.

(ii) The exhaust gas temperature on 200° [10:06:84]; 200° [40:18:42]; 194° [10:08:82]; 194° [40:18:42]; 188° [10:10:80]; 188° [40:24:36]; 180° [10:20:70] and 180° [40:25:35] microemulsions was observed to range from 240°C to 547°C ; 212°C to 577°C ; 244 to 592.8°C ; 260°C to 595°C ; 227°C to 570°C ; 315°C to 592°C ; 246°C to 567.6°C and 347°C to 660°C , respectively.

(XVII) The carbon monoxide emission CO from the exhaust of the engine was observed high on the microemulsions having lower % of ethanol and

observed low CO emission on the microemulsions having high percent of ethanol at full brake load condition. The carbon monoxide emission was found higher on all microemulsions having ten percent ethanol ranging from (200^o to 180^o) proofs where as it was found lower on all mixtures having forty percent ethanol ranging from 200^o to 180^o proofs compared to diesel at full load conditions.

(XVIII) The trend of the lubricating oil temperature on microemulsified fuels was observed almost similar to that on diesel. However, slightly increased engine oil temperature was observed on microemulsified fuels as compared to diesel.

- a. The range of temperature of engine oil on diesel was found to vary from 58^o to 66.3^oC.
- b. The range of engine oil temperature on 200^o [10:06:84]; 200^o [40:18:42]; 194^o [10:08:82]; 194^o [40:18:42]; 188^o [10:10:80]; 188^o [40:24:36]; 180^o [10:20:70] and 180^o [40:25:35] was observed to vary from 50 to 71.1^oC; 55 to 72.0^oC; 53.0 to 70.0^oC; 58 to 70.0^oC; 48 to 64.6^oC; 63.0 to 89.3^oC; 62 to 68.2^oC and 46 to 67^oC, respectively.

On the basis of above findings, it can be concluded that anhydrous 2-Ethyl-1-Hexanol may be used as emulsifier to prepare stable and homogeneous microemulsions of anhydrous (200^o proof) and aqueous ethanol (194^o, 188^o and 180^o proof) with diesel under wide ambient

temperature range of 0° to 45°C. However, the requirement of 2-Ethyl-1-Hexanol surfactants was found to be high with 188° and 180° proofs ethanol. Eight stable microemulsions used for experimental investigations were found to have their fuel properties compatible with diesel.

The performance evaluation of a 3.73 KW constant speed C.I. engine indicated that power producing capabilities of the selected microemulsions were found similar to that of diesel.

On the basis of observed fuel properties and engine performance tests on different microemulsified fuels, it may be recommended that the microemulsions 200° [40:18:42] and 194° [40:18:42] are capable of replacing around 58% diesel in C.I. engine as fuel.

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Appendix A- 1: Engine performance test results of a 3.73 KW Kirloskar AVI engine on diesel microemulsions

**Ambient Temperature : 34°C
Injection Timing : 27°C BTDC (Standard)**

Brake load (%)	Engine Torque (%)	Engine Speed (rpm)	Brake Power		Fuel Consumption		Break Specific Fuel Consumption		Brake Thermal Efficiency (%)	Energy Input (MJ/h)	Exhaust Emissions					Exhaust gas Temperature (C°)	Lubricating oil Temperature (C°)
			(KW)	(hp)	Time taken to consume 25ml fuel sample (sec.)	(l/h)	(kg/KW-h)	(g/bhp-h)			NO (ppm)	NO ₂ (ppm)	NOx (ppm)	UBHC (%)	CO (%)		
-		1597	0	0	210.5	0.428	00	00	0	19.40	28	2.2	30.2	0.030	-		
20	4.75	1562	0.78	1.046	159.6	0.564	0.62491	464.99	10.95	25.56	65	2.3	67.3	0.025	-	177	58
40	9.50	1541	1.53	2.052	127.5	0.706	0.39700	296.01	17.24	32.00	79	2.4	81.4	0.03	-	22.5	59.3
60	14.25	1530	2.28	3.057	106.4	0.846	0.33182	247.81	20.62	38.34	106	2.5	108.5	0.07	-	304	60.0
80	19.00	1502	2.99	4.010	88.2	1.020	0.29386	218.97	23.286	42.23	124	3.8	127.8	0.06	-	334	62
100	23.74	1498	3.72	4.989	73.1	1.231	0.28449	212.36	24.05	52.79	140	4.6	144.6	0.07	0.054	399	63
110	26.12	1467	4.01	5.377	53.0	1.698	0.36412	271.75	18.79	76.96	124	4.3	128.3	0.07	-	495	64.5

