
CHAPTER 1

INTRODUCTION

1.1 Motivation

The primary concern at present is fulfilling the energy demand with minimum consequences. As per the International Energy Agency (IEA) report, 80% of the total worldwide energy demands are compensated by fossil fuels. The global population is increasing exponentially, and it is expected to be raised by about two billion over two decades, due to which energy demand will also be enhanced. The increasing energy demand improved the application of fossil fuels and energy costs. The significant consequence of applying fossil fuels is an enhancement in pollution levels. The rising energy demand and environmental deterioration are two major factors driving the search for alternative fuels to replace conventional petroleum fuels for motor vehicles. Among all the alternative fuels, biodiesel is one of the most widely investigated as a replacement for diesel fuel due to its renewability, potential to reduce greenhouse gas emissions, and inhibition of soot formation.

The concept of application of biofuel (vegetable oil) was first provided by Rudolf diesel in his newly invented diesel engine, and G. Chavanne first discovered the process of production of biodiesel in 1937 through a transesterification process. Nowadays, much research is going on to produce biodiesels through different techniques (Pyrolysis, acidic catalysis, enzyme catalysis, etc.) and using other feedstock (rapeseed oil, sunflower oil, canola oil, animal fat, etc.). Biodiesel blending in diesel fuel reduces the dependency on foreign oil. Its application in compression ignition engines leads to an increase in

fuel consumption, a reduction in HC, CO, smoke, and particulate emissions, and a slight increase in NO emissions. Several investigations have been carried out on biodiesel's influence on a diesel engine's unregulated emissions.

Biodiesel blending is reduced by using water in diesel emulsion (WiDE) fuel. The application of water in engine cylinders was first analyzed by Prof. B. Hopkinson (Vellaiyan et al., 2016). Application of WiDE fuels reduces NO emission via dilution, thermal, and chemical effects, and the reduction in smoke is due to the micro explosion phenomenon and the long ignition delay. Water in diesel emulsion fuel and its application in CI engines is an advanced field of research. Water in diesel emulsion and biodiesel fuels is a direct substitute for diesel fuel with little or no modification in a diesel engine.

Several investigations on the influence of nano-incorporated fuel on the diesel engine have been carried out to reduce engine emissions. The incorporation of nano additives reduces the NO, smoke, and PM emissions. Fuel properties, emission characteristics, and performance parameters of diesel engines charged with nano additives (i.e., Al_2O_3 , CuO, MgO, MnO, and ZnO, etc.) incorporated fuels have been investigated by many researchers. Experimental results showed that nano additives reduced NO and CO emissions significantly. This thesis investigates the diesel engine's energy, exergy, and emissions performances with WiDE-based nano fuels. Taguchi and grey analysis are also performed to optimize the engine performances and emissions attributes.

1.2 Biofuels

Biodiesel is the primary type of biofuel which are used in the diesel engine. Biodiesel is a combination of methyl esters of fatty acids and an oxygenated fuel. First of all, in 1890, biodiesel is prepared by Rudolf diesel using vegetable oils. The

recent technique of biodiesel production, i.e., transesterification, was discovered in 1930 in Belgium by G. Chavanne. The different methods of biodiesel production i.e., pyrolysis, dilution, microemulsion, and transesterification, and their further classifications, have been shown in Fig.1.1. Based on available feedstock for biodiesel production, it is classified into three generations, i.e., first generation, second generation, and third generation biodiesel. The first-generation biodiesels are produced by edible oil feedstock (rapeseed oil, sunflower oil, soybean oil, sesame oil, etc.). The second-generation biodiesels are produced by non-edible feedstock (neem oil, jatropha oil, sal oil, orange peel oil, animal fat oil, etc.). The major advantages of the production of second-generation oils are fewer land requirements for oil production, low cost of biodiesel production, and abolish the food imbalance. The major disadvantages are the high viscosity of non-edible oil and the increased requirement for alcohol for biofuel production. Microalgae produce third-generation biodiesels. The significant advantages of third-generation biodiesel are high productivity and higher oil content, and the major disadvantages are large capital investment, sunlight requirement, and oil extraction problems.

