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PERFORMANCE AND ANALYSIS OF SINGLE CYLINDER DIESEL ENGINE USING WATER IN DIESEL EMULSIFIED FUEL WITH REDUCTION OF NO_x

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ABSTRACT

The emission of pollutants especially particulate matter and nitrogen oxides, generated by the operation of a diesel engine, poses a threat to the ecology of our planet and is detrimental to human health. The application of an emulsification technique to prepare the fuel has been considered to be one of the possible approaches to as well as the rate of fuel consumption. Water-in-diesel oil emulsified formulations are reported to reduce the emission of nitrogen oxides (NO_x), sulfur oxides (SO_x), carbon monoxides (CO), black smoke and particulate matter (PM) without compensating the engine's performance. This paper presents an experimental result carried out to evaluate performance and exhaust gas emissions of a small diesel engine when operated on neat diesel oil and its emulsions with water. Emulsified diesel fuels of 0, 5, 10, 15 and 20 water/diesel ratios by volume, were used in a single cylinder, direct injection diesel engine, operating at 1500 rpm. A comparative study involving speed, brake specific fuel consumption (BSFC), brake thermal efficiency, exhaust gas temperature, hydrocarbon (HC), nitrogen oxides (NO_x), carbon monoxides (CO), carbon dioxide (CO₂) emissions and black smoke capacity can be used without engine modification.

Keywords--Emulsion; Diesel; NO_x; Engine, Co

INTRODUCTION

At present, the diesel engine is still the most efficient combustion engine. It has high thermal efficiency, a high power/weight ratio, high fuel economy, and a simple and strong structural design. Diesel engines have been the main power source for on-land and on-sea transport vehicles such as buses, trucks, ships and agricultural vehicles. It is expected that diesel engines will continue to be widely used in the foreseeable future. Diesel engine generates undesirable emissions during the combustion process. The pollutants that are exhausted from the Diesel engine affect the atmosphere and contribute largely to problems such as global warming, smog, acid rain, respiratory hazards etc. These emissions are mostly due to non-stoichiometric combustion, dissociation of nitrogen and impurities in the fuel and air. Exhaust gas emissions of Diesel engine have been considered a very serious issue regarding air quality and the environment and strict norms such as Euro 4 or Bharat Stage IV are getting implemented. The main

pollutants produced from the exhaust of Diesel engine are hydrocarbon HC, nitrogen oxides (NO_x), particulate matter, black smoke, carbon monoxide, and carbon dioxide. As a result, efforts are underway to minimize the emissions from diesel engines which are already in operation and include a variety of strategies from fuel reformulations to engine retrofits. Therefore, ways to reduce the emission of pollutants by diesel-powered vehicles are of worldwide importance.

EMISSION FORMATION

Though there is large variation in the percentage distribution of various emissions for petrol and diesel engines, the basic formation principle of emissions like HC, NO and CO remain same for both. Unburned HC emissions originate when fuel escapes combustion due to several processes such as flame quenching in narrow passages present in the combustion chamber and on cold chamber walls, and incomplete oxidation of fuel that is

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Trapped or absorbed in oil film or deposits. NO_x is formed by oxidation of molecular nitrogen. During combustion at high flame temperatures, nitrogen and oxygen molecules in the inducted air break down into atomic species which react to form NO. Some NO₂ is also formed and NO and NO₂ together are called as NO_x. CO results from incomplete oxidation of fuel carbon, when insufficient oxygen is available to completely oxidize the fuel. CO rises steeply as the air-fuel (A/F) ratio is decreased below the stoichiometric A/F ratio.

EXISTING METHOD

3 METHODS OF WATER ADDITION

- Direct water separate injection
- Water injection into the intake air
- Hybrid direct water injection
- Diesel water emulsion

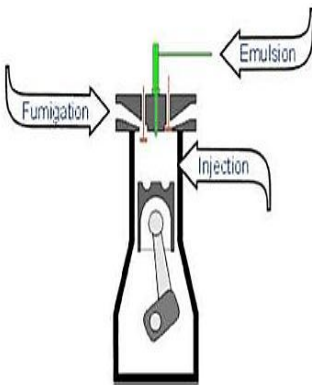


Fig 1 Different Method Water Injection Method

DIRECT WATER SEPARATE INJECTION (DWSI)

In-cylinder injection of water requires a separate, fully independent injection system, preferably under electronic control. This method offers the capability to inject very large quantities of water without the need to de-rate the engine. This system also allows to switch the water injection on and off, as may be needed, without affecting engine reliability. Direct water injection needs to be carefully optimized with respect to injection timing, water consumption, emissions, and other parameters. This flexibility in optimizing parameters allows to achieve NO_x reductions similar to those seen in emulsion systems, despite the fact that water is not introduced directly into the diesel flame area as an integral part of the spray. However, PM emission reductions, if any, do not

Match those with the emulsified fuels. The complex development work required for water injection systems in different engine types makes this approach suited for OEM rather than for retrofit applications.

