EFFECT OF WATER CONTENT IN DIESEL-WATER EMULSIFIED FUEL ON DIESEL ENGINE PERFORMANCE

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Abstract:
Diesel engines are still the most fuel-efficient internal combustion engines and the pollutants exhausted from diesel engines are considered as one of the major sources of air pollution. The heterogeneous results regarding the use of diesel-water emulsion as fuel for diesel engines suggested that more experimental work is recommended.
In this paper, an experimental investigation was conducted on an agricultural tractor diesel engine fueled with diesel-water emulsion and standard diesel fuel at different engine load and speed. The engine torque decreased with the increasing of water content in the diesel-water emulsion due to the reduction of lower heating value of diesel-water emulsion compared to pure diesel fuel. Diesel-water emulsion determined a reduction of NOx emission. The carbon balance proved that an increase of cumulated CO and CO2 emission accounts for a reduction of solid carbon from exhaust.

Keywords: diesel engine, diesel-water emulsion, NO_x emission, PM emission

1. Introduction

At present, diesel engines are still the most fuel-efficient internal combustion engines and diesel fuel is the dominant fuel used by the commercial transportation sector [1]. How-ever, the pollutants (such as NOx, SOx, CO, CO2, and unburned hydrocarbon particles) exhausted from diesel engines have been considered as one of the major sources of air pollution in urban regions, which seriously affect human health, environment, and economic development [2].

The trend towards more stringent regulations on emissions has been an important driving force in the search for internal combustion engines more environmentally friendly [3]. To reduce the pollutant emissions, researchers have focused their interest on the domain of fuel-related techniques, such as the use of alternative fuels of renewable nature that are friendly to the environment [4]. As alternative fuels, oxygenated fuels present reduced particulate matter (PM) emissions, but usually with an escorting increase of the emitted nitrogen oxides (NOx).

Alternative fuels need not be alternatives to fossil fuels [5]. Also fossil fuels can be modified in such a way that they can be classified as ‘‘alternative fuels.’’ One such modification is incorporation of water in diesel fuel [5] in a form of emulsion for use in diesel engines [6] without engine retrofitting [7].

Emulsions of diesel fuel-water offer the potential to simultaneously reduce NO and soot emissions while maintaining a high-thermal efficiency [8]. The lower peak temperature in cylinder due to water content in emulsion fuel accounts for lower NOx [7,9], while the enhanced mixing with air due to micro-explosions of water micro-droplets accounts for lower smoke emission [9].

There is a relative large number of papers dealing with tests performed on diesel engines fueled with diesel-water emulsions, in order to determine how the emulsion fuel influences the engine performance as: power (torque), fuel consumption, NOx and PM (soot and smoke) emissions. A synthesis of four papers is presented in table 1. Analysis of data from table 1 reveals both convergent and divergent results. In general, engine power (torque) decreases with water content, due to lower heating value of emulsion compared to pure diesel fuel. Fuel consumption is increasing due to the same reason.

On the other hand, diesel-water emulsion leads to a reduction of NOx and PM emissions. Differences between emission results, sometimes in a significant degree, may be caused by: engine (compression ratio, fuel system), emulsion (type of emulsion, water content, surfactant type and content, emulsion preparation) and test conditions (engine load, speed and injection timing). According to the engine test results, both NOx and smoke tend to decrease as the emulsion water content increases [9].

The heterogeneous results regarding the use of diesel-water emulsion as fuel for diesel engines suggest that more experimental work for optimizing the emulsion formulation in terms of water content is recommended. In this respect, an experimental investigation was conducted on an agricultural tractor diesel engine fueled with diesel-water emulsion at different engine load and speed. The engine testing was carried out with different water content in diesel-water emulsion as well as with standard diesel fuel.

2. Fuel and experimental set-up

The emulsion system that was used for testing the diesel engine is an on board emulsion system patented by Scarabaeus Gmbh, Simmern, Germany. The pre-mixed emulsions (always micro-emulsions) have a fixed diesel-water mixture ratio [1]. The on board generated emulsions prepared in a mixer unit of the Scarabaeus company could be adjusted with the desired diesel-water mixture ratio according to the set operating point of the engine [4].

