The Effect of Nano-Additive Blended Water-Diesel Emulsion Fuel on CI Engine Performance and Emissions- A review

Rajwinder Singh
Mechanical Engineering Department
Thapar University
Patiala, Punjab, India

Sumeet Sharma
Mechanical Engineering Department
Thapar University
Patiala, Punjab, India

D.Gangacharyulu
Chemical Engineering Department
Thapar University
Patiala, Punjab, India

ABSTRACT
Nano-additives blended water-diesel emulsion fuel is the alternative fuel for compression ignition (CI) engine that reduce the NO_x emission and at the same time increase the brake thermal efficiency due to combined effect of nanoparticles and micro explosion phenomenon of water diesel emulsion. This review paper addresses emulsion, emulsion types, micro-explosion phenomenon of water-diesel emulsion and impact of nano-additive blended water diesel emulsion on the performance and exhaust emission of CI engine. Further, this review paper discusses the long run scope of nanoparticles in water diesel emulsion. .

General Terms
Water-diesel emulsion, CI engine performanceand emission characteristics

Keywords
Micro-explosion, Hydrophilic lipophilic balance, Three phase emulsion, Engine performance, Emission, Nano-fluids

1. INTRODUCTION
Diesel engines have significant role in transportation, agriculture, heavy industries and power generation due to their high power to weight ratio, better fuel economy and low breakdown rate [1]. In spite of its numerous advantages over spark ignition engine (SI) engine, they are also responsible for nearly forty harmful pollutants such as NO_x, HC, CO, PM, CO_2 and SO_X, etc [1, 2, 3]. The emission mixture contains very small size carbon particles having size less than one micron. These particles combine with hazardous compounds and inhaled into lungs due to their small size and leads to severe asthma attacks [3].

A change in climate due to fast increase of greenhouse gases in the atmosphere is the major problem in the front of whole world. Due to emission problem, permissible level of particulate matter (PM) in Euro 6 is reduced to 0.0045 g/Km from 0.025 g/Km of Euro 4 in all passenger cars and light commercial vehicles, whereas 50% reduction of PM emission is targeted in case of heavy duty diesel engine in Euro 6 [4].

Further, this present situation gets complicated with the depletion of natural resources. From the past several years, research is going on to tackle these problems by providing hardware and fuel based solutions. Modern hardware solutions to control pollution are piezo-injectors, high-pressure fuel injection equipment, exhaust gas recirculation system and diesel particulate filters [5-8]. However, the problem with these systems is that they require modification in the existing engines which is time consuming and costly. On the other hand, fuel based solutions are viewed as a possible as well as economical solution which can solve both the problems (emission and depletion of resources) at the same time. Various fuel-based solutions are:-

1.1 Biodiesel
Biodiesel is always considered as a substitute of diesel fuel for compression ignition (CI) engines. Biodiesel contain 10% - 15% oxygen by weight, which helps in complete combustion of fuel inside the combustion chamber. This leads to lesser emission from biodiesel engine as compared to diesel fuel [9]. Other advantages of biodiesels are their high lubricating efficiency, higher cetane number, high flash point and very low sulphur content due to which it is also known as sulphur free fuel [10, 11]. However, as compared to diesel fuel, biodiesel is more expensive due to high price of plant oil and expensive processing technologies for producing it [12]. Moreover, the heating content of biodiesel is 12% less then neat diesel on the mass basis. This means for obtaining same engine efficiency, additional fuel is required to burn [9]. Further, they also give rise to the formation of deposits and plugging of filters [13].

1.2 Water-diesel emulsion
Research witnessed that both primary and secondary water-diesel emulsions can be utilised as an alternative fuel for CI engine. Presence of water in the combustion chamber reduces the adiabatic flame temperature, which leads to the reduction of NO_x emission. Research shows that the addition of 5% to 20% of water reduces the NO_x emission from 10% to 35%, respectively [14]. Furthermore, micro-explosion phenomenon helps in complete combustion of fuel in combustion chamber due to secondary atomization. Fahd et al. [15] investigated the effect of 10% water in diesel emulsion on 2.5L four cylinder turbocharged CI engine and the results illustrate a reduction in both NO_x and CO emission at higher engine loads. Two other methods practiced to inject water into CI engine (other than emulsion) are injection of water in intake manifold and direct injection of water into the combustion chamber with the help of separate injector [8]. Both methods reduce the NO_x emission but they increase HC and CO emission. Furthermore, they gave rise to oil contamination and engine wear.

