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Water addition in combustion chamber of single cylinder diesel engine A Review study

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Abstract *— The concept of water addition to the IC engine has been around for over 50 years. This review of research targets comparing effect of water addition by fumigation, direct injection and emulsion. Fumigation shows simplest technique to introduce water in combustion chamber, with minimum modification in engine setup. Direct water injection require major modification but suitable for variable load condition, emulsion shows most promising technique compare to other two with advantage of microexplosion phenomena. Water–diesel emulsion results in higher ignition delays, peak pressures and rates of pressure rise. , higher potential of simultaneous reduction of NO and smoke emissions at all loads compare to other methods.*

Keywords: *Diesel engine ,water , Emission, Emulsion, NOx*

I. INTRODUCTION

Diesel engines offer better fuel to power conversion efficiency and due to their better fuel economy, diesel engines are the dominant class of engines in mass transportation, heavy industries, and agricultural sectors. In spite of their preferable advantages, they are one of the major pollution contributors to the environment. Primary pollutants emitted from diesel engines are particulate matters (PM), black smoke, nitrogen oxides (NO*x*), sulphur oxides (SO*x*), unburned hydrocarbon (HC), carbon monoxide (CO), and carbon dioxide (CO2)[6].

Recent fluctuations in fuel prices have underscored some of the pressures under which the engine industry operates. In many industries, fuel economy is a primary concern, yet health risks from high concentrations of airborne toxins cannot be ignored. Thus, constraints from legislating bodies combine with market forces to push engine manufacturers towards creating engines that simultaneously use less fuel and produce fewer harmful pollutants [2].

The concept of water addition to the IC engine has been around for over 50 years. Diesel engines are nominated for highly emission producer like NOx, CO, CO2 and HC. These emissions are highly depending upon the combustion chamber temperature .Therefore by controlling peak combustion chamber temperature NOx formation can be controlled effectively.[9]

Researchers have attempted to reduce the emission and improve the fuel conversion efficiency of diesel engines. One promising method may be the use of water emulsified diesel which can economically accomplish both of these goals.

The proven benefit of the water introduction with diesel is that the heat absorption by water vaporization causes a decrease of local adiabatic flame temperature and therefore reduces the chemical reaction in gas phase to produce thermal NOx.[9] The latent heat of evaporation of water is 2256 kJ/kg.

The use of water as supplement to fuel-air mixture has been considered repeatedly since the early development of internal combustion engines (ICEs). Water has been added as an internal coolant and a means to control emissions. [1]

II. INTRODUCTION OF WATER IN COMBUSTION CHAMBER

As shown in figure 1 , water can be introduced into the combustion chamber in three different ways : (a) Fumigation , (b) Parallel water and diesel injections, and (c) Emulsion .[10]

A. Fumigation

Fumigation is where water in liquid or vapour form is injected into the intake manifold upstream of the intake valve. The fumigation technique has been shown to reduce NOx emissions in DI Diesel applications but suffers from the drawback that the liquid water in the combustion chamber is typically in areas where it is less effective at reducing emissions. Therefore, fumigation requires approximately twice the liquid volume for the same reduction in engine out NO_x when

compared to DW injection. Additionally, liquid water present after combustion can contaminate the oil and increase engine wear.[2]

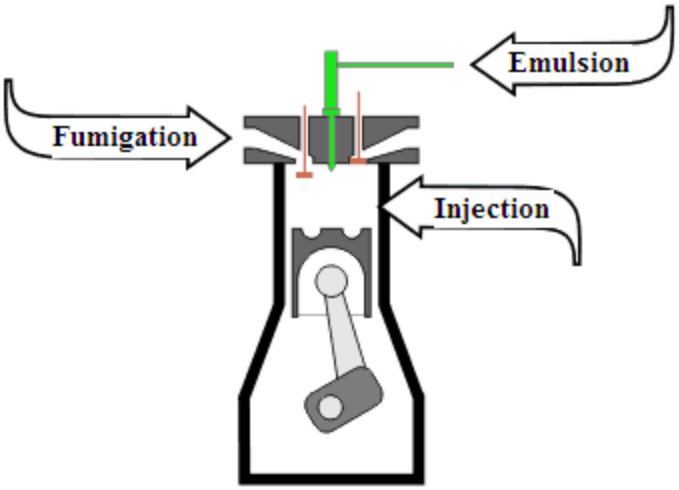

Figure 1. Techniques of water introduction in Combustion Chamber of IC engine[11]

