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CFD Analysis of Emission Characteristics of CI Engine by Using Jatropha Biodiesel

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ABSTRACT
With depletion of conventional fuel source at tremendous rate and increasing environment pollution has motivated extensive research in alternative fuel and engine design. Biodiesel is an alternative fuel for diesel engine and being environmental friendly, usually lower exhaust emission and better lubrication properties can be suitable alternative. The main emissions like hydrocarbons (HC), carbon monoxide (CO) ,nitrogen oxides(NOx) and oxides of sulphur (SOx) emitted from automobile engines. In order to reduce the emissions various research is going on petrol and diesel engine. The performance of single cylinder water-cooled diesel engine using diesel additive of Jatropha oil as the fuel was evaluated for its exhaust emissions. Jathopha curcus is a renewable and non-edible plant and easily available in India. In this work an attempt is made to obtain the better emissions characteristics by using Jatropha biodiesel. The Analysis was performed on a single cylinder, air cooled, direct injection diesel engine for this purpose. The Analysis results are validated with a two zone model program developed using a ANSYS (FLUENT) software.

INTRODUCTION
Background of Diesel engine
Automotive engines are one of the major sources of pollutant, which is harmful to living creatures and causes damage to the environment (Liu 1999; Hester et al. 2004). The transportation sector accounted for 21% of all CO2 emissions worldwide in 2002 which is the major cause to the global warming issues. In recent years, many countries have applied stringent emission standards to automotive manufacturers. Therefore, modern diesel engines are equipped with many features such as EGR and common rail fuel injection system to control their emissions while maintaining or improving the performance of the engine.

Diesel Engine Technology
The diesel engine was named after Dr Rudolf Diesel who in 1897 invented an engine with direct injection of liquid fuel into the combustion chamber. The engine was originally designed to work with peanut oil. The diesel engine is also known as a compression ignition (CI) engine due to its principles of cycles. The ignition of fuel in the combustion chamber occurs due to high temperature and pressure during the compression stroke. The diesel engine is not throttled the amount of fresh air enters the engine as Otto cycles is used to control the output power. Instead, the power is controlled by the amount of fuel injected into the cylinder. Thus designing a good air induction system (AIS) is vital to a diesel engine to achieve higher engine performance.

Diesel engine performance is well known to be limited by the formation of smoke, which forms if there is inadequate mixing of the fuel and air (Ferguson 2001). Therefore, much research has been conducted on optimisation of the AIS as well as the combustion chamber to improve the diesel mixing process. Many attempts have been conducted to improve emissions by new techniques and devices such as exhaust gas recirculation system (EGR), after treatment technology, catalytic converter. Others have tried with alternative fuels such as biodiesel and alcohol.

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Alternative Fuels for Diesel Engines

The exhaust emissions generally result from the combustion of fossil fuel in vehicle engines. Moreover, the mineral diesel fuel itself is toxic and may cause long term adverse effects to the aquatic environment. Experimental studies have found that the polycyclic aromatic hydrocarbons contained in diesel may induce skin cancer, as reported on gas oil safety data sheet by Oil UK Ltd (BP 1998).

Biodiesel is one of the most important renewable energy resources, which is produced from vegetable oil or animal fat by transesterification of triacylglycerols, yielding monoalkyl esters of long-chain fatty acids with short-chain alcohols (Meng et al. 2008). The main benefit of biodiesel is that it is ‘carbon neutral’. Although the engines running on biodiesel produce more CO2 compared to conventional diesel fuels, if the analysis includes the carbon cycle, the use of biodiesel actually emits less CO2 to the atmosphere. The biodiesel could be used on it own or blended with conventional fossil fuel without having to make any modification to the standard diesel engines because biodiesel has comparable properties to diesel (Agarwal 2007; Tsolakis et al. 2007).

The advantage of biodiesel has been reported by many researchers as renewable energy, non- toxic, biodegradable and sulphur free. In addition, a mixture of biodiesel with standard diesel fuel improves the lubricating properties of the fuel and reduced cylinder friction.

Combustion in Diesel Engines

The combustion process in compression ignition (CI) engines is very complicated. Much research has been conducted to study the behavior of the combustion process in an engine cylinder. In a CI engine, the combustion started just after a few crank angle degree of start of injection. The chemical reaction occurs in an engine cylinder which produce diffusion flame at the interface between fuel and air. The heat release begins and increases as a rapid burning spreads through combustion chamber and decreases as the available oxygen is depleted.