1.3 Nano-fluids
Advancement of nanoscience makes it possible to get desired fuel properties by adding nanoparticles/nanotubes into diesel, biodiesel and water diesel emulsion. Addition of nanoparticles changes the thermo-physical properties of base fluid due to their large surface area to volume ratio, which helps in rapid

oxidation process [16-18]. Metal-based additives also reduce emission from CI engine by producing hydroxyl radicals, which helps in soot oxidation [19-23]. Keshin et al. [24] have experimentally investigated the effect of Mg and Mo nanoparticles on the performance and emission characteristics of single cylinder direct injection diesel engine. They observed a significant improvement in brake thermal efficiency whereas CO emission and smoke opacity reduced by 56.42% and 30.43%, respectively.

2. EMULSION

An emulsion is a colloidal suspension of water in diesel with the help of emulsifying agents/surfactants. Three basic requirements to make stable emulsion are [25]:

- Two fluids must be insoluble or immiscible in one another.
- Adequate agitation must be applied to disperse one liquid into another.
- An emulsifier or a mixture of emulsifiers must be present.

Surfactants weaken the surface tension of base fluid and helps in making stable emulsion. It was found that mixture of surfactants shows better stability of emulsion as compared to single surfactant. Surfactants consist of hydrophilic head (polar) and hydrophobic tail (non-polar). During emulsification, hydrophilic head is oriented towards water whereas hydrophobic tail towards oil, results into a non-adhering film around dispersed droplet [26-28].

2.1 Types of emulsion

Two different techniques to produce emulsification are two phase emulsion (primary emulsion) and three-phase emulsion (secondary emulsion/ multi-phase emulsion) technique. This classification based on the number of phases present in the emulsion. If two phases are present then it is called two phase emulsion, if three phases then three phase emulsion and for more than three phases, it is called multiphase. Further, this classification subdivided on the way these different phases are present in emulsion.

2.1.1 Primary emulsion

Primary emulsions are also called two-phase emulsion. It consists of continuous phase and dispersed phase. Two phase emulsion is the most common type of emulsion that is found in our daily life as butter, margarine mayonnaise. It is subdivided into-

- Water-in-oil emulsion
- Oil-in-water emulsion

The emulsion in which water act as a dispersed phase in oil (continuous phase) is called water-in-oil emulsion. Hydrophilic lipophilic balance (HLB) is used for mixing two surfactants to get desired properties. HLB value 6 to 8 shows better stability in case of water-diesel emulsion. The emulsion in which oil act as a dispersed phase in water (continuous phase) is called oil-in-water emulsion [4].

2.1.2 Secondary emulsion

Emulsion that contain one continuous phase and two or more dispersed phase called secondary emulsion or three-phase emulsion. Its further classification is-

- Oil-in-water-in-oil emulsion
- Water-in-oil-in-water emulsion

Since the focus of this paper is on emulsion as a fuel for CI engine, therefore only oil-in-water-in-oil emulsion is explained in detail. Mostly oil-in-water-in-oil emulsion is prepared in two steps.

- Making of two-phase oil-in-water emulsion with the help of hydrophilic type of surfactant.
- Further, emulsification of oil-in-water emulsion to oil with the help of lipophilic type of surfactant.

Yuan and Hua [29] worked on three-phase emulsion, and indicated that oil-in-water-in-oil emulsion have lower brake specific fuel consumption, CO emission but have higher NO_x and smoke opacity as compared to water-in-oil emulsion. Furthermore, high cost of production and more time consumption limits the use of three-phase emulsion.

2.2 Micro explosion phenomenon

Breakdown of a single droplet of fuel into a number of droplets is called micro-explosion. Both water and diesel have different boiling point and evaporation rate. Due heat transfer (by convection and radiation) in combustion chamber, water (water in oil emulsion) reaches their superheated state faster than diesel and create vapour expansion breakup of emulsified fuel droplets. Water in diesel emulsion shows better mixing of fuel in combustion chamber, higher brake thermal efficiency and lesser NO_x and PM emission [30-33]. The main principle behind the working of water in diesel emulsion is micro-explosion as explained above due to increase in surface area exposed of fuel to air as a results breakup of single droplet into a number of droplets. Figure 1 shows micro explosion phenomenon. Morozumi and Saito [34] studied the effects of different factors on micro-explosion occurrence in water in oil emulsion droplets and it was found that micro-explosion is mainly influenced by the amount of water and volatility of base fuel.