B. Direct Water injection

In-cylinder injection of water requires a separate, fully independent injection system, preferably under electronic control. This method offers the capability to inject very large quantities of water without the need to derate the engine. This system also allows to switch the water injection on and off, as may be needed, without affecting engine reliability. Direct water injection needs to be carefully optimized with respect to injection timing, water consumption, emissions, and other parameters. This flexibility in optimizing parameters allows to achieve NO_x reductions similar to those seen in emulsion systems.[1] DW injection has the advantage over fumigation of having the liquid water close to the flame and away from the wall. Unlike emulsified fuels, DW injection allows the fuel-water percentage to be changed for cold start or different operating ranges .Although the injection system needs to be modified for DW injection. [2]

C. Emulsion

An emulsion is a mixture of two or more liquids immiscible in nature, one presents as droplet or dispersed phase distributed throughout the other or the continuous phase.[10]. It is generated by means of mechanical agitation in presence of surface active agent also known as emulsifier or surfactant for stability.

When diesel-water mixed directly as diesel being a lighter liquid then water results settles of water in the bottom. By using an appropriate surfactant the molecules of water and diesel can be bound together. The stability of emulsion is very important, because if it is not stable for an appreciable period of time it would not be practically useful.

There are two types of emulsification techniques, namely water in oil emulsion (W/O) and oil in water emulsion (O/W). In the first type of emulsion water droplet are dispersed and encapsulated within the oil while in second type of emulsion oil droplets are dispersed and encapsulated within water column.[10]

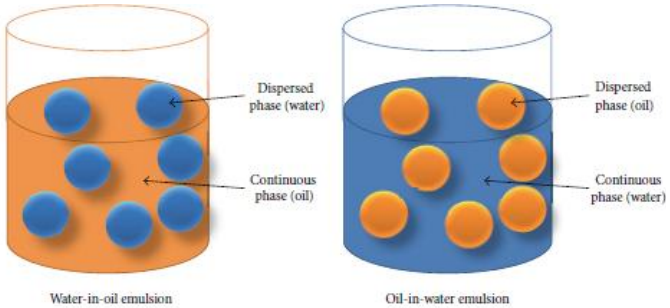

Figure 2. Concept of water in oil and oil in water emulsion[10]

Water content affect combustion chamber under two accounts .The first is reduced peak temperature in the cylinder, resulting in lower level of NO_X formation. The second is the microexplosion phenomenon, which is due to volatility difference between water and diesel.

In the water-in-diesel emulsion, water remains embedded inside diesel droplets with the help of the surfactant. When this type of emulsion is sprayed on a hot combustion chamber, heat is convected on the surface of the fuel droplet. [8] As water and diesel have different boiling temperatures, the evaporation rates of these two liquids will be different. As a result, the water molecule will reach its superheated stage faster than diesel creating vapour expansion breakup. Micro-explosion is a quick breakdown of droplets. There will be secondary atomization of droplets in the micro-explosion phenomenon in which droplets disintegrate further into smaller sizes resulting in an increase in the surface volume. This in turn enhances the mixing of air and fuel as shown in Figure.