FUMIGATING WATER INTO THE INTAKE AIR (FWIA)

Fumigation, meaning the introduction of water into the intake air is the simplest method of water addition. This method offers very little control over the injection parameters such as timing or spatial coordinates. For this reason, observed NO_x reduction tends to be lower than those with emulsions or direct injection. Fumigation typically reduces NO_x emissions by 10% for each 20% water addition to the fuel.

If the fumigated water does not completely evaporate in the intake air, it will impinge on the cylinder walls causing disintegration of the lube oil film and engine damage. A safer approach is to fumigate water vapor rather than liquid. Water vapor may be generated using waste heat from the engine, such as from the exhaust gas and/or from the compressed charge air. Another possibility is to use steam, which may be available in stationary engine applications.

HYBRID DIRECT WATER INJECTION (HDWI)

Hybrid injection, using a single injector or a stratified diesel-water-diesel fuel injection by means of a specially modified nozzle



Fig 2 Hybrid Direct Water Injection

DIESEL WATER EMULSIONS (DWE)

Diesel water emulsions have come into recent field of study. When mixed directly, diesel being a lighter liquid than water comes to the top and water settles in the bottom. By using an appropriate surfactant the molecules of water and diesel can be bound together. The stability of the emulsion made is very important, because if it's not stable for an appreciable period of time it won't be practically useful. Using water mixing agent with diesel has many benefits on its own. It has been shown in many previous researches that it reduces the flame temperature thereby reducing the NOx emissions significantly. Addition of water also improves atomization and mixing which is attributed to droplet microemulsion. The improved mixing is due to the increased vaporized jet fuel momentum giving air more way to get into the fuel jet. This also assists in reduction in NOx from diffusive burning portion of combustion event as well as reducing the carbon formation. This effect along with the chemical effect of water results in increase in ignition delay. There is also a considerable proof that adding water to diesel can reduce the particulates and smoke emission. There has been a growing interest in the diesel fuel industry to produce and utilize the diesel water emulsion as a suitable fuel for diesel engines. Fuel additive manufacturers try to make diesel oil and water oil mix, or can be neighborly enough to form pollution cutting diesel fuel. There have been several trials done to produce a stable emulsion which will stay the same way for a long period of time. If the emulsion remains still for many days, larger droplets of chemically coated water may settle to the bottom of the tank, or it's also been seen that coagulated particles settle down in the bottom of the tank. The fuel, however, will mix again if agitated slightly, and thus the tank is refueled to mix it again. The influence of water on some of the performance parameters, exhaust emission of diesel engine has been studied by many works. However, its effect on the heat flux crossing the combustion chamber components

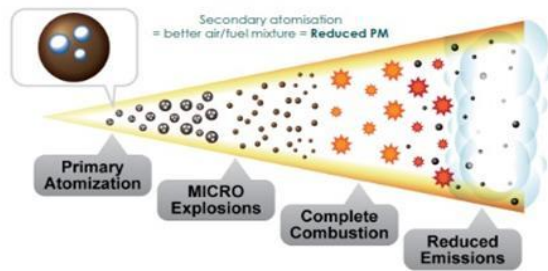


Fig3 combustion accrued inside cylinder using DWE

PROBLEM IDENTIFICATION IN EXISTING METHOD

Comparison of Water Addition Methods

PROCESS	DWSI	HDWI	FWIA	DWE
RELATIVE NOX REDUCTION	Poor	Best	Poor	Good
EFFECT ON PM EMISSIONS	Poor	Best	Poor	Good
VARIABILITY OF WATER ADDITION	Good	Poor	Good	Good
LUBRICATING OIL DILUTION	High	Low	High	Low
EXPENDITURE	High	Average	Low	Average

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Table 1 Comparison of Water Addition Method

MAIN DIESEL POLLUTANTS

➤ **CARBON MONOXIDE:** CO gas formed by the incomplete combustion of carbon-containing fuels. The more efficient the combustion process, the lower the emissions. The main outdoor source of CO is currently road transport.

