CHAPTER 2

LITERATURE REVIEW

This chapter comprises the various literature reviews based on the preparation of biofuels and their blends, water-emulsified fuel, nano additive incorporated fuels, their application in CI engines, and the application of Taguchi-grey techniques in experimental design and optimization. The literature review is bifurcated into four sections. The first section comprises the preparation of biofuels and their blends and application in CI engines. The second section consists of preparing water-emulsified fuels and their blends and application in CI engines. The third section comprises the preparation of nano additive incorporated fuels and their application in CI engines. The fourth section contains the literature reviews based on applying Taguchi-grey experimental design and optimization techniques.

2.1 Preparation of Biofuels, Their Blend, and Their Application in CI Engines

The production of biofuels depends mainly upon two factors, i.e., available feedstocks and the method of biodiesel production. There are especially four methods of biodiesel production named direct blending, pyrolysis, microemulsion, and transesterification. The transesterification method is commonly used because the thermophysical properties obtained by the biofuels are found to be superior to others (Ma et al., 1999). The feedstocks available for biofuel production are classified into edible, non-edible, and other sources like animal fat and waste cooking oil (Gurunathan et al., 2015). The pros and concerns of applying various feedstocks in biodiesel production are discussed by Ambit et al. (2018). There is much literature available on the preparation of biofuels, their blend, and their application in CI engines (Man et al., 2016, Sathiyamoorthi et al., 2017, Karthickeyan et al., 2019, Lv et al.,2019,Venkatesan et al.,2020,Asadi et al., 2020, Hadhoum et al., 2021).

Sahoo and Das (2009) prepared the jatropha, polanga, and karanja biodiesel through the transesterification process and performed experiments with their blends. Experimental results revealed that the biodiesel blends had a shorter ignition delay period compared to diesel fuel. Qi et al. (2010) performed an experimental study of a diesel engine with a 50% biodiesel- diesel blend and methanol additive (5% and 10%). The biodiesel was prepared using Alkaline-catalyzed transesterification. The peak pressure, the peak of heat release rate, and the peak of pressure rise rate with methanol additive fuels were observed higher than the simple biodiesel blended fuel, and CO and smoke emissions were found reduced with an increase in additive percentage compared to blend fuel. Ilkılıç et al. (2011) prepared Safflower oil biodiesel using a transesterification process and performed an experimental analysis of diesel engines with biodiesel-diesel blends (5%, 20%, and 50% v/v) fuel. Experimental results revealed that with increasing biodiesel percentage average engine performances reduced, smoke and PM emissions reduced considerably, but NOx emission enhanced.

Kousoulidou et al. (2012) performed an experimental investigation of diesel engine performance emission parameters with pure biodiesel and 30% biodiesel-diesel blended fuel using a common rail fuel injection method and unit fuel injection system. The experimental results revealed that the common rail injection system was more compatible with biodiesel than the unit injector system in terms of NOx and PM emissions. The average NOx emissions were observed to increase and PM emissions were reduced with the biodiesel blend. Palash et al. (2013) performed an experimental analysis of a diesel engine with biodiesel using NOx emissions reduction techniques, i.e., additive addition, water emulsion, injection time retardation, and low-temperature combustion. Experimental investigation revealed that the low-temperature combustion method was the most efficient and prompts technique for NOx emissions reduction.

Harch et al. (2014) analyzed the diesel engine performance and emission parameters with biodiesel-diesel blended fuel (5% and 10% v/v). With 10% biodiesel blend fuel, improved performance and reduced emission level had been observed than the 5% blend fuel. Paul et al. (2014) performed an experimental and numerical analysis of diesel engine performance and emission parameters with diesel, biodiesel, and 50% biodiesel-diesel blend fuel. Experimental and numerical results revealed that BSFC enhanced, BTE reduced, and NOx emission enhanced with biodiesel blending. Pali et al. (2015) performed an experimental analysis of diesel engine performance and emission parameters with sal methyl ester blended fuel. Experimental results revealed that Sal methyl ester-diesel blends up to 40% volume could be used as a fuel in a diesel engine without any modification. Millo et al. (2015) performed an experimental analysis of diesel engine performance and emission parameters with diesel, diesel-rapeseed methyl ester (RME) (30% v/v) blend, diesel-hydro treated vegetable Oil (HVO) (30% v/v) blend fuels. Experimental results revealed that Torque output and smoke emission reduction were significant for RME blends. The CO and HC emissions reduction were substantial for the HVO blend. The NOx emissions with exhaust gas recirculation technology were notable for RME blend fuel compared to diesel and HVO blend fuel. Nabi et al. (2015) performed an experimental analysis of diesel engine performance and emission parameters with diesel-licella biofuel (5%, 10%, and 20%) blended fuels. Experimental results revealed that BTE and mechanical efficiency with biodiesel blend fuels were identical to diesel fuel and HC and NOx emissions enhanced with biodiesel blends. PM emissions were lowest with 20% biodiesel blended fuel. Shehata et al. (2015) analyzed the thermophysical properties of 20% soybean (S20) and

20% corn (C20) biodiesel-diesel blends. Experimental results revealed that the density, viscosity, and oxygen content were higher in C20 biodiesel blended fuel compared to S20 and diesel. The peak cylinder pressure was most elevated for diesel fuel with 200 bar induction pressure. Engine BTE was highest with S20, followed by C20 and diesel fuel.