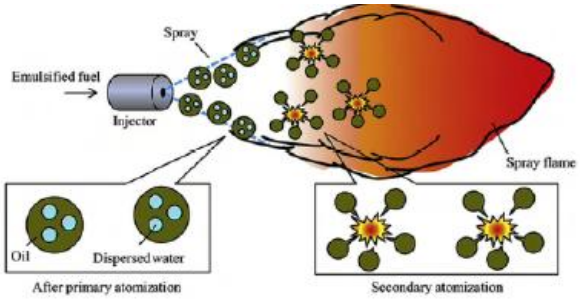

Figure 3. Primary and secondary atomization in spray flame of emulsified fuel[6]

Water added diesel can reduce NO_x and smoke simultaneously. Smoke reduction may be due to improvement in mixing rate of fuel with air by micro-explosion phenomenon and increase in premixed combustion phase due to long ignition delay.[9] However, emulsified fuel blends tend to lower the combustion temperature indiscriminately. Lower temperatures too early in combustion can lead to increased ignition delay and engine noise. Although there is little or no increase in engine cost when using emulsified fuels, the engine injection timing must be changed to take advantage of the new mixture.

A more significant drawback to emulsified fuels is that the percentage of water is constant and cannot be changed for cold start or other transient operating conditions. In other words, a particular blend of fuel and water may be optimal for one operating condition but degrade performance for other points in the design envelope.

Higher fuel efficiency can be achieved by complete combustion of fuel. Increase amount of water in emulsion also rises in brake thermal efficiency because the micro explosion of water in diesel gives addition torque on top of piston which increase expansion work, (D 20) emulsion shows highest thermal efficiency across all load engines.[4] Engine torque and engine power increases with an increase in the percentage of water in the emulsion.[8] The total fuel as a sum of both the quantity of diesel and water resulting to an increased BSFC with an increase in the percentage of water in the emulsion. The second considered diesel alone as a total fuel and the analysis resulted with a decrease in BSFC with an increase in the percentage of water in the emulsion, the minimum value is reported to be at 20% water in the emulsion. The main reason for the reduction in BSFC is due to the secondary atomization of spray because of microexplosion.[10]

D. Comparison

The effects of using water – diesel emulsion as the fuel have been compared with water injection at same water – diesel ratio (0.4:1) on the performance, combustion and emission characteristics of the diesel engine.[6]

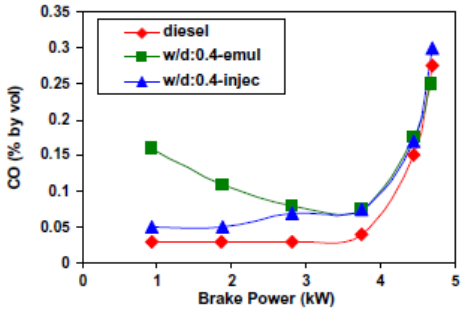

Figure 4. Comparison of CO emission with emulsion and injection. [6]

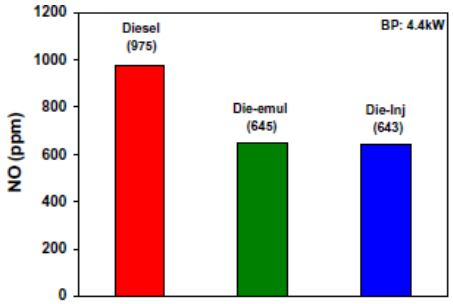

Figure 5. Comparison of NO emission with emulsion and injection at 100% load[9]

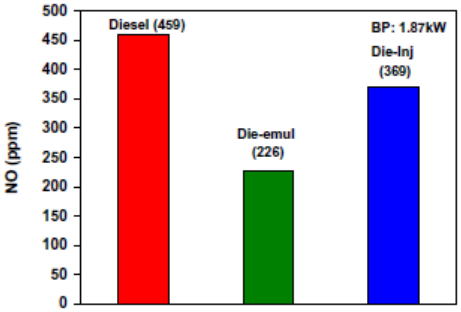

Figure 6. Comparison of NO emission with emulsion and injection at 40% load[6]

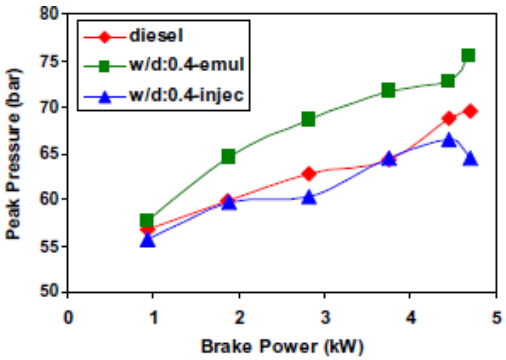

Figure 7. Comparison of peak pressure with emulsion and injection[6]