➤ **NITROGEN OXIDES:** NOx All combustion products in air produce oxides of nitrogen: nitrogen dioxide (NO₂) and nitric oxide (NO)—collectively known as NOx. Road transport accounts for about 50% of total emissions, more than the electricity supply industry and the industrial and commercial sectors put together. NOx is also a precursor of ozone and therefore an indirect greenhouse gas.

➤ **PARTICULATES:** PM10 Particulate matter smaller than 10 microns (10 millionths of a meter). They consist of primary particles arising from combustion sources (mainly road transport); secondary particles (mainly sulphate and nitrate formed by atmospheric chemical reactions); and coarse particles (suspended soils and dusts, sea salt, biological particles and particles from construction work).

➤ **ULTRA-FINE PARTICLES** (smaller than 2.5 microns) are mainly primary and secondary.

➤ **SULPHUR DIOXIDE:** SO₂, the predominant source is the combustion of sulphur-containing fossil fuels, principally coal and heavy oils. Output from road vehicles is relatively small, but combustion of fuel (especially

diesel) makes a significant contribution to emission levels in urban areas.

➤ **1,3BUTADIENE:** As a gas at normal temperatures and pressures deriving mainly from the Combustion of diesel and petrol engines.

➤ **VOLATILE ORGANIC COMPOUNDS:** VOC In sunlight these react with NO_x to form ozone. It can therefore be considered an indirect greenhouse gas. So high concentrations generally occur downwind of the source emissions, most frequently in summer, in the south, and in rural and suburban areas.

PROPOSED METHOD

OBJECTIVE

The aim of this research is to create a new fuel that can be used in a diesel engine as a fuel. The fuel is created by making an emulsion of diesel and water by using a suitable surfactant with stability and homogeneity being the key concerns. This emulsion is then used in a laboratory installed diesel engine coupled with an eddy current dynamometer. The emission and performance characteristics of the engine are thus noted down and put in tabular form. Then the engine is run with regular diesel fuel and same observations are taken. A comparison is done between the two cases in terms of performance and emission properties of the fuel.

WATER IN DIESEL EMULSION:

An emulsion can be defined as a mixture of two liquids in which one is present in droplets of macroscopic or ultramicroscopic size, distributed throughout the other. Emulsions are made from the constituents spontaneously or by a mechanical way. In spontaneous emulsions, the mixing is easy and spontaneous. But if they don't mix properly then a third chemical called a surfactant is used to bind the molecules of the constituent liquids. Surfactants are compounds that lower the surface tension of a liquid that is in contact with another liquid or a solid. Surfactants decrease the interfacial tension between two liquids, or that between a liquid and a solid.

Water in diesel emulsion comes under the category of water in oil emulsion. The surfactant that has to be used should have an HLB value in the range of 7 to 11. One surfactant with this value can be used otherwise mixed surfactant can be used to obtain the required HLB value. In the latter case the two surfactants should be

Chosen carefully so that one is hydrophilic and the other is lipophilic. In this experiment, a mixed surfactant is made and has been used for further trials.

PREPARATION OF EMULSION:

Components required for making emulsion are: Mechanical agitator, diesel, distilled water, burette, and pipette.

1. The pipette, burette and container were thoroughly washed and cleaned dry.

2. Diesel was measured in the burette in required volume and poured into container. Now calculated volume of each surfactant (Span-60 and Tween-60) were measured in the pipette and poured into the container. Same done for water.

3. Now the container is placed under the mechanical agitator and the mixture is thoroughly mixed for about 10-15 minutes.

4. The emulsion thus obtained is checked for stability. Varioustrials were carried out before obtaining a stable emulsion.



Fig4 Water in Diesel Emulsion

METHODOLOGY AND EXPERIMENT SETUP



Fig5 Schematic Diagram of the Experimental Setup

ENGINESPECIFICATIONSANDAPPARATUS:

Cometdieselenigne, twincylinder,verticalwatercooled, 7.5KW @ 1500rpm.Compression ratio=17.5,Eddy currentdynamometer,Fuelmeasuring device,Stopwatch scaleand,Springbalance.