Second and third-generation biodiesel is highly likely to become an alternative to fossil fuel because it can be used in CI engines without modification. Second-generation production costs are less than third-generation biodiesel production costs, so second-generation biodiesel attracted the researcher's focus for investigations.

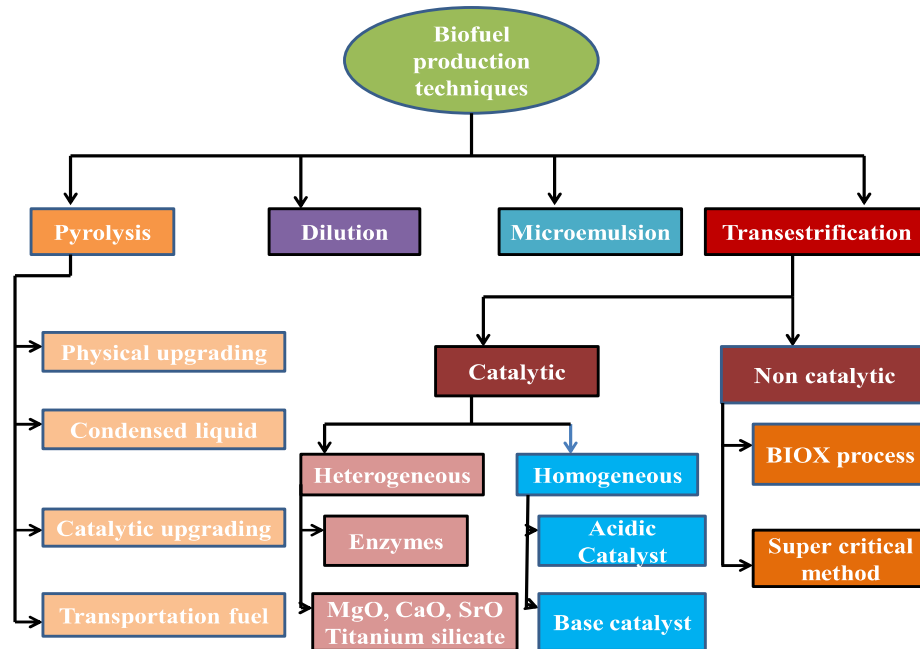


Figure 1.1 Methods of biodiesel production

1.3 Water Emulsion Fuel

The higher depletion rate of fossil fuels has motivated researchers to invent alternate fuels for IC engines, and they invented biodiesel as an alternative. Biodiesel has reduced foreign dependency, but some issues arise with it. The biodiesel has an excess amount of oxygen which causes increased engine cylinder temperature, hence higher NO formation. To diminish NO emissions, many methods have been developed from which the addition of water is a suitable technique. There are three water addition techniques, i.e., in-cylinder water injection, water injection into the air, and emulsification. Due to the cooling property of water, the cylinder inside temperature is reduced, which also diminished the NO emissions. The in-cylinder water injection method and water injection into the air method are costlier because some extra equipment is required for water addition by these methods. The emulsion of water in diesel fuel has many privileges which make it superior to the other two methods. The emulsion is a mixture of two or more immiscible liquids, in which one is present as

droplets and distributed throughout the other. The emulsifications are classified into the following three sections:

- Water in diesel emulsion (WiDE)
- Oil in water emulsion
- Multiphase emulsion

Based on research data, water in diesel emulsion is found to be superior to other methods. In the water in diesel emulsion fuel, diesel is in dispersed form, and water is in droplet form. When the water in diesel emulsion fuel enters the engine cylinder, water particles absorb heat from the engine cylinder. Because of the lower latent heat of vaporization than diesel fuel, it is vaporized and explodes. This phenomenon is known as micro-explosion. Due to the micro explosion, secondary atomization takes place inside the cylinder, as shown in Fig.1.2, which improves the combustion efficiency of the fuel. The micro-explosion effect is an extra privilege of water in diesel emulsion fuel rather than a cooling effect.