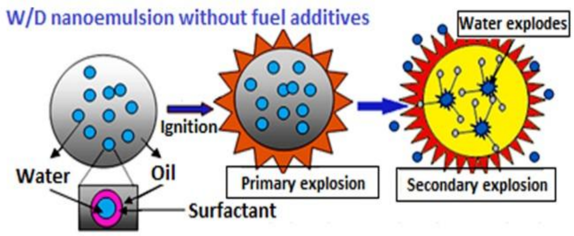

Fig 1.Micro-explosion phenomenon of water diesel emulsion droplet in combustion chamber [38]

3. EFFECT OF NANO ADDITIVES BLENDED WATER DIESEL EMULSION ON PERFORMANCE AND EMISSION CHARACTERISTICS

Sasi and Senthil [35] investigated the effect of aluminum nanoparticles on the performance and emission characteristics of single cylinder,four-stroke,speed well oil engine. Two-phase water-diesel emulsion with 15% water content was used as a base fluid for adding 25 ppm aluminium nanoparticles. Increase in brake specific fuel consumption and brake thermal efficiency was observed at part load due to the addition of aluminium nanoparticles. Both CO and HC emission reduced by 30 % and 26 %, respectively whereas NO_x emission reduces to 800 ppm from 850 ppm with the addition of nanoparticles.

Table 1. Engine performance of nanoparticle blended water diesel emulsion under various testing conditions

Engine Type	Water content	Surfactant and its amount	Nano particles	Amount of nano particle	Effect on specific fuel consumption	Effect on brake thermal efficiency	Effect on NO_x	Effect on HC	Effect on CO	Ref.
1C, 4S Speed well oil engine Ltd &SW-3B	15% by volume	Span 80, 2% by volume	Aluminum oxide	25 ppm	Reduced at part load	Higher than diesel at part load	50 ppm lower in diesel	30% reduction	26% reduction	35
1C, 4S DI Kirloskar engine	15% by volume	Mixture of Span 80 and Tween 80, 2% by volume	Al_2O_3 (51 nm size)	25, 50 and 100 ppm	Decreases with the increase of nanoparticles	Increases with the increase of nanoparticles	Decreases with the increase of nanoparticles	Lowest for 100 ppm concentration	Decreases with the increase of nanoparticles	36
4S, CI water cooled Kirloskar engineTV1 engine	0.5%, 1% and 2% by volume	Span 80	Aluminum (5 to 150 nm)	Aluminum particles - 0.1% by wt.	21% reduction	Increased by 16%	Increased by 5%	4% reduction	--	37
			Nano silicon (5 to 140 nm)	NanoSilicon - 0.1% by wt.	37% reduction	Increased by 14%	Increased by 4%	9% reduction	--	37
Engine test bed (Model SOLTEQ TH 03) and Diesel engine (MODEL YANMAR L48N)	0.7% to 1% by volume with step size – 0.1% by volume Triton X-100,	0.25% to 0.40% by volume with step size 0.05% by volume	Cerium oxide	80 ppm	Highest reduction of 24% at 0.8% water content	Increased by 8.77%	Reduced	Reduced	Increased	38

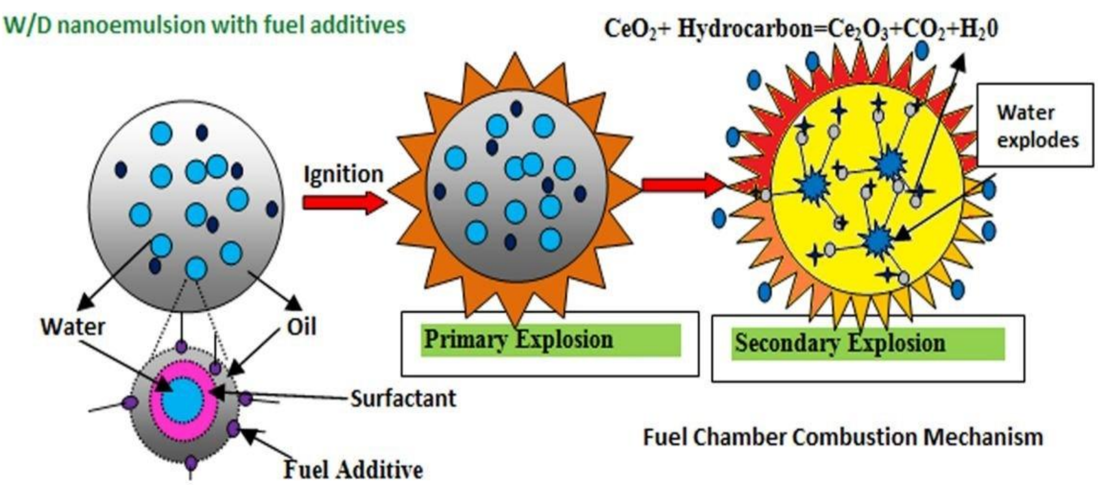

Fig 2.Micro-explosion phenomenon of water diesel emulsion droplet in with CeO_2[38].