The combustion process can be classified in two phases. Premixed combustion and mixing controlled combustion. The liquid fuel supplied to the engine is compressed into a finely atomized state, vaporized, and penetrates into the hot and highly compressed air in the combustion chamber. The combustion starts when the local temperature reaches or goes above the auto-ignition temperature. The time interval between the start of injection (SOI) and the start of combustion (SOC) is derived as ignition delay. This parameter plays an important role to the quality of combustion in a diesel engine.

JATROPHA AND ITS APPLICATIONS

Jatropha production system

The aim of the chapter is to describe the whole system of Jatropha biodiesel production, from seed to biodiesel. The characteristics of the Jatropha plant are described together with its ecologic preferences and cultivation practices, followed by the process of turning the seed into biodiesel. The chapter concludes with the environmental impacts of the described production system.

Biology of Jatropha

Jatropha Curcas L., in this report referred to only as Jatropha, is a small tree or large bush belonging to the Euphorbiaceae family (Achten 2008). See Figure 1 for examples of two Jatropha plants. Normally the plant reaches a height of three to five meters but can reach up to eight to ten meters when grown under favourable conditions. It has a life expectancy of up to 50 years, maturing after four to five years, and grows into different shapes, with one stem with no or few branches, or with branches growing from below. The plant initially develops one central deep tap root and four lateral roots. (Kumar 2008) The tap root can stabilize the soil and prevent landslides while the more shallow roots are assumed to prevent soil erosion caused by wind and water. (Achten 2008)

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Figure 1. Examples of two Jatropha plants in Southern India.

Jatropha is a plant of deciduous type and sheds its leaves during dry season and also under stressful conditions (Fact Foundation 2009a). The leaves are green, smooth, 4-6 lobed and 10-15 cm in width and length (Achten 2008). The plant has separate male and female flowers which are organized in clusters, inflorescences. The plant carries more male than female flowers, the male-to-female ratio is 29:1. Brittaine and Lutaladio (2010) report that the ratio may decrease with plant age implying increased fruiting capacity with age. Flowering normally occurs once a year, during rainy season, but in permanently humid areas or under irrigation it flowers throughout the whole year.

After pollination by insects, mainly honey bees, approximately ten green fruits having an ellipsoidal shape are formed by each inflorescence (Kumar 2008). Each fruit is about 40 mm long and contains three seeds. Occasionally a fruit can contain four to five seeds. (Fact Foundation 2009a) It takes three to four months after the flowering for the seeds to mature. The seeds are black, measuring on average 18 mm in length, 12 mm in width, and 10 mm in thickness (Fact Foundation 2009a). The seeds weigh between 0.5 and 0.8 grams and the average number of seeds per kilo is 1375 seeds (Kumar and Sharma 2008). The seed yield per tree is reported to range from 0.2 to 2.0 kilos per year (Brittaine 2010). The seed's shell and inner kernel account for on average 37 and 63 percent of the total weight, respectively. Oil content of the seeds range from 32 to 40 percent; the average is 34 percent. The seed contains toxins, such as phorbol esters, curcin, trypsin inhibitors, lectins, and phytates, which render the seeds, oil, and seed cake non-edible if not detoxified. (Achten 2008) See Figure 3 for examples of fresh fruit and seeds.

Figure 3. Examples of fresh fruits and seeds

Jatropha biodiesel

The harvested Jatropha seeds are used for production of Jatropha oil and biodiesel. The first step is to extract the oil in the seeds, which can later be converted into biodiesel.

Mechanical and chemical oil extraction

There are two different options for extracting oil from the Jatropha seeds: mechanical extraction and chemical extraction. In both cases the seeds have to be dried prior to extraction, either in an oven or in the sun. (Achten 2008)

Mechanical cold pressing of seeds is the conventional extraction method, due to its simplicity and affordable investment cost already at small scale (Aadrians 2006). For mechanical extraction either an engine-driven press or a manual press can be used, where the engine-driven option is reported to extract a higher percentage of the available oil, normally 75-80 percent compared to 60-65 percent for the manual press. The mechanical expeller can be fed with either whole seeds, kernels or a mix of the tw Chemical extraction methods were developed in order to achieve a more complete extraction, where the amount of oil per ton of seed increased. The chemical extraction methods use a solvent. The most common solvent used in extraction of Jatropha oil n- hexane, which extracts 95-99 percent of the oil. However, the use of solvent-based oil extraction is only economical at large-scale production. Also, the use of n-hexane as a solvent generates large amounts of waste water, requires high energy consumption and causes emissions of volatile organic compounds, and affects human health by forcing operators to work with hazardous and flammable chemicals. (Aadrians 2006) New production units for extraction with n-hexane as a solvent are more efficient and have a lower environmental impact, but research and development of alternatives, such as supercritical or bio-renewable solvents, could be useful. Environmental impacts can also be decreased by substitution of solvent based oil extraction with aqueous enzymatic oil extraction, but that would lead to decreases in the percentages of oil extracted. (Achten 2008)