Man et al. (2016) performed an experimental analysis of diesel engine performance and emission parameters with waste cooking oil biodiesel-diesel blended (10%, 20%, 30%, and 100%) fuels. Experimental results revealed that the HC, CO, and PM emissions were reduced, and NOx, formaldehyde, acetaldehyde, and benzene emissions increased with the biodiesel percentage in the blend. Abedin et al. (2016) analyzed the diesel engine performance and emission parameters with biodiesel –diesel fuel prepared by fumigation, lend, and emulsion dual fuel operating method. The analysis results declared that the BTE was enhanced in the emulsion method and reduced in the blend and fumigation method. NOx emissions were enhanced in the blend method and decreased fumigation and emulsion. CO and HC emissions were reduced in the blend method and improved in the fumigation and emulsion method. Dhinesh et al. (2016) performed an experimental analysis of diesel engine performance and emission parameters with Cymbopogon flexuosus biofuel blends (10, 20, 30, 40, and 100%). Experimental results revealed that the 20% Cymbopogon flexuosus biofuel blend fuel provided results closer to diesel fuel. Engine BTE enhanced, and HC, CO, and smoke emissions were reduced with 20% blend fuel. The 20% Cymbopogon flexuosus biofuel blends fuel could become the alternative fuel. Devarajan et al. (2017) performed an experimental analysis of diesel engine performance and emission parameters with palm oil biodiesel-diesel blend with cyclo ethanol additive. Experimental results revealed that the octanol and biodiesel blends provided earlier combustion than neat palm oil biodiesel. Higher thermal efficiency, lower fuel consumption, lower peak pressure, and shorter ignition delay have been observed. All the emissions were also found to be reduced with the octanol additive. Pradhan et al. (2017) examined the thermal kinetics of Shorea robusta seed during the pyrolysis process and the physicochemical properties of sources. Shorea robusta seed had low ash content, high volatility, and calorific value to suit pyrolysis applications. Deep et al. (2017) performed an experimental analysis of diesel engine performance and emission parameters with a 20% castor biodiesel diesel blend. The 20% castor biodiesel diesel blend fuel acts better with its original configurations and can be an alternative fuel for CI engines without any modification.

Gad et al.(2018) performed an experimental analysis of diesel engine performance and emission parameters with palm oil methyl ester (POME) blended (20% and 100% v/v) diesel fuel and declared that the engine performance and emission parameters improved with up to 20% POME blend by volume compared to diesel fuel. Sivaramakri-shnan (2018) performed an experimental analysis of diesel engine performance and emission parameters with karanja biodiesel–diesel blend (20%, 25%, and 30% v/v) and concluded that the engine BTE was observed as highest, and BSFC lowest with 25% biodiesel blend fuel. The NOx emission enhanced with the percentage of biodiesel blend. The engine performance and emission were observed optimum with a 25% biodiesel blend and 18 compression ratios. Ray et al. (2018) analyzed diesel engine performance and emission parameters with waste vegetable oil biodiesel and concluded that up to 20% biodiesel blend, the diesel engine's performance was observed almost similar to diesel fuel, but for more than 20% blends, engine performance was slightly reduced. Kill at al. (2019) performed an experimental analysis of diesel engine performance and emission parameters with low proportion (5%, 10%, 15%, 20%) of n- butanol to blends with a karanja methyl ester. Experimental results revealed that the 15% blends of n butanol- karanja methyl ester exhibit the best performance and lowest emissions among all four blends. Yesilyurt (2019) performed an experimental analysis of diesel engine performance and emission parameters with waste cooking oil biodiesel diesel blends varying injection pressure from 170 bar to 220 bar and the results revealed that the optimum fuel injection pressure was 210 bar for waste cooking oil biodiesel and diesel blends. Karthikeyan et al. (2019) performed an experimental analysis of diesel engine performance and emission parameters with diesel-water hyacinth biodiesel (WHB) blend fuel (10, 20, 30, 40, and 100% v/v). Experimental results revealed that the 20% WHB blend fuel had similar characteristics as diesel in terms of in-cylinder pressure, heat release rate, BTE, HC, CO, and smoke emission. The NOx and CO_2 emissions were slightly enhanced with 20% WHB blend fuel. Rajak et al. (2019) performed an experimental analysis of diesel engine performance and emission parameters with diesel and microalgae spirulina biodiesel blends (0, 20, 40, 60, 80, and 100% v/v). Experimental results revealed that the performance and emission characteristics were found to be optimum with a 20% spirulina biodiesel blend. The BSFC and CO_2 emissions were enhanced, and BTE, CO, HC, and NOx emissions were reduced at optimum for a 20% blend compared to pure diesel fuel.

Hariram et al. (2020) performed an experimental analysis of diesel engine performance and emission parameters with jojoba biodiesel-diesel blends. Experimental results revealed that the BTE and NOx emission was enhanced while CO, HC, smoke emission, and engine BSFC were reduced with escalating compression ratio from 17 to 18. Karthikeyan et al. (2020) performed an experimental analysis of diesel engine performance and emission parameters with diesel-S. marginatum macro algae biofuel – blends (20, 50, 75, and 100 % v/v). Experimental results revealed that the engine

BSFC, BTE, and exhaust gas temperature improve up to 20% in biofuel blends. Venu et al. (2020) performed an experimental analysis of diesel engine performance and emission parameters with chlorella emersonii methyl ester (CEME)- diesel blend fuels (10, 20, 30, 40, and 100 %). Experimental results revealed that the 20% CEME blend fuel had similar characteristics as diesel in terms of in-cylinder pressure, heat release rate, BTE, HC, CO, and smoke emission. The NOx and CO_2 emissions were slightly enhanced with 20% CEME blend fuel. Venkatesanet al. (2020) performed the experimental analysis of diesel engine performance and emission parameters with hybrid biofuel (Pine oil (100, 75, 50, and 25%) and soapnut oil (0, 25, 50, and 100%))-diesel blend. Experimental results revealed that up to 50%, pine biodiesel blended fuel had similar performance and emission characteristics and can be used as diesel engine fuel without any engine modification.