Sadhik and Anand et al. [36] studied the effect of Al_2O_3 blended water-diesel emulsion fuel on single cylinder four stroke direct injection kirloskar engine.Mixture (2% byvolume) of span 80 and tween 80 were used to obtain two-phase water-diesel emulsion with 15% water content. Three different concentrations of Al_2O_3nanoparticles (25 ppm, 50 ppm and 100 ppm) were used in the study. Decrease in brake specific fuel consumption and increase in brake thermal efficiency was observed when Al_2O_3 concentration increases from 25 ppm to 100 ppm. Lower NO_x, HC and CO was observed with 100 ppm concentration of Al_2O_3.

Mehta et al. [37] experimentally investigated the effect of aluminium and nano-silicon blended water diesel emulsion on four cylinder water cooled compression ignition kirloskar engine. Both Aluminium nanoparticles (0.1% by weight) and nano-silicon (0.1% by weight) added (separately) into water-diesel emulsion with 0.5%, 1% and 2% water content. Aluminium nanoparticles blended water-diesel emulsion fuel (W/DA) reduces the brake specific fuel consumption by 27% whereas 37% reduction was observed in nano-silicon blended water-diesel emulsion fuel (W/DS). Both W/DA and W/DS increase the brake thermal efficiency by 16% and 14%, respectively. However, in case of NO_x emission, both W/DA and W/DS shows negative effect. However, 4% and 9% reduction was observed in HC with W/DA and W/DS, respectively.

Bidita et al. [38] studied the effect of different surfactant concentrations, water concentration and cerium oxide nanoparticles on diesel engine. In experiment, different blends of water diesel emulsion of 0.7%, 0.8%, 0.9% and 1% water content (by volume) was prepared with the help of 0.25%, 0.30%, 0.35% and 0.40% Triton X-100 surfactant (by volume). Concentration of cerium oxide (80ppm) was held constant during the experiment. Highest reduction of 24% in brake specific fuel consumption was observed in 0.8% water content whereas highest brake thermal efficiency of 37.2% was observed with 0.40% surfactant concentration. Highest reduction of 61% in NO_x emission was observed with 0.1% water and 0.40% surfactant concentration which can be due to the conversion of CeO_2 to more thermally stable Ce_2O_3 as a result of oxidation of hydrocarbons as shown in figure 2.

A broad classification of the review data in this paper has been presented in table 1.

4. CONCLUSION

A plenty of research have been done on emulsion preparation methods, performance and emission characteristics of compression ignition engines by varying the amount of water in diesel.Further, many researchers have reported the effect of various emulsion preparation methods on the stability of emulsified fuel.With the advancement of nanofuids, many researchers have examined the impact of varies nanoparticles on the performance and emission characteristics of CI engine but most of the current research and development have been focused solely on nanoparticles dispersed in diesel or biodiesel as base fluid. However, the experimentation done on the emulsion prepared by dispersing water in diesel have shown promising results, hence the effect of nanoparticles in emulsion used as a fuel for compression ignition needs to be studied because experimental data of nanoparticles in diesel and biodiesel had encouraging results.

Settlement of nanoparticles is the main problem, which limits its use in diesel, biodiesel as well as in water-diesel emulsion. Therefore, there is a need to find better surfactant or techniques, which ensure higher stability of nanoparticles in all the above-mentioned fuels.

So far, all the experiments have only shown the effect of alternative fuels on enhancement in the performance of engine like brake specific fuel consumption, brake thermal efficiency, and exhaust emissions. However, none of these experiments has given an insight on the long-term effects that these fuels may have on the engine that is piston, cylinder and ring wear, injector nozzle wear and the level of contamination of engine oil taking place.

Another point of concern is the effect of nanoparticles used in the fuel on exhaust gas and its impact on the environment.

All the above-mentionedpoints areneeded to be investigated carefully to deeply understand the influence of nanoparticle blended water diesel emulsion on CI engines. Further, more experiment investigations are needed, to optimize nanoparticle blended water diesel emulsion for commercialization.