Appendix A- 2: Engine performance test results of a 3.73 KW Kirloskar AVI engine on 200° [10:06:84] diesel-ethanol microemulsions

**Ambient Temperature : 34°C
Injection Timing : 27°C BTDC (Standard)**

Brake load (%)	Engine Torque (%)	Engine Speed (rpm)	Brake Power		Fuel Consumption		Break Specific Fuel Consumption		Brake Thermal Efficiency (%)	Energy Input (MJ/h)	Exhaust Emissions					Exhaust gas Temperature (C°)	Lubricating oil Temperature (C°)
			(KW)	(hp)	Time taken to consume 25ml fuel sample (sec.)	(l/h)	(kg/KW-h)	(g/bhp-h)			NO (ppm)	NO ₂ (ppm)	NOx (ppm)	UBHC (%)	CO (%)		
-		1614	0	0	210.5	0.428	00	00	0	18.82	13	1.2	14.2	0.057	-		
20	4.75	1606	0.777	1.072	159.6	0.564	0.62491	475.652	10.95	25.62	14	1.3	15.3	0.017	-	214	50
40	9.50	1575	1.53	2.101	127.5	0.706	0.39700	294.742	17.24	31.27	21	1.4	22.4	0.033	-	232.3	63
60	14.25	1551	2.283	3.103	106.4	0.846	0.33182	281.239	20.622	40.56	31	1.5	32.5	0.037	-	298	66.1
80	19.00	1541	2.988	4.112	88.2	1.020	0.29386	263.330	23.286	54.68	45	1.7	46.7	0.023	-	345	66
100	23.74	1508	3.724	5.027	73.1	1.231	0.28449	237.310	24.05	60.24	56	1.9	57.9	0.057	0.061	355.6	67
110	26.12	1490	4.013	5.466	53.0	1.698	0.36412	235.976	18.79	65.14	82	2.0	84.0	0.037	-	452	70

Appendix A- 3: Engine performance test results of a 3.73 KW Kirloskar AVI engine on 200° [40:18:42] diesel-ethanol Microemulsions

**Ambient Temperature : 34°C
Injection Timing : 27°C BTDC (Standard)**

Brake load (%)	Engine Torque (%)	Engine Speed (rpm)	Brake Power		Fuel Consumption		Break Specific Fuel Consumption		Brake Thermal Efficiency (%)	Energy Input (MJ/h)	Exhaust Emissions					Exhaust gas Temperature (C°)	Lubricating oil Temperature (C°)
			(KW)	(hp)	Time taken to consume 25ml fuel sample (sec.)	(l/h)	(kg/KW-h)	(g/bhp-h)			NO (ppm)	NO ₂ (ppm)	NOx (ppm)	UBHC (%)	CO (%)		
-		1559	-	0	215.03	0.419	00	00	0	15.85	18	1.4	19.4	0.09	-	212	55
20	4.75	1549	0.77	1.034	162.87	0.553	452.652	0.60706	12.90	20.92	35	1.5	36.5	0.085	-	245.7	64
40	9.50	1516	1.51	2.022	128.87	0.698	283.910	0.38068	20.57	26.40	40	1.8	41.5	0.07	-	302	66
60	14.25	1487	2.22	2.976	99.87	0.901	248.912	0.33383	23.46	34.08	52	1.9	53.9	0.04	-	357.5	67
80	19.00	1485	2.96	3.963	76.5	1.176	244.022	0.32726	23.95	44.49	66	2.1	68.1	0.06	-	428	69
100	23.74	1498	3.72	4.994	62.8	1.433	235.888	0.31633	24.76	54.21	72	2.2	74.2	0.06	0.040	502	71.3
110	26.12	1440	3.94	5.378	58.15	1.548	254.765	0.34163	22.93	58.56	85	1.9	86.9	0.03	-	577	72.0

Appendix A- 4: Engine performance test results of a 3.73 KW Kirloskar AVI engine on 194° [10:08:82] diesel-ethanol microemulsions