The Scarabaeus emulsion technology has several advantages:

- diesel-water mixture is prepared in a separate device and not in the fuel tank;
- water ratio in diesel fuel is electronically controlled;

Table 1. *Influence of diesel-water emulsion on diesel engine performance.*

Engine type and test conditions	Emulsion W/O (%v/v)	Power/ torque	Fuel consumption	NOx	PM (soot & smoke)	Reference
Isuzu, 4 cyl, 3856 cm^3, ε=17 65,6 kW @ 2800 rpm	10 and 20% Surfactant: 2%	NA	+	–	–	Lin and Wang, 2004 [10]
Ford, 4 cyl, 1753 cm^3, ε=21,5 44,7 kW @ 4800 rpm	5, 10 and 15% Surfactant: 0,2-1,0%	–	+	– –	– –	Nadeem et al, 2006 [1]
4 buses Euro 2, (2 old and 2 new)	13,5% Surfactant: NA	NA	+	+ & –	–	Tzirakis et al, 2005 [11]
Engine of 6 cyl, 11149 cm^3, ε=16,4	15% Surfactant: NA	–	+	–	–	Park, Kwak and Oh, 2004 [12]

Symbols: ε-compression ratio; + increasing, but in less degree; + + increasing, but in significant degree; – reduction, but in less degree; – – reduction, but in significant degree; NA-not available data

- there is no engine retrofitting;
- high homogenizing degree of diesel fuel and water due to emulsion system.

Water for emulsion is stored in a separate tank and no surfactant was used to stabilize the diesel-water emulsion. The water/diesel fuel static ratio in the emulsion is set by a screw adjusting valve. During engine test, the water ratio in the emulsion is around the static ratio, according to engine load and speed.

The diesel-water emulsion, prepared by Scarabaeus emulsion system, using standard commercial diesel fuel and water, is homogenous and yellow-milky in color (fig. 1).

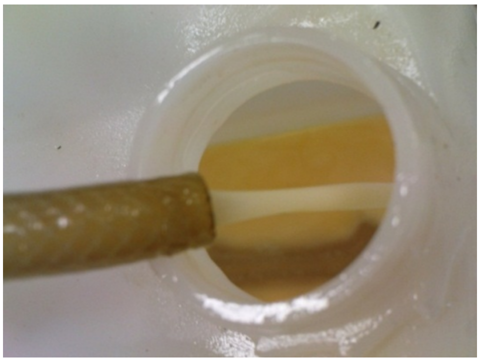


Fig. 1 *Diesel-water emulsion prepared by Scarabaeus emulsion system.*

Table 2*. Main technical data of TCD 2012 L04 V4 diesel engine*

Stroke	130 mm
Bore	101 mm
No. of cylinders	4, in line
Rated power	113 kW (152 HP)
Speed	2100 rpm
Compression ratio	18
Fuel system	Deutz Common Rail

Diesel engine used for testing the diesel-water emulsion was an agricultural engine type TCD2012 L04 V4, supercharged, produced by DEUTZ Company. The main engine constructive and operating data are presented in table 2

The tested TCD2012 L04 V4 diesel engine was mounted on a test rig along with the Scarabeus emulsion system (fig. 2). The engine loading was performed with an AVL eddy current brake.

Data regarding in-cylinder pressure and temperature, speed and crankshaft angular position, exhaust gas temperature and exhaust emissions were recorded and processed using IndiWin and Infralyt Software. Engine load and speed were set through INCA Software.

The experimental investigation was performed at engine torque of 10, 150, 300, 450 Nm and at maximum fuel supply. For every engine torque, the engine speed was set at 800, 1100, 1400, 1700 and 2100 rpm, and the water ratio of diesel-water emulsion was set at 0 (standard commercial diesel fuel), 15 and 25%.