Hadhoum et al. (2021) performed an experimental analysis of diesel engine performance and emission parameters with olive mill wastewater (OMWW) biofuel blends (10%, 20%, and 30% v/v). Experimental results revealed that the 10% OMWW biofuel blended fuel provided the best result regarding BTE, HC, CO, and PM emissions. With 20 and 30%, OMWW biofuel blended fuel BTE reduces compared to diesel fuel. Boomadevi et al. (2021) performed an experimental analysis of diesel engine performance and emission parameters with microalgae spirulina biofuel blend (20, 40, 60, 80, and 100% v/v). Experimental results revealed that the 20% microalgae spirulina biofuel blended fuel provides good results in terms of engine performance. The CO, CO_2, and NOx emissions were reduced with increasing blend percentages, but at higher % blend results, the results obtained were negative due to lower energy input.

2.2 Preparation of Water Emulsion Fuels and Their Application in CI Engines

To minimize the gas pollutants and particulate matter emissions, efforts of many researchers and scientists are underway, and some provide methods like the application of post-combustion emission equipment, exhaust gas recirculation, different injection time, additive addition, water emulsion, and low-temperature combustion. Among all the proposed methods, applying water emulsion effectively minimizes gas pollutants and particulate matter (Palash et al., 2013). The application of diesel water emulsion fuel reduces the NOx emission due to dilution, thermal and chemical effects, and reduction in smoke due to micro explosion phenomenon and long ignition delay (Miyauchi et al., 1981, Murayama et al., 1978).

Lin et al. (2008) performed an experimental analysis of diesel engine performance and emission parameters with water in diesel emulsion fuel prepared with a mechanical homogenizer and ultrasonic vibrator method. The comparative analysis revealed that the emulsion prepared by ultrasonic vibrator had smaller dispersed water droplets, lower separation rate, larger emulsion stability, and viscosity, larger content of water emulsification, lower BSFC, lower fuel consumption rate, and significantly lower CO emissions than fuel prepared by a mechanical homogenizer. Kannan et al. (2009) performed an experimental analysis of diesel engine performance and emission parameters with diesel and water-emulsified diesel (10%, and 20% v/v). Experimental results revealed that engine brake thermal efficiency and BSFC improved, and NOx and HC emissions were reduced with an increase in water percentage. Selim and Ghannam (2009) performed an experimental analysis of the stability of water in diesel emulsion fuel with and without surfactant. Experimental results revealed that without surfactants, WiDE fuel had not shown stability. 10% water emulsion at 15000 rpm for 2 min with 0.2% surfactant has four-week strength, 20% water emulsion at 15000 rpm for 10 min with 1% surfactant has four-week stability, 30% water emulsion at 20000 rpm for 2 min with 1.7% surfactant had one-week stability. Alhmer et al. (2010) performed an experimental analysis of diesel engine performance and emission parameters with water-diesel emulsion fuel (0 to 30% blend). Experimental results revealed that the engine BSFC was the lowest, and torque, bmep, and BTE were the highest, with 5% water emulsion and 2000 rpm. Morozumi et al. (2010) analyzed the influence of emulsification on micro explosion occurrences and concluded that emulsifier affects the temperature of micro explosion and waiting time. Increasing the content of emulsifiers negatively affects micro-explosion occurrence.

Subramaniun et al. (2011) analyzed the effect of diesel emulsion and water injection into the intake manifold on diesel engine performance, combustion, and emission characteristics. Experimental results revealed that the emulsion method has a higher potential for simultaneous reduction of NO and smoke emissions at each load than the injection method. Tesfa et al. (2012) performed an experimental analysis of diesel engine performance and emission parameters with an injection of water in the intake manifold. Experimental results revealed that the injection of water into the intake manifold slightly improved the engine BTE and BSFC and reduced the NOx emissions significantly while enhancing the CO emissions. Ithnin et al. (2015) performed an experimental analysis of diesel engine performance and emission parameters with water-diesel emulsion fuel (5, 10, 15, and 20% water). Experimental results revealed that the 20% emulsion fuel produces maximum in-cylinder pressure and pressure rise rate. The water in diesel emulsion fuel is an appropriate alternative fuel that can bring about greener exhaust emissions and fuel savings without changing engine performance. Morsy et al. (2015) performed an experimental analysis of diesel engine performance and emission parameters with water-ethanol fumigation fuel. Experimental results revealed that the NOx emissions were reduced with water fumigation and were slightly enhanced with pure ethanol. The energy and exergy efficiency improved with water-ethanol fumigation. Vellaiyan et al. (2016) performed an experimental analysis of diesel engine performance and emission parameters with water-diesel emulsion fuel. Experimental results revealed that the NOx emission was reduced by 45%; PM emission was reduced by 80-90% with water-emulsified fuel. Incorporating nanoparticles with WiDE provided good combustion, performance, and emission characteristics with a shorter ignition delay period and complete combustion.