**Ambient Temperature : 34°C
Injection Timing : 27°C BTDC (Standard)**

Brake load (%)	Engine Torque (%)	Engine Speed (rpm)	Brake Power		Fuel Consumption		Break Specific Fuel Consumption		Brake Thermal Efficiency (%)	Energy Input (MJ/h)	Exhaust Emissions					Exhaust gas Temperature (C°)	Lubricating oil Temperature (C°)
			(KW)	(hp)	Time taken to consume 25ml fuel sample (sec.)	(l/h)	(kg/KW-h)	(g/bhp-h)			NO (ppm)	NO ₂ (ppm)	NOx (ppm)	UBHC (%)	CO (%)		
-	-	1591	0	0	190.0	0.474	00	00	0	20.06	24	1.0	25.0	0.08	-	244	53
20	4.74	1573	0.78	1.049	143.73	0.626	0.67982	506.789	10.64	24.90	31	1.1	32.1	0.07	-	273	59
40	9.50	1545	1.54	2.061	116.33	0.774	0.42735	318.699	16.93	32.76	39	1.2	40.2	0.06	-	321.7	61.2
60	14.25	1526	2.28	3.053	92.87	0.969	0.36134	269.493	20.02	41.02	42	1.3	43.3	0.024	-	387	64
80	19.00	1509	3.00	4.026	75.16	1.209	0.33861	252.483	21.36	50.67	51	1.5	52.5	0.023	-	448	65.3
100	23.74	1498	3.72	4.993	67.16	1.430	0.30547	227.832	23.68	56.72	55	1.8	56.8	0.024	0.611	567	68
110	26.12	1493	4.08	5.476	60.5	1.615	0.30940	230.753	23.38	62.99	63	2.0	65.0	0.028	-	592.8	70

Appendix A-5: Engine performance test results of a 3.73 KW Kirloskar AVI engine on diesel/194° [40:18:42] diesel-ethanol microemulsions

**Ambient Temperature : 34°C
Injection Timing : 27°C BTDC (Standard)**

Brake load (%)	Engine Torque (%)	Engine Speed (rpm)	Brake Power		Fuel Consumption		Break Specific Fuel Consumption		Brake Thermal Efficiency (%)	Energy Input (MJ/h)	Exhaust Emissions					Exhaust gas Temperature (C°)	Lubricating oil Temperature (C°)
			(KW)	(hp)	Time taken to consume 25ml fuel sample (sec.)	(l/h)	(kg/KW-h)	(g/bhp-h)			NO (ppm)	NO ₂ (ppm)	NOx (ppm)	UBHC (%)	CO (%)		
-	-	1588	0	0	236.7	0.380	00	00	0	14.24	24	1.0	25	0.07	-	260	58
20	4.75	1563	0.78	1.041	166.93	0.539	0.57319	427.279	13.85	20.20	33	1.0	34	0.06	-	290.4	65
40	9.50	1554	1.55	2.073	129.50	0.695	0.37087	276.584	21.20	26.04	40	1.2	41.2	0.06	-	342	66
60	14.25	1517	2.26	3.036	97.03	0.928	0.33800	252.051	23.48	34.77	45	1.3	46.3	0.026	-	408.6	66
80	19.00	1494	2.97	3.987	74.47	1.209	0.33537	250.327	23.66	45.30	50	1.4	51.4	0.026	-	498	67
100	23.74	1500	3.73	5.003	62.93	1.430	0.31824	235.835	25.10	53.58	61	1.7	62.7	0.024	0.0303	573	68.6
110	26.12	1486	4.07	5.451	55.73	1.615	0.32775	244.417	24.21	60.52	72	1.07	72.1	0.026	-	595	70

Appendix A-6: Engine performance test results of a 3.73 KW Kirloskar AVI engine on diesel/188° [10:10:80] diesel-ethanol microemulsions