III. LITERATURE REVIEW

Sr. No.	Investigators	Title	Name of Journal	Description of Work	Results
1	R. Lanzafame	Water injection effects in single cylinder CFR engine	SAE 1999	Effects of water injection in the intake pipe are investigated from both a theoretical and experimental viewpoint. Pressure vs. time diagrams were recorded on a single-cylinder CFR engine. The water to fuel mass flow rate ratio was varied in the range 0 to 1.5	Results have shown that water injection really represents a new way to avoid detonation, to reduce compression work and to control NOx formation in SI engines increase of volumetric compression ratio and water injected mass flow rate, measured Research Octane number increases to 93 from 70 and Motor Octane number to 90 from 64.
2	F. Bedford and C. Rutland, P. Dittrich, A. Raab and F. Wirbeleit	Effects of Direct Water Injection on DI Diesel Engine Combustion	SAE 2000	The effects of in-cylinder water injection on a direct injection (DI) Diesel engine were studied using a computational fluid dynamics (CFD) program based on the Kiva-3v code	Liquid penetration increased approximately 35% with 23% of the fuel volume replaced by water, due mostly to the increase in latent heat of vaporization.
3	K. Kannan and M. Udayakumar	No_x and HC emission control using water emulsified diesel in single cylinder diesel engine	ARPN Journal of Engineering and Applied Sciences 2009	Effect of water emulsified diesel fuel combustion on brake thermal efficiency, brake specific fuel consumption and NOx and hydrocarbon emissions in a diesel engine	Improve brake thermal efficiency and brake specific fuel consumption. The NOx and hydrocarbon emissions were found to decrease with increase in water percentage in the emulsified diesel
4	Hagos, Ftwi Y.; Aziz, A. Rashid A.; Tan, Isa M.	Water-in-Diesel Emulsion and its Micro-Explosion Phenomenon -Review	IEEE 3rd International Conference on Communication Software and Networks (ICCSN) - Xi'an, China 2011	This review paper addresses the influence of micro-emulsion on the combustion and emission of water-in-diesel emulsion fuel. It also presents the effect of operating parameters on the micro-emulsion.	It has benefits in the simultaneous reduction of both NOx and particulate matters. Furthermore, it has huge impact in the combustion efficiency improvement. Micro-explosion is the most important phenomenon of waterin-diesel emulsion inside an internal combustion engine chamber. It affects both the emission reductions and combustion efficiency improvement directly and indirectly. It is affected by the volatility of the base fuel, type of emulsion, water content, diameter of the dispersed liquid, location of the dispersed liquid and ambient conditions
5	K.A.	A comparison	Energy cconversion	Experiments were conducted to compare	The experimental result indicates the both methods