Park et al. (2016) analyzed the stability of water in diesel emulsion fuel prepared mixing with various surfactants (Span 80, Lecithin, PGO, Lanolin) and concluded that water-diesel emulsion fuel prepared using Span 80 and PGO had fine particle size and excellent stability. It was also found that less than 20% water diesel emulsion fuel can be used in a diesel engine. Khalife et al. (2017) performed an experimental analysis of diesel engine performance and emission parameters with water-emulsified diesel biodiesel blend fuel. Experimental results revealed that low-level water addition in the diesel biodiesel blends significantly reduced HC, CO, NOx, and CO_2 emissions. The optimum level of water emulsion was found at 4% by weight. Elsanusi et al. (2017) performed an experimental analysis of diesel engine performance and emission parameters with water-emulsified diesel biodiesel blend fuel. Experimental results revealed that the addition of biodiesel and water in diesel fuel enhanced droplet size and reduced the stability of the fuel. The NOx and smoke emissions were reduced, while CO emissions were enhanced with the increase in the level of water emulsification. Perumal et al. (2018) performed an experimental analysis of diesel engine performance and emission parameters with water-emulsified pongmia biodiesel –diesel blend. Experimental results revealed that the engine BSFC enhanced, and BTE, NOx, CO, and smoke emissions were reduced with water-emulsified pongmia biodiesel –diesel blend fuel. Moussa et al. (2018) analyzed the fuel properties of water in diesel emulsion and concluded that the ohnesorge number (oh) was an adequate parameter to know the effect of emulsion properties, droplet size, interference tension, and oil viscosity. For ohnesorge number 0.12, the rate of micro-explosion was found to be the highest. Wang et al. (2018) analyzed the combustion and micro-explosion phenomena of 10% ethanol bended diesel fuel (E10 and 10% water-emulsified fuel (W10). The spray and flame volume enhancement was observed higher in E10 and W10 fuel than in neat diesel fuel due to the micro explosion phenomenon. With E10, the micro explosion started at a lower and with W10 at a higher temperature. Ithnin et al. (2018) performed an experimental analysis of diesel engine performance and emission parameters with water-in-diesel emulsion with Span 80 and without any emulsifier. Experimental results revealed that the engine BTE and BSFC improved significantly with the emulsion fuel without surfactant. The NOx and PM emissions also reduced significantly.

Zhang et al. (2019) performed an experimental analysis of diesel engine performance and emission parameters with water-emulsified biodiesel–diesel blend fuel. Experimental results revealed that low-level water addition reduced NOx, CO, and CO_2 emissions. The optimal water addition level in terms of performance and emission characteristics is 4% (w/w) in biodiesel fuel. Mondal and Mandal (2019) reviewed the effect of water in diesel emulsion on engine performance and emission parameters. The review report concluded that the engine BSFC reduced and BTE enhanced with water emulsification. The NOx, HC, and PM emissions were reduced, and CO emissions were enhanced. Antonov et al. (2019) analyzed the effect of water-emulsified diesel biodiesel fuel on micro-explosion phenomena and concluded that the time to micro-explosion reduced with an increase in temperature and fuel droplet size, which weakly depends on fuel fraction. Preetika et al. (2019) analyzed the effect of Span 80, Tween 20, and a mixture of Span 80 and Tween 80 surfactants on the stability of water-emulsified diesel fuel and concluded that the emulsion fuel prepared using a mixer of Span 80 and Tween 20 surfactants shows higher stability than individual surfactants. A high level of 10% (v/v) surfactant fine droplet size was obtained.

Maawa et al. (2020) performed an experimental analysis of diesel engine performance and emission parameters with water-emulsified diesel palm oil biodiesel fuel. Experimental results revealed that the 5% water-emulsified diesel biodiesel (20% v/v) blend fuel shows the greatest improvement in engine torque and reduction in BSFC. The NOx emissions are reduced with an increase in the level of water emulsification. Patidar and Raheman (2020) performed an experimental analysis of diesel engine performance and emission parameters with water-emulsified diesel palm oil biodiesel fuel. Experimental results revealed that the 10% water-emulsified diesel biodiesel blend fuel had a higher ignition delay and heat release rate than diesel biodiesel blend fuel and diesel fuel. The engine BTE improved, and emissions like HC, CO, and NOx were reduced with emulsification. Khatri and Goyal (2020) reviewed the effect of water-emulsified diesel fuel on engine performance and emission parameters. The review study concluded that the engine with water-emulsified diesel fuel had insignificantly marginal differences in engine performance, while NOx and PM emissions were reduced significantly. Vellaiyan, (2020) performed an experimental analysis of diesel engine performance and emission parameters with water-emulsified soybean oil biodiesel fuel. Experimental results revealed that the 10% water-emulsified soybean biodiesel improved engine performance and reduced NOx, CO, smoke, and HC emissions. Jhalani et al. (2021) performed an experimental analysis of diesel engine performance and emission parameters with cow urine-emulsified diesel. Experimental results revealed that the 15% cow urine emulsified diesel fuel provides a remarkable change in engine BTE. The NOx and smoke emissions were also reduced.

2.3 Preparation of Nano Emulsion Fuels and Their Application in CI Engines

From the literature review shown above, it is found that the water emulsion technique is very effective in terms of reduction of NOx and PM emissions, but due to water emulsion in diesel engine ignition lag period enhances which causes higher pre mixed combustion rate and heat release rate (Subramanian and Ramesh, 2002, Patidar and Raheman, 2020). Many types of research are going on to shorten the ignition delay of diesel engines. Incorporating nano additives in diesel engine fuel increases the radiative/mass transfer properties and ignition temperature and reduces the ignition lag (Tyagi et al., 2008). The incorporation of Al nano additive in water-emulsified fuel acts as a catalyst and activates the molecular bonding of the water–diesel emulsion, due to which significant improvement in engine performance and emission parameters were observed (Kao et al., 2008).