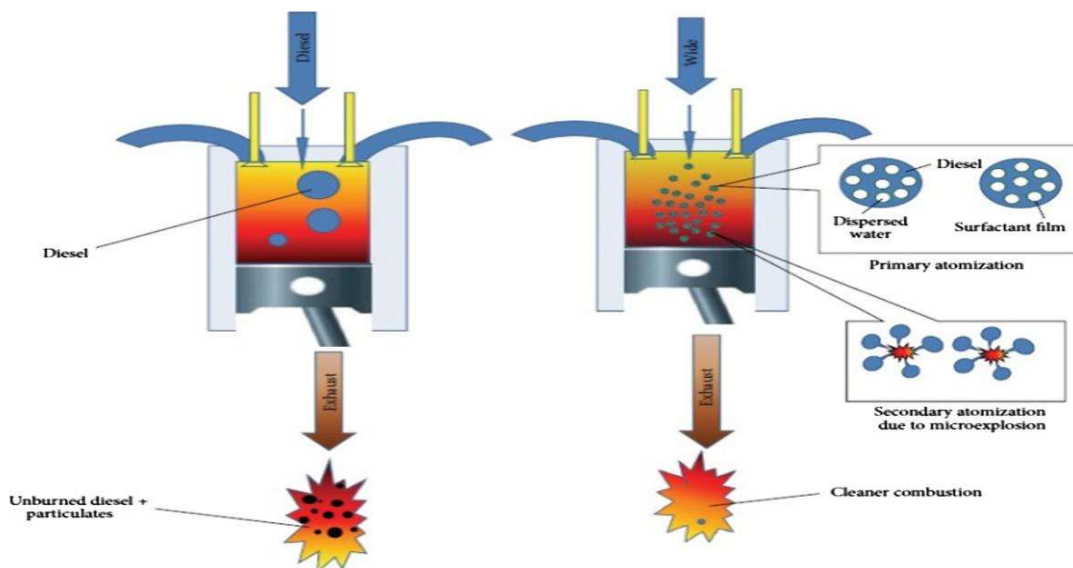


Figure 1.2 Primary and secondary atomization in spray flame of emulsified fuel

(Khan et al. 2014)

1.4 Nano Fuel

Many researchers have developed fuel modification and enrichment techniques to improve the performance and emission characteristics of CI engines. Incorporating nano additives in base fuel (Diesel, Diesel-biodiesel blend fuel, etc.) is a part of developing such techniques. Nano fuel is defined as the ultrasonicated mixture of base fuel and nanoparticle. The base fuel is continuously formed, and the nano additive is dispersed. Using an ultra-sonication method, nano fuel is prepared using base fuel, nano additive, and surfactant. The various types of base fuel, nano additive, and surfactants are shown in Fig.1.3. The primary base fuels for nano fuel preparation are diesel, biodiesel, and fuel derived from diesel and biodiesels. Nano additives are metal nano additives, metal oxide nano additives, carbon nano additives, organic nano additives, and magnetic nano additives. The applications of organic nano additive and magnetic nano additive are limited in nano fuel preparation. Different researcher, with and without surfactants, has prepared nano fuels. The nano fuel prepared with surfactant is found to be more stable.

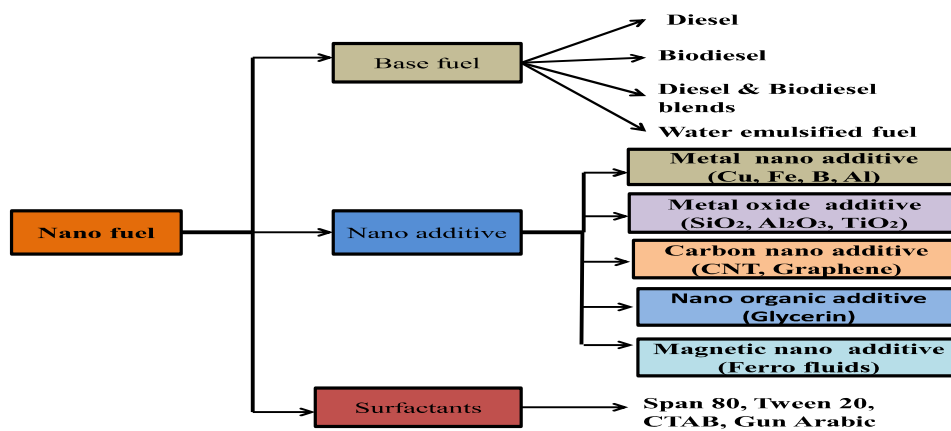


Figure 1.3 Various base fuels, nano additives, and surfactants used in the preparation of nano fuel