Conversion to biodiesel

The Jatropha oil can be used directly as a liquid fuel in older diesel motors, in generators and pumps running at a constant speed, or in newer engines with small modifications in the fuel system. The Jatropha oil can also be mixed with fossil diesel before use in the engine, which combines the properties of the fossil fuel with the lower environmental impact of the vegetable oil. (Siddharth 2009, Achten 2008) However, Jatropha oil has a viscosity that is 20-25 times higher than the viscosity of conventional diesel, which causes problems when using the unmodified oil or blends with a high percentage of Jatropha oil in an engine.

Thus, there is a need for modification of the oil to reduce viscosity and make it more suitable as an engine fuel. (Siddharth 2009) Methods for this are pyrolysis and micro-emulsification with solvents like methanol, ethanol, and butanol, but the most common method is to convert the Jatropha oil into biodiesel through transesterification. This method transforms an ester into another ester; in this case a reaction between Jatropha oil and methanol is used to produce a methyl-ester (biodiesel) with glycerol as a by-product. The biodiesel can be used directly in a diesel engine or in a blend with conventional diesel. (Siddharth 2009, Achten 2008)

Environmental impact

The environmental impact of the Jatropha biodiesel production has been evaluated by several studies applying the Life Cycle Assessment approach. This approach shows the total environmental impact for the production system during its whole life cycle. It determines the processes in the system that contribute most to environmental impact and where the possibilities for improvement are. These assessments show varying results, possibly due to differences in methodology.

Energy balance

If the energy output of a given system is greater than the energy input, the system has a positive energy balance. However, energy balance is affected by energy quality and the utility of different energy carriers. A high energy input can be acceptable if the input energy is low-quality and the output a high-quality energy carrier, such as a liquid fuel usable for vehicle operation. The production of Jatropha biodiesel reportedly has a positive energy balance (Achten 2007). The largest differences in energy requirement between different production sites are derived from differences in cultivation intensity, as irrigation and use of fertilizers are energy intensive practices (Achten 2007). Higher cultivation intensity does not always pay off in higher energy production, and optimization of inputs and yield is required for maximized positive energy balance. Another energy intensive production step is the transesterification of Jatropha oil into biodiesel, which implies that the direct use of crude Jatropha oil would improve the energy balance. However, in the use phase, the combustion of Jatropha oil instead of biodiesel is less energy efficient and causes problems to the engine. Hence, possibilities for improvement of energy balance lie in the cultivation and transesterification steps. (Achten 2008).

Global warming potential

Studies report that production of Jatropha biodiesel releases less greenhouse gas (GHG) emissions compared to production of fossil diesel (Prueksakorn 2006). The largest GHG contributing phases of the

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production are use of fertilizers and irrigation, if applied in the cultivation process, and transesterification. Hence, intensification of cultivation will have a negative effect on the global warming potential of Jatropha biodisel production. However, Prueksakorn and Gheewala (2006) find the end-use phase of the biodiesel to be the main contributor of GHG emissions, responsible for 90 percent of total life cycle emissions (Prueksakorn 2006), and therefore changes in production processes would only affect total emissions marginally. Further, Prueksakorn and Gheewala mention that GHG emissions from production and use of biodiesel are 23 percent of emissions from fossil diesel. The main reason for this is that biodiesel is produced from biomass, and its carbon dioxide (CO2)
emissions from combustion in the engine are considered GHG neutral. (Prueksakorn 2006)

Biodiesel in general releases less emissions than fossil diesel, except for emissions of nitrogen oxides (NOx), where emissions are slightly higher (Siddharth 2009). Nitrous oxide (N2O) emissions from the use of nitrogen fertilizers also need to be considered; IPCC estimates the emissions to be one percent of nitrogen input from fertilizers. (IPCC 2006) As nitrous oxide is a potent GHG, with a global warming potential that is 296 times higher than that of carbon dioxide, it is important to optimize the input of fertilizer to the output from cultivation to reach a reduction in global warming potential for the system. (Achten 2008).