Selvan et al. (2009) performed an experimental analysis of diesel engine performance and emission parameters with ceria nano additive incorporated biodiesel ethanol blend fuel. Experimental results concluded that the significant ignition lags shortening, reduction in heat release rate, and engine emission parameters. Sajith et al. (2010) performed an experimental analysis of diesel engine performance and emission parameters with ceria nano additive incorporated jatropha biodiesel fuel. Experimental results concluded that the engine BTE improves and NOx and HC emissions were reduced significantly. Basha and Anand (2011) performed the hot plate characteristics test showing a significant reduction in evaporation time by incorporating Alumina nano additive in water-emulsified diesel fuel. The remarkable enhancement in engine performance and reduction in emissions were also observed. Gan and Qiao (2012) analyzed the effect of Aluminium oxide and Aluminium nano additive incorporated ethanol fuel on fuel evaporation rate and concluded that the addition of nano additive enhanced ethanol fuel's radiation absorption capacity, which enhanced the nano fuel droplet temperature and evaporation rate. Balamurugan et al. (2013) performed an experimental analysis of diesel engine performance and emission parameters with Copper nano additive incorporated 10% soybean biodiesel blended diesel fuel. The remarkable enhancement in engine performance and reduction in NOx and smoke emissions were observed with copper nano additive incorporated with 10% soybean biodiesel blended diesel fuel.

Attia et al. (2014) performed an experimental analysis of diesel engine performance and emission parameters with Alumina nano additive (10 to 50 mg/l) incorporated 20% jajoba biodiesel blended diesel fuel. The fuel prepared by adding 30 mg/l nano additive shows optimum engine performance. The reduction in engine BSFC and emissions were highest with 30 mg/l nano additive. Mehta et al. (2014) performed an experimental analysis of diesel engine performance and emission parameters with Aluminium, Boron, and Iron nano additive incorporated in diesel fuel. Experimental results concluded that nano additive incorporated diesel fuel reduced ignition delay and sustained a longer flame. Maximum reduction in HC and CO emissions was observed with Aluminium nano additive. Shaafi and Velraj (2015) performed an experimental analysis of diesel engine performance and emission parameters with diesel- soybean biodiesel-ethanol blends, with alumina as a nano additive. Experimental results revealed that the cylinder pressure and heat release rate was higher, and the exhaust gas temperature was lower with the Alumina nano additive. The CO and HC emissions were reduced significantly with nano additive fuel.

Vellaiyan et al. (2016) performed an experimental analysis of diesel engine performance and emission parameters with water in diesel emulsion fuel and nano additive. Experimental results revealed that the water in diesel emulsion fuel enhanced the BTE and reduced the NOx emission of the diesel engine. The performance and emission attributes improved significantly with nano additive incorporation in water-based diesel emulsion fuel. Annamalai et al. (2016) performed an experimental analysis of diesel engine performance and emission parameters with Cerium oxide nanoparticles as an additive in Lemongrass Oil emulsion fuel. Experimental results revealed that the BTE improved for nano emulsion fuel. The CO, HC, and NOx emissions were reduced significantly with Cerium oxide nanoparticle additive fuel compared to Lemongrass oil emulsion fuel. Aghbashlo et al. (2017) prepared diesel engine fuels using 95% diesel, 5% biodiesel, and 3, 5, 7 (w/w %) of water emulsion. 0 and 90 ppm CeO_2 were used as a nano additive for analysis of performance and emission parameters. Experimental results revealed that the fuel prepared with diesel, 5% biodiesel blend, 3% water emulsification, and 90 ppm CeO_2 nano-additive had the best sustainability index. El-seesy et al. (2017) performed an experimental analysis of diesel engine performance and emission parameters by blending 20% jatropha biodiesel in diesel and containing multi-wall carbon nanotube (MWCNT) nano additive (10, 20, 30, 40, and 50 mg/L) fuels. Experimental results revealed that the 50 mg/L nano additive sample significantly improved the performance and combustion behavior. However, a 20 mg/L nano additive sample substantially reduced the emission level of the engine. The overall engine outcomes were optimal with a 40 mg/L nano additive. Hosseini et al. (2017) performed an experimental analysis of diesel engine performance and emission parameters with fuel prepared to blend diesel- biodiesel and CNT (30, 60, and 90 ppm) nano additive. Experimental results revealed that the addition of nano additive enhanced the power exhausts gas temperature (EGT) and reduced the BSFC, emissions like CO, UHC, and soot.