The addition of nano additive enhanced the thermal physical properties (i.e., density, lower heating value, viscosity, etc.) and heat transfer rate. The nanoparticle

incorporation oxidized the fuel blend rapidly because of the higher surface area to volume ratio and more explored the reactive area. The addition of nanoparticles improves fuel evaporation rate and provides better secondary atomization and flame sustainability. Incorporating nano additives in base fuel reduces the ignition delay period, flash point, and exhaust emission. It enhances the oxygen concentration in the engine cylinder, viscosity, and chemical-to-chemical contact (Ribeiro et al., 2007).

Incorporating nano additives in base fuel enhances the micro explosion and secondary atomization phenomena, improving fuel combustion efficiency. Due to the enhanced combustion rate, the BSFC and emissions rate of the engine diminishes. The engine BTE enhances with the incorporation of nano additive due to better fuel evaporation rate because of the larger surface area to volume ratio of nano additive.

1.5 Contribution of Study

Due to the various advantages of blending biofuels with diesel fuel, the biodiesel-diesel blend fuel can be used to run the CI engine without any modification. The enhanced NO emission of CI engines with biodiesel-diesel blend fuel is a significant limitation. This limitation of applying the biodiesel-diesel blend fuel can be avoided by using water in the diesel emulsion technique. The WiDE-based fuel also improves engine BTE and reduces other emission characteristics. Incorporating nano additives further improves the engine performance parameters and emission characteristics. To quantify the improved performance parameters and reduced emission a characteristic, an experimental investigation has been planned on the CI engine with the biodiesel-diesel blend fuel, water-emulsified fuel, and nano fuel.

The novelty of the current experimental study is the application of novel fuel prepared by the optimum level of biodiesel blend, optimum level of water emulsification, and the incorporation of different nano additives (Al_2O_3 and CNT) in CI

engine performance and emission characteristics investigation. The fuel samples prepared for the consideration of analysis are diesel, OPB-diesel blend, water emulsified OPB-diesel blend, Al_2O_3 incorporated water emulsified OPB-diesel blend, CNT incorporated water emulsified OPB-diesel blend, SOB-diesel blend, water emulsified SOB-diesel blend, Al_2O_3 incorporated water emulsified SOB-diesel blend, and CNT incorporated water emulsified SOB-diesel blend. The OPB and SOB fuels are examined respectively as they can be readily available in many parts of the world. The effect of different operating parameters such as engine power, engine speed, and fuel type has been examined on different engine outcomes. The engine outcomes are divided into three parts, i.e., energy parameters (brake specific fuel consumption, brake thermal efficiency, and exhaust gas temperature), exergy parameters (exergy efficiency, exergy destruction rate, entropy generation rate, and engine sustainability), and emission parameters (HC, CO, CO_2 , NO, and smoke).

1.6 Thesis Structure (Methodology)

The current thesis is structured, including seven chapters. The first chapter of the thesis illustrates the basic need of the recent research brief introduction to biofuel, water emulsion fuel, and nano fuel. The *second chapter* of the thesis contains a detailed literature review based on the application of biofuels, water-emulsified fuels, nano fuels, and the Taguchi-grey method of experimental design and optimization on CI engines. The *third chapter* of the thesis consists of biofuel preparation methods, blends, water-emulsified fuels, and nano-additive incorporated fuels. The measurement method and data of thermophysical properties of prepared fuel samples and the characterization of nano fuel are also presented in this chapter. The *fourth chapter* presents the experiment methodology, Taguchi experimental design methods, grey optimization techniques, and mathematical model for outcomes evaluation. In the *fifth chapter* of the

thesis, the experimental investigation of CI engine performance and emission parameters based on various blends of OPB, SOB, water emulsification, optimum level of OPB and SOB biodiesel blend, and optimum level of water emulsification with and without incorporation of Al_2O_3 and CNT additive is performed. In the *sixth chapter* of the thesis, the outcomes data was optimized according to Taguchi's experimental design using grey optimization techniques to select the optimum level of biofuel blend and water emulsification. Furthermore, the best outcomes data is also optimized using grey optimization techniques to obtain the best results. The *seventh chapter* contains concluding allusions and future scope.



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