	Subramanian	of water diesel emulsion and timed injection of water into the intake manifold of a diesel engine for simultaneous control of NO and smoke emissions	and Management 2011	the effects of water – diesel emulsion and water injection into the intake manifold on performance, combustion and emission characteristics of a DI diesel engine under similar operating conditions. The water to diesel ratio for the emulsion was 0.4:1 by mass. The same water – diesel ratio was maintained for water injection method in order to assess both potential benefits. All tests were done at the constant speed of 1500 rpm at different outputs. The static injection timing of 23_ BTDC was kept as constant for all experimental tests.	(emulsion and injection) could reduce NO emission drastically in diesel engines. At full load, NO emission decreased drastically from 1034 ppm with base diesel to 645 ppm with emulsion and 643 ppm with injection. But, NO emission reduction is lesser with injection than emulsion at part loads. Smoke emission is lower with the emulsion (2.7 BSU) than with water injection (3.2 BSU) as compared to base diesel (3.6 BSU). However, CO and HC levels were higher with emulsion than water injection. As regards NO and smoke reduction, the emulsion was superior to injection at all loads. Peak pressure, ignition delay and maximum rate of pressure rise were lesser with water injection as compared to the emulsion. It is well demonstrated through this comparative study that the emulsion method has higher potential of simultaneous reduction of NO and smoke emissions at all loads than injection method.
6	Angela Chiosa, Dan Scarpete, Raluca-Cristina Buturca	An overview on combustion and performance characteristics of diesel engine using diesel-water emulsion	5th International Conference on Thermal Engines and Environmental Engineering Galati,Romania 2013	Review on experimental achievements regarding the effects of diesel-water emulsions on burning characteristics and performance parameters of diesel engines; ,advantages and disadvantages of the utilization of water emulsified diesel fuel.	Improving full load brake thermal efficiency and lowering NOx and smoke levels , higher ignition delays, peak pressures and rates of pressure rise .
7	Sagar Patel , Gaurav Rathod, Tushar Patel	Experimental investigation of diesel engine with water injection system on emission parameters	IOSR Journal of Mechanical and Civil Engineering 2014	Water injected in intake manifold of diesel engine is by using calibrated burette. For Constant compression ratio, 9, 16, 38ml/min water mass supply to engine. Results are observed for 1 to 8 load condition. The obtained results are compared with conventional diesel engine in terms of NOx, CO, CO2, HC emissions	1) Water injection at intake manifold does not significantly affect cylinder pressure and heat release rate of CI engine operating with diesel. The results shows that water injection at the intake manifold affects the premixed combustion chamber which is mainly cause of NOX formation. 2) The water injection in to intake manifold reduces the NOX emission up to 46 % over the entire load range but noticeable increase in HC and CO2. However CO emission increased by about 0.02% to 0.08%.

					3) Water injection into the intake manifold has capability of reduce NOX emission with loss of power and has negative effect on specific fuel consumption.
8	Mohammed Yahaya Khan, Z. A. Abdul Karim, Ftwi Yohaness Hagos, A. Rashid A. Aziz, and Isa M. Tan	Current Trends in Water-in-Diesel Emulsion as a Fuel-Review	The Scientific World Journal 2014	Review paper addresses the type of emulsion, the microexplosion phenomenon, emulsion stability and physiochemical improvement, and effect of water content on the combustion and emissions of WiDE fuel	Reduction of both NOx and particulate matters, reduction in peak cylinder temperature , secondary atomization by a further breakup of fuel spray due to microexplosion. The effects of various surfactants with several blends of emulsified fuel on the combustion characteristics studied.
9	Sagar Patel , Gaurav Rathod, Tushar Patel	Water Injection Effects On Performance Characteristics Of A CI Engine	IOSR Journal of Mechanical and Civil Engineering 2014	The performance of diesel engine investigate by injecting water in small quantities with the intake air	1) It shows from experiments water contains in combustion chamber carry heat developed during the expansion stroke and lowering brake thermal efficiency. 2) Highly reductions in emission parameters like NOx 3) Mechanical efficiency was almost increasing with increase in flow rate compared to normal air supply

IV. CONCLUSION

From this review article, following review remarks were made.

1. If water added in diesel at appropriate proportion, it will improve the engine performance and emission characteristics. If proportion of water-diesel is more, than engine performance declines and emission increases.
2. There have been inconsistent results reported by different researchers with regard to the effect of water content on the engine combustion characteristics. Besides, all the reports are based on different engine setups and methodologies.
3. There was a common agreement by most of the researchers on the report of the effect of water content on the simultaneous reduction of both NOx and particulate matter. The inconsistency was on the percentage amount reduction compared to pure diesel. Up to 37% reduction NOx and 90% reduction in particulate matter were reported by different researchers.
4. Water–diesel emulsion is more effective in improving full load brake thermal efficiency and lowering NO and smoke levels.
5. Emulsion method has higher potential of simultaneous reduction of NO and smoke emissions at all loads than injection and fumigation method. [6]

A systematic approach of studying the optimization of water content in the emulsion for best engine performance and emission by both experimental and numerical investigations is necessary so that it can give the best recommendations for the commercialization of Water in diesel emulsion as an alternative source of energy for the future Diesel.

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