- 1. AVL Smoke Analyzer
- 2. Single Cylinder Diesel Engine
- 3. AVL Gas analyzer
- 4. Load parameters
- 5. Control panels

Fig6EngineandAuxiliarysetup

AVLGASANALYZERANDSMOKEMETERE:

Gasalyzer andsmokemeterareusedtomeasure the exhaustgasescoming outfromtheengine.TheAVLgas analyzermeasureCO₂,CO,HC,O₂andNO_xcoming out oftheengine.Itmeasuresthestandardvaluesof8.3

MECHANICALAGITATOR:

Thisisusedtothoroughly mixthemixtureandformthe emulsion.Itconsistsofamorotor whichis usedtorotate the bladeswhich isdippedinthemixture. Thereisspeed controlknobto optimizethe speedofthemotor.

Fig6SchematicDiagramoftheExperimentalsetup

EXPERIMENTALPROCEDURE:

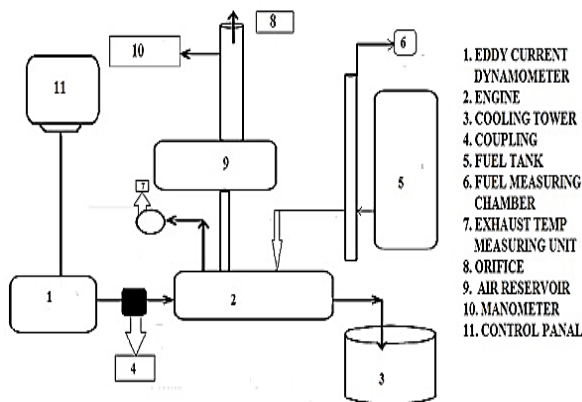


Fig 7 Experimental setup

1. The filtersoftheengine werereplacedandtheinjectors Werecleanedandcalibratedaccording totheddesired pressure.
- 2.The AVL gasalyzerandsmoke meterwereinstalled. Theinputtothegasalyzerwastakenfrom theexhaust portoftheengine.
- 3.Thefuel tankwas thenfilledwithdiesel andtheengine wasrun.
4. The engine was run at various loads of the dynamometer –5,10,15kgsandrespective readingswere taken forfuelconsumption/sec.
5. Thereadings ofgasalyzerandsmokemeterwere notedineachcase.
- 6.Afterallthereadingsweretaken,theleftoverdiesel wasdrainedoutofthetankandemulsionwaspoured.
- 7.Samestepsweretaken andthereadingswerenoted down fortheemulsion.
- 8.Beforeusingthenextemulsiontheenginewasagain run withdieselsothattheresultsare notbiased.
- 9.Aftertakingallobservations graphswereplottedto comparetheperformancecharacteristics andemission characteristics of theengineincaseofdieselandemulsion.

RESULTSANDDISCUSSIONS

PERFORMANCECHARACTERISTICS:

Brakepoweratdifferentloads

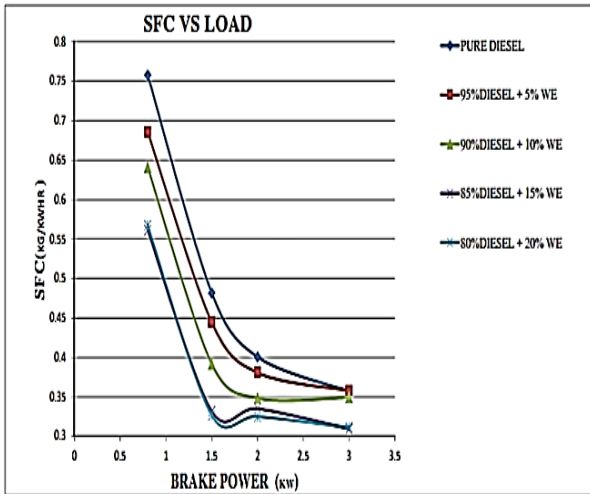
LOAD (in kg)	BRAKE POWER(kW)
0	0
5	1.35
10	2.7
15	4.05
20	5.4

Table1 Brakepoweratdifferentloads

BRAKESPECIFICFUELCONSUMPTION:

Brakespecificfuelconsumptionofanengineisdefined astheamount offuelusedinkgsperbrakepowerper second. Thisisanimportantperformance parameterasit determines themileage ofthevehicle.Inpractical purposes thisvery importantaspectaconsumer looksfor, asit determineswhethertheproductisvalueformoneyor not. Itisseenfrom thegraph thatthebsfcofthe engine increaseswhenemulsionisused,butitalsodependson theconcentrationwater inthe emulsion.It decreasesupto