**Ambient Temperature : 34°C
Injection Timing : 27°C BTDC (Standard)**

Brake load (%)	Engine Torque (%)	Engine Speed (rpm)	Brake Power		Fuel Consumption		Break Specific Fuel Consumption		Brake Thermal Efficiency (%)	Energy Input (MJ/h)	Exhaust Emissions					Exhaust gas Temperature (C°)	Lubricating oil Temperature (C°)
			(KW)	(hp)	Time taken to consume 25ml fuel sample (sec.)	(l/h)	(kg/KW-h)	(g/bhp-h)			NO (ppm)	NO ₂ (ppm)	NOX (ppm)	UBHC (%)	CO (%)		
-	-	1626	0	0	168.5	0.534	00	00	0	22.14	6	1.1	7.1	0.06	-	227	48
20	4.75	1578	0.79	1.063	128.67	0.699	0.74357	554.323	13.12	28.98	10	1.2	11.2	0.06	-	240	51
40	9.50	1564	1.56	2.087	109.57	0.821	0.44052	328.439	16.47	34.04	12	1.4	13.4	0.05	-	302.8	53
60	14.25	1527	2.28	3.056	89.20	1.009	0.36945	275.518	19.64	41.83	25	1.6	26.6	0.021	-	399.2	55
80	19.00	1525	3.03	4.069	73.27	1.225	0.36693	251.230	21.53	50.79	36	2.0	38.0	0.022	-	468	58
100	23.74	1507	3.75	5.023	60.20	1.496	0.33321	248.499	21.77	62.02	38	2.6	40.6	0.026	0.061	513.6	61
110	26.12	1448	3.96	5.312	56.47	1.594	0.33577	250.376	21.61	66.08	43	2.2	45.2	0.018	-	570	64.6

Appendix A-7: Engine performance test results of a 3.73 KW Kirloskar AVI engine on 188° [40:24:36] diesel-ethanol microemulsions

**Ambient Temperature : 34°C
Injection Timing : 27°C BTDC (Standard)**

Brake load (%)	Engine Torque (%)	Engine Speed (rpm)	Brake Power		Fuel Consumption		Break Specific Fuel Consumption		Brake Thermal Efficiency (%)	Energy Input (MJ/h)	Exhaust Emissions					Exhaust gas Temperature (C°)	Lubricating oil Temperature (C°)
			(KW)	(hp)	Time taken to consume 25ml fuel sample (sec.)	(l/h)	(kg/KW-h)	(g/bhp-h)			NO (ppm)	NO ₂ (ppm)	NOx (ppm)	UBHC (%)	CO (%)		
-	-	1582	0	0	217.4	0.414	00	00	0	16	2	1.9	3.9	0.06	-	315	63
20	4.75	1535	0.76	1.025	160.33	0.561	0.59929	446.693	16.50	16.68	9	2.5	11.5	0.05	-	340.8	64
40	9.50	1539	1.53	2.053	124.43	0.723	0.38536	286.635	25.65	21.50	11	2.9	13.9	0.04	-	397	64
60	14.25	1499	2.24	3.000	96.93	0.929	0.33859	252.477	29.20	27.62	20	3.1	23.1	0.029	-	467	65
80	19.00	1485	2.96	3.963	71.43	1.261	0.34787	259.385	28.42	37.49	25	3.6	28.6	0.032	-	518	66
100	23.74	1506	3.74	5.021	60.13	1.497	0.32602	243.100	30.32	44.51	28	3.7	31.6	0.024	0.0611	540.4	67
110	26.12	1494	4.09	5.481	55.58	1.617	0.32258	240.538	30.65	48.08	42	4.0	46.0	0.019	-	592	69.3

Appendix A-8: Engine performance test results of a 3.73 KW Kirloskar AVI engine on 180° [10:20:70] diesel-ethanol microemulsions

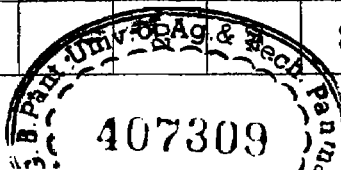
**Ambient Temperature : 34°C
Injection Timing : 27°C BTDC (Standard)**