Vigneswaran et al. (2018) performed an experimental analysis of diesel engine performance and emission parameters with water in diesel emulsion along with a 1-4-dioxane multipurpose additive. Experimental results revealed that the fuel with a 10% additive significantly improved performance and emission attributes. Jiaqiang et al. (2018) performed an experimental analysis of diesel engine performance and emission parameters with fuel blends prepared using diesel-biodiesel and 2, 4, 6 (w/w %) of water emulsion with CeO_2 nano additive. Experimental results revealed that the addition of water up to 4% was beneficial, and the addition of nano additives enhanced the performance and reduced the emissions of the diesel engine. Najafi et al. (2018) performed an experimental analysis of diesel engine performance and emission parameters with the CNT and Ag nano additive incorporated diesel fuel. Experimental results revealed that with the addition of nano additive, the ignition delay period was reduced, and the heat release rate and peak cylinder pressure were enhanced. The best result was observed with a 120 ppm CNT nano additive. Hasannuddin et al. (2018) performed an experimental analysis of diesel engine performance and emission parameters with 10% water in diesel emulsion fuel incorporated with different nano additives (Al_2O_3, CuO, MgO, MnO, and ZnO). Experimental results revealed that the water in diesel emulsion with Al_2O_3 additive had the smallest droplet size, enhanced the torque, and reduced BSFC, BSCO, and BSNOx among all nano fuels. Ozcan et al. (2019) performed an experimental analysis of diesel engine performance and emission parameters with Al_2O_3 nano-additive (50 and 100 ppm) incorporated diesel-biodiesel blends fuel. Experimental results revealed that the addition of nanoparticles in greater instinct enhanced the engine's performance and reduced entropy generation and unaccounted losses.

Gharehghani et al. (2019) performed an experimental analysis of diesel engine performance and emission parameters with water-emulsified biodiesel-diesel blends incorporated with a nano-additive fuel. Experimental results revealed that with a 5% biodiesel-diesel blend, 7% water, and 90 ppm CeO_2 nano additive, the BSFC, CO, and NOx emissions were reduced significantly. Hawi et al. (2019) performed an experimental analysis of diesel engine performance and emission parameters with biodiesel-diesel blends incorporated with Iron dopes CeO_2 nano additive fuel. Experimental results revealed that the NOx and CO emissions were reduced significantly with nano additive; the best engine performance was observed with 30% biodiesel with 20% FeO_2 compared to 30% biodiesel with 10% FeO_2. Kumar and Raheman (2020) performed a characterization of water-emulsified biodiesel blends incorporated with nano-oxide additive fuel. The characterization results showed an optimal parameter for 69.7 ppm nano oxide concentration, 1% surfactant, 2500 rpm stirrer speed, and 10% water for stable fuel. Hoseini et al. (2020) performed experimental analysis of diesel engine performance and emission parameters with diesel biodiesel blends incorporated with graphene oxide powder. Experimental results revealed that the exhaust gas temperature was found to be significantly higher, and CO, HC, and NOx emissions were reduced with the graphene oxide powder. Mujtaba et al. (2020) performed experimental analysis of diesel engine performance and emission parameters with a diesel-biodiesel blend with oxygenated alcohols and CNT and TiO_2 nano additives. Experimental results revealed that maximum engine BTE and minimum CO and HC emissions were observed with 30% biodiesel- DMC alcohol blended fuel. NOx emissions were reduced highly with the CNT nano additive. Khatri and Goyal

(2020) performed an experimental analysis of diesel engine performance and emission parameters with Silicon dioxide (SiO_2) nanoparticles (25, 50, 75, and 100 ppm) on water diesel emulsified fuel. The performance of the engine with 50 ppm SiO_2 fuel was observed as optimum. With advancing injection time, the engine performances in BTE and BSFC improved, and engine emissions were reduced significantly. Wei et al. (2021) performed an experimental analysis of a diesel engine with Aluminum oxide (Al_2O_3) nanoparticles (25, 100 ppm) incorporated diesel-methanol blends. Experimental results revealed that the cylinder peak pressure, heat release rate, and engine BTE improved while ignition delay and combustion duration were reduced with the Al_2O_3 nano additive.

2.4 Application of Taguchi-Grey Experimental Design and Optimization Technique

Many experimental and optimization studies were performed to produce biodiesel from different sources and also examined the performance and emission characteristics using biodiesel and diesel blends as engine fuel. Taguchi method (Ganapathy et al., 2009, Sivaramakrishnan et al., 2012), response surface methodology (Hajra et al., 2015), grey relational analysis (Karnwal et al., 2011), nonlinear regression (Maheswari et al., 2011), and genetic algorithm (Alonso et al., 2007) is the most used optimization techniques for multi-response optimization. Deng first proposed grey relational analysis in 1989 to convert a multiple-response-optimization problem into a single-response optimization problem. Taguchi method is mostly used for parametric optimization in experimental design.

Kanwal et al. (2011) performed the optimization of engine output using the Taguchi-grey method with varying injection pressure, injection timing, compression ratio, and fuel blends. Optimization results revealed that the 30% thumba biodiesel blend fuel, 14 compression ratio, 250 bar injection pressure, and 20° bTDC injection timing provided optimum engine output. Sivaramakrishnan and Ravi kumar (2012) performed the optimization of engine output using the Taguchi method with variables injection pressure, injection timing, compression ratio, engine load, and fuel blends. Optimization results revealed that the 30% karanja biodiesel blend fuel, 17.9 compression ratios, 230 bar injection pressure, 27° bTDC injection timing, and 70% engine load were optimum input variables for optimum engine output. Pohit and Misra (2013) performed the optimization of engine output using the Taguchi-grey method with different blends of karanja biodiesel-diesel fuel. Optimization results revealed that the 50% karanja biodiesel blend fuel was the most suitable fuel for optimum engine output. Mohan et al. (2014) performed the optimization of engine output with variable fuel injection timing, injection pressure, and fuel blends. Optimization results revealed that the 20% mahua biodiesel blended fuel, either enhancing nozzle opening pressure to 275 bar or reducing injection timing to 21° bTDC provided the lowest engine emissions, which satisfies the norms of the Central Pollution Control Board. Roy et al. (2014) performed the optimization of engine output using the Taguchi-grey method with variable engine load, fuel injection pressure, and CNG blends. Optimization results revealed that the optimum engine input combination was a 4 kg load, 540 bar fuel injection pressure, and a 15% CNG energy supply. The engine load was observed as the most influencing factor.