Advantages of Jatropha :

i) The oil is extensively used for making soap in some countries beacause it has a very high saponification value.

ii) The oil is used as a illuminants as it burns without emitting smoke.

iii) The latex of jatropha contains an alkaloid know as jatrophine which is belived to have an anti cancerous properties.

iv) From the bark of Jatropha curcus a dark blue dye is produced which is used for coloring cloth, fishing nets etc.

v) The byproducts of Jatropha seeds high nitrogen, phosphorous and potassium which is used for fish foods, domestic animals foods and in land as fertilizers.

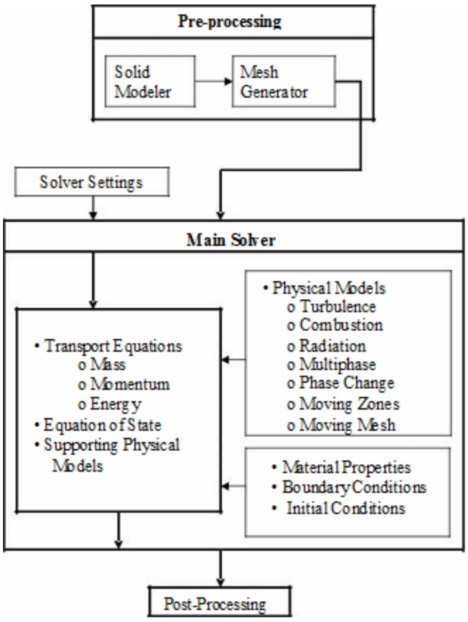

Figure 4.1: Overview of the CFD Modeling Process

CFD PROGRAMS

The availability of affordable high performance computing hardware and the introduction of user-friendly interfaces have led to the development of commercial CFD packages. Before these CFD packages came into the common use, one had to write his own code to carry out a CFD analysis. The programs were usually different for different problems, although a part of the code of one program could be used in another. The programs were inadequately tested and reliability of the results were often questioned. Today, well tested commercial CFD packages not only have made CFD analysis a routine design tool in industry, but also have helped the research engineer focus on the physical system more effectively. All formal CFD software contain three elements (i) a pre-processor, (ii) the main solver, and (iii) a post-processor

The Pre-processor

Pre-processing is the first step of CFD analysis in which the user

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(a) defines the modelling goals,
(b) identifies the computational domain, and
(c) designs and creates the Mesh system

The process of CFD modelling starts with an understanding of the flow problem and identification of the computational domain. This is followed by generations of the Mesh structure, which is the most significant portion of the pre-processing activity. It is said that over 50% of the time spent by a CFD analyst goes towards Mesh generation. Both computation time and solution accuracy depend on the Mesh structure. Optimal meshes are often non-uniform – finer in areas where large variation of variables is expected and courser in regions with relatively little change. In order to reduce the drudgery of engineers and maximize productivity, all the major CFD programs include facilities for importing shape and geometry information from CAD packages AutoCAD and I-DEAS, and for applying a meshing procedure. Current research is underway to develop CFD codes with an adaptive meshing capability.

Problem Solving Steps

After determining the important features of the problem user will follow the basic procedural steps shown below.
1.Create the model geometry and Mesh.
2.Start the appropriate solver for 2D or 3D modeling.
3.Import the Mesh.
4.Check the Mesh.
5.Select the solver formulation.
6.Choose the basic equations to be solved: laminar or turbulent (or in viscid), chemical species or reaction, heat transfer models, etc. Identify additional models needed: fans, heat exchangers, porous media, etc.
7.Specify material properties. 8.Specify the boundary conditions.
9.Adjust the solution control parameters.
10.Initialize the flow field.
11.Calculate a solution.
12.Examine the results.
13.Save the results.
14.If necessary, refine the Mesh or consider revisions to the numerical or physical model.

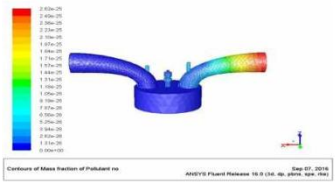
Step 1 of the solution process requires a geometry modeler and Mesh generator. You can use FLUENT or a separate CAD system for geometry modeling and Mesh generation. You can also use TMesh to generate volume Meshs from surface Meshs imported from FLUENT or a CAD package. Alternatively, user can use supported CAD packages to generate volume Meshs for import into TMesh or into FLUENT. In Step 2, user will start the 2D or.When interphase coupling is to be included, the source terms in the appropriate continuous phase equations may be updated with a discrete phase trajectory calculation. A check for convergence of the equation set is made.