Brake load (%)	Engine Torque (%)	Engine Speed (rpm)	Brake Power		Fuel Consumption		Break Specific Fuel Consumption		Brake Thermal Efficiency (%)	Energy Input (MJ/h)	Exhaust Emissions					Exhaust gas Temperature (C°)	Lubricating oil Temperature (C°)
			(KW)	(hp)	Time taken to consume 25ml fuel sample (sec.)	(l/h)	(kg/KW-h)	(g/bhp-h)			NO (ppm)	NO ₂ (ppm)	NOx (ppm)	UBHC (%)	CO (%)		
-	-	1584	0	0	111.53	0.807	00	00	0	27.31	10	1.4	11.6	0.05	-	246	62
20	4.75	1551	0.71	1.034	95.37	0.943	1.02232	762.289	8.704	31.91	15	1.4	16.4	0.05	-	270	63
40	9.50	1545	1.54	2.061	94.4	0.953	0.51826	386.491	17.17	32.25	18	1.5	19.5	0.04	-	292.4	64
60	14.25	1535	2.29	3.072	91.77	0.981	0.35765	266.727	24.88	33.20	30	1.6	31.6	0.03	-	3.48	65
80	19.00	1515	3.01	4.041	77.17	1.166	0.32329	241.130	27.52	39.46	33	1.9	34.9	0.024	-	417	66.3
100	23.74	15.6	3.74	5.021	67.03	1.343	0.29963	223.424	29.70	45.44	35	2.0	37.0	0.024	0.0686	498	67.6
110	26.12	1494	4.09	5.481	58.83	1.530	0.31274	233.201	28.45	51.77	42	2.1	44.1	0.029	-	567.8	68.2

Appendix A-9: Engine performance test results of a 3.73 KW Kirloskar AVI engine on diesel 180° [40:25:35] diesel-ethanol microemulsions

**Ambient Temperature : 34°C
Injection Timing : 27°C BTDC (Standard)**

Brake load (%)	Engine Torque (%)	Engine Speed (rpm)	Brake Power		Fuel Consumption		Break Specific Fuel Consumption		Brake Thermal Efficiency (%)	Energy Input (MJ/h)	Exhaust Emissions				Exhaust gas Temperature (C°)	Lubricating oil Temperature (C°)	
			(KW)	(hp)	Time taken to consume 25ml fuel sample (sec.)	(l/h)	(kg/KW-h)	(g/bhp-h)			NO (ppm)	NO ₂ (ppm)	NOx (ppm)	UBHC (%)			CO (%)
-	-	1570	0	0	195.63	0.460	00	00	0	13.18	32	1.2	33.2	0.04	-	347	46
4.75	4.75	1522	0.76	1.015	158.1	0.569	0.62340	464.943	16.73	16.30	38	1.3	39.3	0.04	-	377.4	54
9.50	9.50	1518	1.51	2.025	125.23	0.719	0.39456	294.214	26.44	20.59	40	1.4	41.4	0.03	-	428	55
14.25	14.25	1508	2.25	3.017	95.60	0.941	0.34686	258.681	30.07	26.95	48	1.6	49.6	0.026	-	501	58
19.00	19.00	1509	3.00	4.026	75.80	1.187	0.32788	244.486	31.81	34.00	60	2.1	62.1	0.024	-	572	61.3
23.74	23.74	1510	3.75	5.034	65.23	1.380	0.30469	227.215	34.24	39.52	66	2.3	68.3	0.023	0.0203	617.8	63
26.12	26.12	1450	3.97	5.318	59.87	1.499	0.31338	233.711	33.29	42.93	83	2.9	85.9	0.017	-	660	67



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ABSTRACT

The major fuels for I.C. engines are diesel and petrol derived from petroleum. The depleting oil supply and continuous hike in global price of petroleum products reminds us to turn to alternate sources of energy. Two alternate courses are available to solve the problem. Firstly, one can search for an alternative fuel and alternative design of engines which can fully replace the petroleum fuel. Secondly, one can search for the fuel which can partially or fully replace the petroleum fuels in the existing engines. The former choice involves modifications in fuel supply system, carburetion or fuel injection system and it also adds to the cost of the engine. The second objective, if achieved, will prolong the use of petroleum and will give opportunity for the present engine to be used to their full life. The fuels such as alcohol, edible or non-edible oils are thought to be the good alternatives.

Assuming the second objective as the viable solution of the problem, stable microemulsions were prepared and % constituents of ethanol, diesel and surfactants, by volume, containing anhydrous or aqueous ethanol and diesel using 2-Ethyl-1-Hexanol as an emulsifier were identified. The phase separation and homogeneity tests of microemulsions were conducted for a minimum of hundred days from the day of their preparations, both at the room temperature and as well as at 0°C, 1°C, 2°C, 3°C, 4°C, 5°C, 10°C, 15°C, 20°C, 25°C, 30°C, 35°C, 40°C and 45°C temperatures in a Saveer Biotech make walk-in-temperature control chamber.