Hajra et al. (2015) performed the optimization of the fuel preparation method using Response surface methodology and genetic algorithm. The influence of operating parameters and their interaction with biodiesel production has been successfully revealed. Kumar et al. (2016) performed the optimization of the fuel preparation method using the Taguchi-grey method with variable compression ratio, fuel injection timing, and biodiesel blends. Optimization results revealed that the engine operated on 20% blends, with a compression ratio of 18 at full load, and 23° bTDC injection timing provided the optimum results. Jadhav et al. (2016) performed the optimization of the fuel preparation method using the Taguchi-grey method with varying engine loads, and fuel types. Optimization results revealed that at optimum setting conditions, grey relation grade improved at part load and full load with mangifera indica biodiesel blends compared to other sets. Yadav et al. (2017) performed the optimization of fin design using the Taguchi-grey method with five aesthetic attributes for three levels of each. The experimental study provided the optimal design parameters of the fin as per customer expectations and helped to manufacture for the competitive market. Kumar et al. (2017) performed the optimization of engine output using the Taguchi-grey method with variable fuel injection timing, and biodiesel blends. The optimization results revealed that a 10% Diglyme blend, injected at 21^{o}CA, reduced smoke opacity and NOx emissions with the best engine performance.

Singh et al. (2018) optimized the production of biofuels using the Taguchi-grey method with varying catalytic concentration, molar ratio, reaction time, and reaction temperature as operation parameters. The optimization results revealed that the yield production obtained was 96.90% at a molar ratio of 6:1 with 1% catalyst concentration and a reaction time of 60 min at 60°C. Muqeem et al. (2018) performed the optimization of engine output using the Taguchi-grey method with fuel injection timing, compression ratio, air temperature, and air pressure. The optimum values of performance parameters were determined with the help of the S/N ratio and ANOVA. Natrajan et al. (2018) performed the optimization of engine output using the Taguchi-grey method. The optimization results revealed that the 20% ethanol blend was most suitable for the PPCCI engine in emission and performance responses. Paramasivam et al. (2019) performed the optimization of engine output using the Taguchi-grey method and optimization results revealed that 2 0% (v/v) blends of algae maremelos with diesel fuel provide lower emissions and higher brake thermal efficiency compared to diesel fuel. Vellaiyana et al. (2019) performed the optimization of engine output using the Taguchi-grey method with varying nano additive concentration, surfactant concentration, and water emulsification percentage. Optimization results revealed that the optimal input setting for better performance and lower emission level is 100 ppm ZnO nanoparticle incorporated, 20% water-emulsified diesel fuel with 10% SB concentration. Karthikeyan et al. (2019) performed the optimization of engine output using the Taguchi-grey method with varying exhaust gas recirculation, engine load, biodiesel percentage, and Ethyl Hexyl Nitrate (EHN) concentration. Optimization results revealed that the optimal input setting for optimum engine performance is 10% exhaust gas recirculation, 100% engine load, and 30% biodiesel with 0.5% EHN-diesel fuel. Venkatanarayana et al. (2019) performed the optimization of engine output using the Taguchi-grey method with varying compression ratio, engine load, and fuel injection timing. Optimization results revealed that the compression ratio was the most affecting parameter for BSFC, the load was the most affecting parameter for CO emissions, and injection timing is the most affecting parameter for smoke opacity. Singh et al. (2019) performed the optimization of engine output using the Taguchi-grey method with varying fuel injection timing, injection pressure, and biodiesel blending percentage. Optimization results revealed that the optimal input setting for optimum engine performance and emissions level was 15 ^{o}bTDC injection timing, 221 bar fuel injection pressure, and 40% cassia tora biodiesel blend fuel.

Ganesan et al. (2020) performed the optimization of engine output using the Taguchi-grey method with varying concentrations of nano additive, biodiesel blending percentage, compression ratio, and engine power. Optimization results revealed that with a 30% lemongrass biodiesel blend, 45 ppm CeO_2 nano additive, 14 compression ratios, and 4.4kW brake power, the engine performances were observed at maximum and emissions minimum levels. Chaudhary et al. (2020) performed the optimization of engine output using the Taguchi-grey method with varying engine load, engine speed, and biodiesel blending percentage. Optimization results revealed that the engine BSFC was found minimum at 1900 rpm speed, 75% engine load, and 40% blending of biodiesel in diesel fuel. Pure diesel fuel provided the lowest exergy destruction rate compared to biodiesel-diesel blend fuel. Singh et al. (2020) performed the optimization of engine output using the Taguchi-grey method with varying injection pressure, compression ratio, and engine load. Optimization results revealed that the best engine settings for optimum responses were 17.98 compression ratios, 269.96 bar injection pressure, and 12kgf engine load. Ayhan et al. (2020) performed the optimization of engine output using the Taguchi-grey method with varying engine load, biodiesel blending percentage, engine speed, and exhaust gas recirculation. Optimized results revealed that the BSFC and BTE were optimal at 80% engine load, 10% biodiesel blend with EGR, and 1600 rpm engine speed. The CO, HC, and CO_2 emissions were observed at a minimum at low load, low rate, and without EGR. Kumar et al. (2020) performed the optimization of engine output using the Response surface method with varying engine load, engine speed, and fuel injection timing. Optimized results revealed that the maximum level of smoke reduction was observed at 12 ^{0}CA (crank angle), 70% engine BP and 2300 rpm speed, and the top rank of NOx enhancement was observed at 15 0CA, 70% engine load, and 2300 rpm engine speed with jatropha biodiesel fuel.