RESULTS AND DISCUSSION

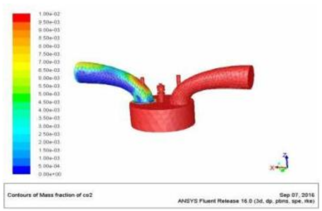
The results shows the contour plots of different pollutants of IC engine like nox ,co,co2

CONTOUR PLOTS OF 30% JATROPHA AND 70% DIESEL

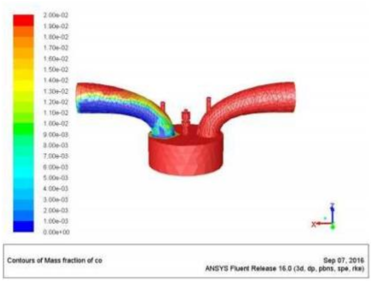
1.Pollutant NOx



2.Mass fraction of CO2



3.Mass fraction of CO



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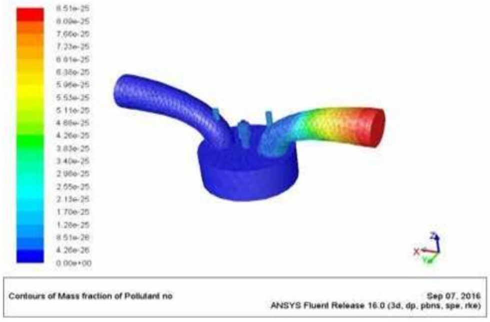
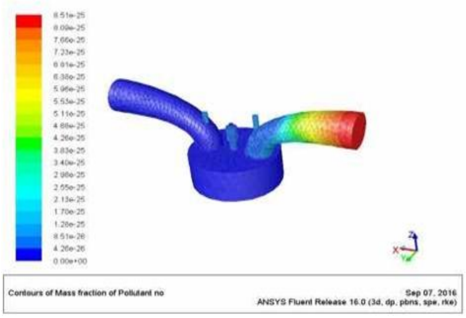
CONTOUR PLOTS OF 40% JATROPHA AND 60%DIESEL

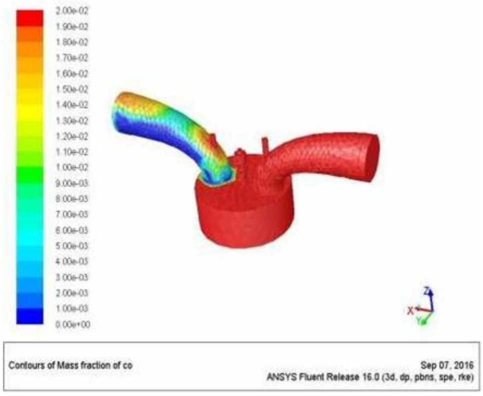
1.Pollutant NOx



2.Mass fraction of CO2

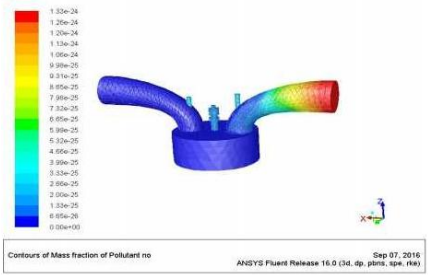


3.Mass fraction of CO

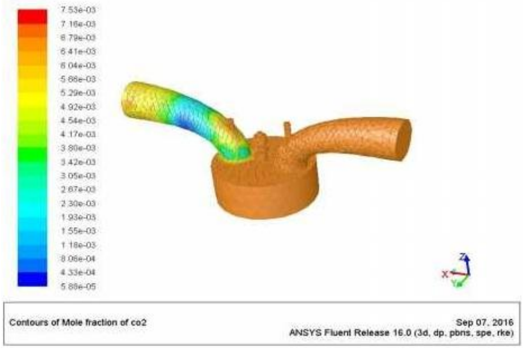


CONTOUR PLOTS OF 50% JATROPHA AND 50% DIESEL

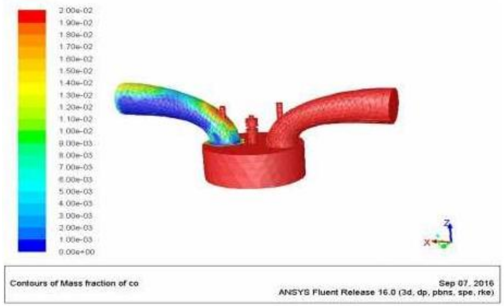
1.Pollutant NOx



2.Mass fraction of CO2



3.Mass fraction of CO



EMISSION ANALYSIS:

The emissions coming out from the internal combustion engine undesirable .These emissions are exhausted into the surrounding pollute the atmosphere and causes the various problems like global warming, acid rain, smog ,odours and hazard to the respiratory system.