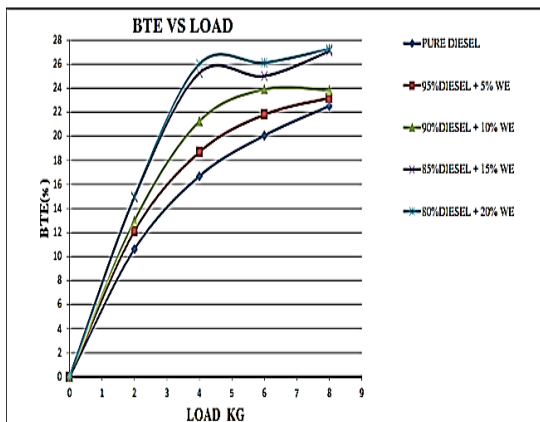
acertainlimitandthenagainincreases. Thebsfcisbest obtainedfortheemulsionwith7.5%ofwater.Useof waterincreasesthecombustionefficiencyoftheengine bykeepingthetemperature intheworking range.Aftera certainpointwhenvolumeofwaterincreasesmore,itinhibitsthe combustion



Graph 1 specific fuel consumption vs. brake power

BRAKE THERMAL EFFICIENCY VS LOAD:

Brake thermal efficiency of a vehicle is a very important performance parameter. It is given by η , it increases with increase in load. It can be seen that it increases linearly for diesel. Whereas for the emulsions it increases initially till a load and then decreases. But it can be observed that BTE for emulsions are always higher than that of diesel except at very high loads. So emulsions prove out to be better fuels when BTE is concerned

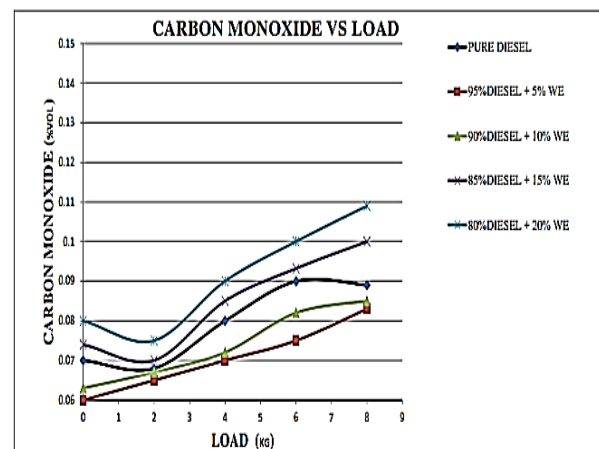


Graph 2 Brake thermal efficiency vs. load

EMISSION CHARACTERISTICS:

CARBON MONOXIDE:

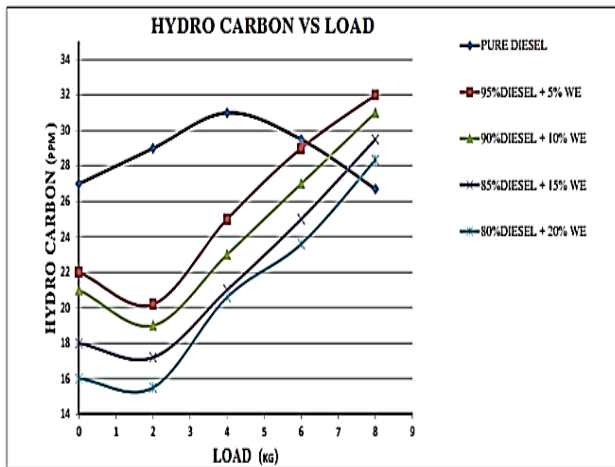
Carbon monoxide is emitted as a result of incomplete combustion of carbon and oxygen under high temperature inside the cylinder. With increase in load CO emission increases for all the fuels used. It has been observed that emission of CO increases with increase in volume of water in the emulsion. This happens because with increase in water the temperature inside the cylinder decreases slowing down the combustion of carbon, as a result of which incomplete combustion occurs.