Yessian et al. (2020) performed the optimization of engine output using Taguchi-grey relational analysis and concluded that with the copper zirconium catalytic coated piston engine performance parameters were observed to improve, and emission levels reduce.

Singh et al. (2021) performed the optimization of engine output using the Response surface method with varying engine load, compression ratio, and biodiesel blending percentage. The predicted model at 64.634% engine load, 16.50 compression ratio, and 20% biodiesel blended fuel provided 274.97g/kWh engine BSFC, 31.57% BTE and lower value of PM, CO_2, and NOx emissions. Subramani et al. (2021) performed the optimization of engine output using Taguchi-grey relational analysis, and concluded that the best engine running conditions for optimized NOx emission were observed with diesel fuel, 15% propanol & 10% butanol, 23 ^{0}CA, 250 bar IP, 15% EGR, and toroidal piston.

2.5 Highlights

The literature study found many types of oil sources, i.e., edible (palm oil, rapeseed oil, coconut oil, etc.) and non-edible (Jatropha oil, microalgae oil, mahua oil, sal seed oil) have been used for biofuel production. The pros and consequences of the application of these oils are also discussed. The different methods of biofuel production, like pyrolysis, direct blending, and transesterification, are also studied. The transesterification method is most suitable for producing biofuel in terms of fuel thermo physical properties, and percentage yields. The literature review also declared that due to the application of biofuel blending, engine performances deteriorated, and NOx emissions enhanced. Some researchers added water to diesel fuel to overcome the consequences of biofuel blending. The water in diesel fuel is added by different methods like direct mixing, water adding into the intake manifold, and water emulsification, but a literature review resulted that water in diesel emulsification technique of water addition is the best technique. The engine BTE improves and emissions like HC, CO, and NOx reduce with water emulsification, but at the same time, the ignition lag period and heat release rate enhances. To shorten the ignition lag period, many researchers used nano additives of metal (Al, Cu, Fe, and Zn, etc.), metal oxide (Al_2O_3, TiO_2, and ZnO), and carbon-based additives (SiC, CNT, Graphene, etc.) with base fuel. The nano fuels are prepared by different methods like mechanical homogenization, mechanical agitation, and ultrasonication. The ultrasonication method is found best in terms of fuel particle size and stability. Researchers also used different optimization techniques like Taguchi, response surface methodology, grey relational analysis, and nonlinear regression to optimize engine performance and emission characteristics. Taguchi method is mostly used for parametric optimization in experimental design.

2.6 Research Gap and Scope

The available literature study found that many techniques have been done to improve the diesel engine performance and emission characteristics. However, still, there are the following gap has been observed.

- No literature is found for using orange peel biodiesel and sal seed biodiesel for complete analysis (i.e., energy, exergy, and emission analysis with optimization) in the multi-cylinder diesel engine with varying engine load and engine speed.
- No literature is found on optimizing the level of water emulsion and the level of orange peel biodiesel and sal seed biodiesel blending in diesel fuel.

- No literature is found on the competition for analysis of multi-cylinder diesel engines with varying engine load and engine speed running on optimized levels of water emulsified and orange peel biodiesel and sal seed biodiesel blended diesel fuel.
- No literature is found on comparative analysis of multi-cylinder diesel engines with varying engine load and engine speed fuelled with an optimized level of water emulsified, and optimized level of orange peel biodiesel and sal seed biodiesel blended diesel fuel incorporated with Al_2O_3 and CNT different shapes nano additive.
- No literature is found with mixed Taguchi design, and grey relational analysis of diesel engines running with water-emulsified biodiesel–diesel blend fuel with different shapes of nano additive (Al_2O_3 and CNT).

2.7 Objectives of The Current Study

Following are the main objectives of the current study.

- Develop an experimental framework for the direct use of biodiesels in the diesel engine
- Measurement of thermophysical properties of prepared fuels and nano fuel samples.
- The investigation of the effect of blending of biodiesels, water emulsification, engine load, and engine speed on engine performance and emission characteristics and its optimization.
- Selection of the optimum level of the blend of biodiesels and optimum level of water emulsification based on engine performance and emission characteristics optimization.

- The comparative analysis of the effect of nano fuels, engine load, and engine speed on engine performance, emission characteristics, and optimization.

Hence, a detailed experimental study has been performed in this thesis to accomplish the research mentioned above gaps. Based on the critical examination of the literature review, the primary aim of this thesis is to determine the effects of different levels of water emulsification (5%, 10%, and 15% v/v), the impact of varying levels of biodiesels (OPB and SOB) blend (10%, 20%, and 30% v/v) on engine performance and emission characteristics. Furthermore, the determination of the optimum level for water emulsification and optimum level for biodiesel (OPB and SOB) blending is to obtain an optimum level of engine performance and exhaust emissions. The second objective of this thesis is to perform a comparative analysis of diesel engine performance and emission characteristics based on diesel fuel, the optimum level of diesel-based biodiesel (OPB and SOB) blend fuel. Also, the optimum level of water-emulsified biodiesel (OPB and SOB)- diesel blend fuel with and without Al_2O_3 and CNT nano additive and to obtain the optimum set of input variables for getting the optimum level of engine performances and exhaust emissions have been discussed well.