The engine running with the petrol as the fuel emission parameters are not specifically ideal that results in more emission of unburnt , carbon monoxide (CO) and oxides of nitrogen (NOx) Engine emissions are classified into two types

1.Exhaust emissions

2.Non exhaust emissions

Exhaust emissions:

•Un burnt hydro carbon(HC)

•Oxides of carbon

-Carbonmonoxide(CO)

-Carbondioxide(CO2)

•Oxides of nitrogen(NOx)

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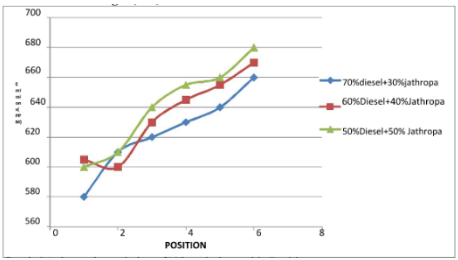
Non exhaust emissions:

Non exhaust emissions are the un burnt hydrocarbons from the fuel tank and crank case emissions

Oxides of Nitrogen(NO) Emissions



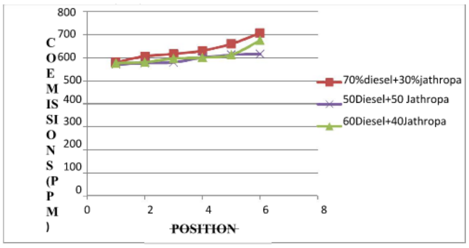
Graph 5.1 shows the variation of NO emissions with Position

The graph shows the NO emission with Position. NO emissions increases with continuously increasing with position increases because of the oxygen present in the Jatropha oil and oxygenated fuel blends causes an increase in NO emission. NO Emissions is found to be increased with the increase of biodiesel percentage in the blends.

Another major reason for raise in NO emission is due to longer ignition delay caused by Jatropha oil and releases more heat during premixed phase of combustion.

An effective technique to reducing NOx emission in diesel engine is Exhaust Gas Recirculation (EGR). NOx are formed when the combustion temperature is high. Any technique that reduces the combustion temperature will thus lead to decreased NOx formation.

Carbon Monoxide (CO) Emissions:



Graph 5.2 shows the variation of CO emission with position.

At initial position CO emissions are reduced and then increases with position. The CO emissions is found to decrease with higher percentages of biodiesel in the blended fuels.The CO Emissions are less in 50% diesel and 50% Jatropha compared to remaining blends.The reason of CO emissions is presence of oxygen in the biodiesel fuel , which augments the complete combustion of fuel and thereby reduces the CO emissions.

Carbon Dioxide (CO2) Emissions :

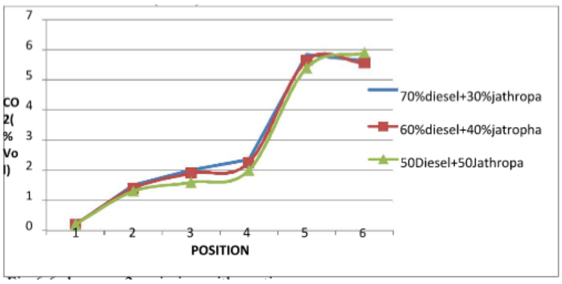


Fig 6.6 shows co2 emission with postion.

CO2 emissions are low due to the reason that the enrichment of O 2 in Jatropha oil principal component of cineole which increases the production of oxygen and promotes for the oxidation of CO2 during the engine exhaust process Another reason is biodiesel contain low carbon content compared to diesel.

CONCLUSIONS

Jatropha based biodiesel is a non-edible, renewable fuel suitable for CI engines and is receiving increasing attention particularly in india because of its relatively low environmental degradation. After the detailed CFD analysis of CI engine the NOx emissions increases with biodiesel concentration in the blending. The CO and CO2 emissions are decreased with increase of biodiesel percentage in the blended fuel.

FUTURE SCOPE

More experiments can be performed.

- By using different kinds of Biodiesel.
- By changing the engine parameters like compression ratio, design of combustion chamber etc.

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- By using different types of fuels and fuel blends.

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