The characteristics fuel properties such as relative density, API gravity, kinematic viscosity, gross heat of combustion, flash point, fire point, cloud and pour point were systematically recorded in accordance with the provisions of Bureau of Indian Standards, New Delhi (Methods of test for petroleum and its products). A total of 473 samples using eight proofs of Ethanol, 3 different types of emulsifiers and the diesel were prepared. Out of these forty three samples using 200^o, 194^o, 188^o and 180^o proof ethanol with 2-Ethyl-1-Hexanol as the surfactant and the diesel were, found stable, homogenous and without a phase separation over a broad temperature range. During the preparation of the samples, replacement of diesel was achieved between 16% to 65%, that of ethanol between 10% to 40% and of emulsifier between 6% to 25%, by volume. It was noted that the requirement of emulsifier for the preparation of stable microemulsions depends significantly upon the ethanol proof as well as % replacement of diesel.

From these 43 microemulsions, eight mixtures of different proofs of ethanol with varying diesel replacement and % of emulsifiers were finally selected for experimental investigations on a C.I. engine. The replacement of diesel was varied from a minimum of 16% to a maximum of 65% whereas the quantity of emulsifier used was the minimum. A stationary 3.73 KW constant speed, compression ignition engine (Kirloskar make) was used for testing purposes and its performance, in respect of brake power; fuel consumption; brake specific fuel consumption; thermal efficiency and emission of CO; UBHC; NO_x; exhaust gas temperature and lubricating oil temperature was recorded to be evaluated. In all experimental investigations on C.I. engine similar power producing capability was recorded with the selected microemulsions as with diesel under all

load conditions. Further, the fuel consumption of the engine slightly increases with the microemulsified fuels tested, compared to diesel, while increasing the brake load.

The brake specific fuel consumption (BSFC) of the engine was observed to decrease with an increase in the brake load and was noted to be the maximum at 20% brake load conditions for all the microemulsions selected as also recorded for diesel. The brake thermal efficiency of the engine on all microemulsified fuels and diesel was found to increase with an increase in the brake load and was observed to be maximum at 100% brake load. It decreases under the overload conditions. The emission of unburnt hydrocarbons (UBHC) from the engine was lower at rated load conditions in case of microemulsions compared to the diesel. The range of emission of NO on all microemulsions, in general, was observed to be lower compared to diesel at rated load conditions, as at other conditions. The emission of nitrogen-dioxide (NO₂) was observed to increase with an increase in the brake load for all microemulsified fuels tested. All microemulsions showed much lower nitrogen dioxide emission (NO₂) compared to diesel at all brake load conditions. The carbon monoxide emission from the engine exhaust was found to be higher with the microemulsions having lower % of ethanol and lower with higher % at full brake load conditions. The carbon monoxide emission was higher with microemulsions having 10% ethanol of 200^o to 180^o proofs. It was found to be lower with microemulsions having 40% ethanol of 200^o to 180^o proofs as compared to diesel, at full load conditions. The exhaust gas temperature of the engine with all the microemulsions was recorded higher compared to diesel and it increases with an increase in the brake load for all types of fuels.

Experimental investigations further showed slightly increase in the engine oil temperature for microemulsified fuels compared to diesel. The analysis of these experimental observations revealed that the brake power developed by the engine on 200^o [40:18:42] and 194^o [40:18:42] microemulsified fuels was almost the same as with diesel. The fuel consumption of microemulsions 200^o [40:18:42] and 194^o [40:18:42] was also same amongst themselves but it was slightly higher than the diesel. Similarly, the brake specific fuel consumption of the above two microemulsions was found almost the same but slightly higher than the diesel at the rated speed. The brake thermal efficiency of diesel oil, 200^o [40:18:42] and 194^o [40:18:42] microemulsions was found as 24.05%, 24.76% and 25.10%, respectively, at rated load conditions. The emission of CO was lower on all mixtures having 40% ethanol of 200^o to 180^o proofs compare to diesel at the full load conditions.

The detailed experimental investigations confirmed that the two combination of microemulsions, viz., 200^o [40:18:42] and 194^o [40:18:42] out of the eight selected for testing, are the most suitable giving the satisfactory engine performance, as obtained with diesel.