5. REFERENCES

[1] Lin, C., Wang, K., Fuel 82, 1365 (2003)

[2] Cai, L. X., Guang, Y. J., Gao, Z. W., Zhen, H., Fuel 83, 2013 (2004)

[3] Wargo, J., Wargo, L., Alderman, N.,The Harmful Effects of Vehicle Exhaust 1 (2006)

[4] Khan, M. Y., Karim, Z. A. A., Hagos, F. Y., Rashid A. A., Isa M. T., Scientific World J. 2014, 527472 (2014)

[5] Lif, A., Holmberg, K., Adv. Colloid Interface Sci. 123–126, 231 (2006)

[6] Kadota, T., Yamasaki, H., Prog. Energy Combust. Sci. 28, 385 (2002)

[7] Armas, O., Ballesteros, Martos, Agudelo, Fuel 84, 1011 (2005)

[8] Ghojel, J., Honnery, D., Khaleef, Appl. Therm. Eng. 26, 2132 (2006)

[9] Kumar, S. D., Pravin, R., Nikul, P., Int. J. Adv. Eng. Technol. 4, 66 (2013)

[10] Demirbas, A., Energy Convers. Manage. 50, 14 (2009)

[11] Gui, M. M., Lee, K. T., Bhatia, S., Energy 33, 1646 (2008)

[12] Singh, G., Sharma, S., IJCET 4, 1034 (2015)

[13] Lapuerta, M., Armas, O., Fernandez, J. R., Prog. Energy Combust. Sci. 34, 198 (2007)

[14] Kadota T., Yamasaki H., Prog. Energy Combust. Sci 28, 385 (2002)

[15] Fahd, M., Wenming, Y., Lee, P. S., Chou, S. K., Yap, C., R., Appl. Energ. 102, 1042 (2013)

[16] Wen, D., Energy Environ. Sci. 3, 591 (2010)

[17] Rossi, C., Zhang, K., Estève, D., Alphonse, P., Tailhades, P., Vahlas, C., Microelectromech. Syst. 16, 919 (2007)

[18] Sun, J., Simon S. L., Thermochim. Acta 463, 32 (2007)

[19] Yang, H. H., Lee, W. J., Mi, H. H., Wong, C. H., Chen, C. B., Environ. Int. 24, 389 (1998)

[20] Kasper, M., Sattler, K., Siegmann, K., Matter, U., Siegmann, H. C., Aerosol. Sci. 24, 217 (1999) Miyamoto, N., Hou, Z., Harada, A., Ogawa, H., Murayama, T., SAE Trans 96, 792 (1987)

[21] Kannan, G. R., Karvembu, R., Anand, R., Appl. Energ. 88, 3694 (2011)

[22] Kumar, A., Sharma, S., IJCET 4, 2892 (2014)

[23] Keskin, A., Guru, M., Altiparmark, D., Bioresour. Technol. 99, 6434 (2008)

[24] Chen, G., Tao, D., Fuel Process. Technol. 86, 499 (2005)

[25] Fingas, M., Fieldhouse, B., Hazard. J., Mater. 107, 37 (2004)

[26] Jiao, J., Burgess, D. J., AAPS PharmSciTech 5, e7 (2003)

[27] Lin, C. Y., Wang, K. H., Fuel 83, 537 (2004)

[28] Lin, C. Y., Lin, S. A., Fuel 86, 210 (2007)

[29] Watanabe, H., Suzuki, Y., Harada, T., Matsushita, Y., Aoki, H., Miura, T., Energy 35, 806 (2010)

[30] Watanabe, H., Matsushita, Y., Aoki, H., Miura, T., Combust. Flame 157, 839 (2010)

[31] Fu, W. B., Hou, L. Y., Wang. L., Ma, F. H., Fuel Process. Technol. 79, 107 (2002)

[32] Lin, C. Y., Chen, L. W., Fuel Process. Technol. 87, 309 (2006)

[33] Morozumi, Y., Saito, Y., Energy Fuels 24, 1854 (2010)

[34] SasiKumar, N., Senthilkumar, M.,JCPS 6, 37 (2015)

[35] Basha, J. S., Anand, R. B., Int. J. Green Energy, 8, 332 (2011)

[36] Mehta, R. N., Chakraborty, M., Parikh, P. A., Int. J. Hydrogen Energy 39, 8098 (2014)

[37] Bidita, B. S., Suraya, A. R., Shazed, M. A., Mohd Salleh, M. A., Idris, A., Energy Fuels 28, 4149 (2014)