Graph 3 Carbon Monoxide emission vs. load

HYDROCARBON EMISSION:

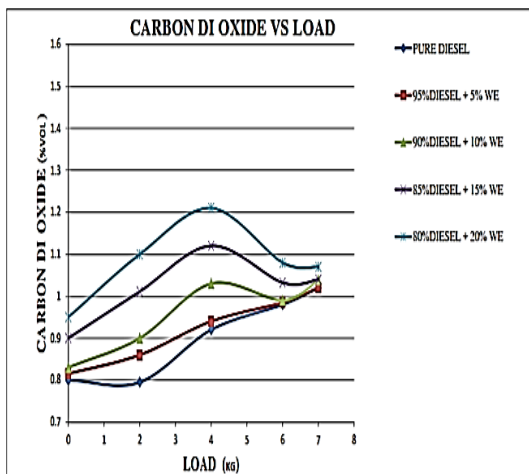
Exhaust gases leaving the combustion chamber of a CI engine contain up to 100 ppm of hydrocarbon. These consist of small nonequilibrium species which are formed when large fuel molecules break up during the combustion reaction. It is often convenient to treat these molecules as if they contained carbon atoms. It is seen that HC emissions increase up to a certain load and then decrease for diesel. For the emulsions it shows an increasing trend as the load increases. Under lower load conditions emission in case of diesel is more than that of emulsions but at higher load conditions the emulsions give more HC emission than diesel.



Graph4Hydrocarbonemissionvs.load

CARBONDIOXIDE:

Carbon dioxide comes as exhaust as a result of complete combustion of carbon particles in the fuel and the combustion of CO inside the cylinder. For diesel it increases linearly with increase in load. For the emulsions too it increases linearly with some variations at some loads. CO₂ emission increases when we add water to diesel. With increase in the percentage of water in diesel CO₂ emission increases.

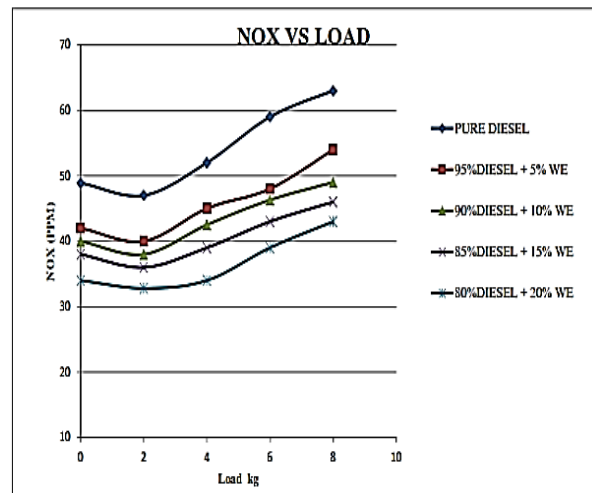


Graph5Carbon dioxide vs. load

NITROGEN DIOXIDE (NOx):

Exhaust gases of an engine can have up to 40 ppm of oxides of nitrogen. Most of this exhaust contains nitrogen oxide (NO) with a small amount of dioxide. These all come under NO_x, representing some suitable number. NO_x is very undesirable as it has many adverse effects on the environment. With increase in load NO_x emission

increases for diesel as well as other fuels. It has been observed that using diesel water emulsion as a fuel greatly reduces the NO_x emissions as compared to diesel. This happens because when water along with diesel enters the combustion cylinder, it is directly vaporized into steam due to the presence of high temperature and pressure inside the cylinder. This takes some of the heat from the combustion chamber and brings down the cylinder temperature. As a result, the conversion of diatomic hydrogen to more reactive monoatomic nitrogen decreases, thereby reducing the chances of formation of NO_x.



Graph6Carbon dioxide vs. brake power

CONCLUSIONS

- The specific fuel consumption was observed to decrease with increase in the percentage of water in diesel. Results show that specific fuel consumption is decreased by 2% to 3% when concentration of water is increased from 5% to 7.5%, but further increase may increase the specific fuel consumption. However, at higher loads, the fuel consumption is more for emulsions than diesel.
- The brake thermal efficiency of the increases with increase in water content emulsion under low load condition. But it decreases at higher loads.
- The NO_x emission is brought down by 30%-50% by use of diesel water emulsion. This trend goes on increasing with increase in amount of water in the emulsion.
- At lower loads, the hydrocarbon emissions are lesser for emulsion as compared to diesel, however, when the load increases, HC emissions are higher for emulsions.
- Carbon monoxide and carbon dioxide emissions increase with increase in water percentage in the fuel.

This is due to the fact that most of the hydrocarbons are burnt at lower loads.

- For optimal results use of diesel water emulsion with 7.5% water content will have the best results in terms of performance and emissions.

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