3. Test results and discussion

Torque

Figure 3 shows the engine torque versus engine speed and water content in diesel-water emulsion. It can be noticed that the torque decreases as the emulsion water content is increasing. This behavior is according to reduction of heating value of the emulsion fuel due to water content in emulsion. The same variation of engine torque, due to water content, was already observed by other researchers (fig. 4).

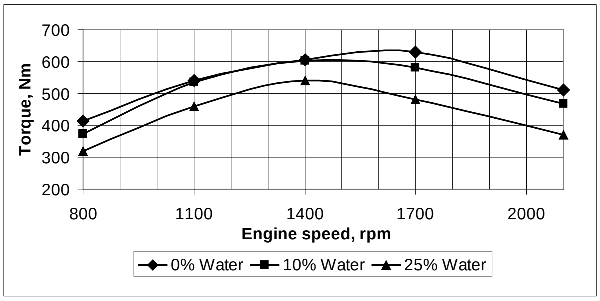


Fig. 3 *Engine torque vs. speed and water content.*

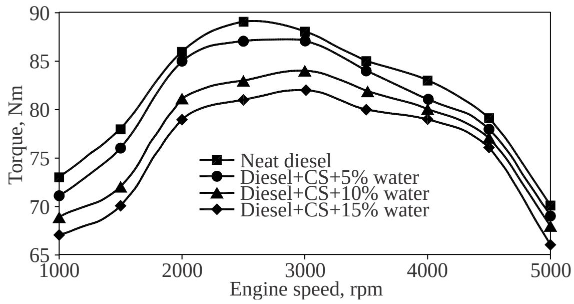


Fig. 4 *Engine's torque vs. speed using neat diesel and emulsified fuels with conventional surfactants (CS) (redrawn after [1]).*

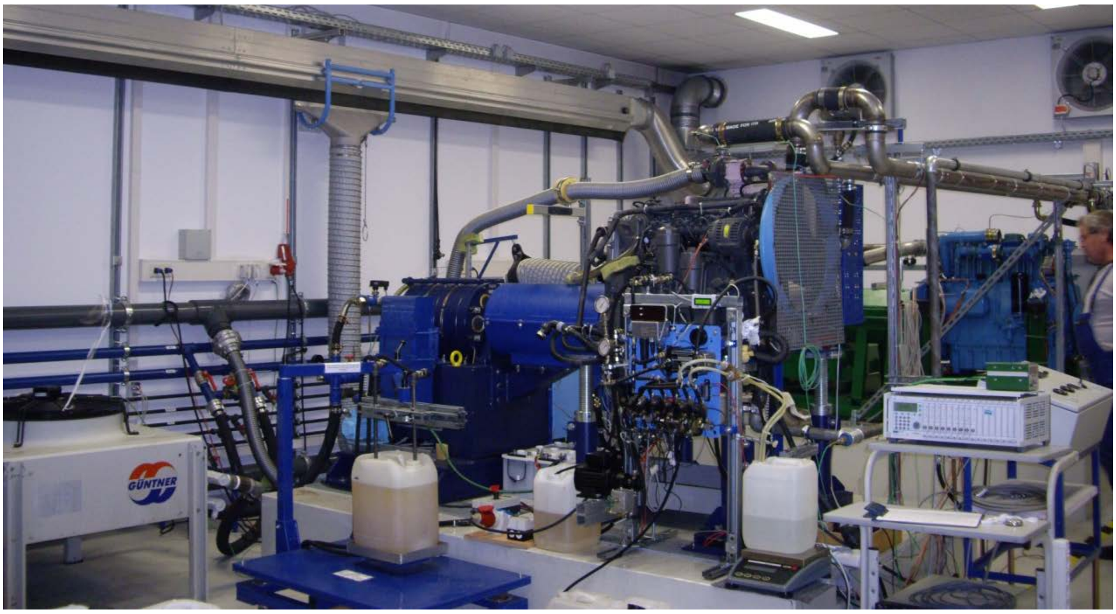


Fig. 2 *Experimental set-up arrangement.*

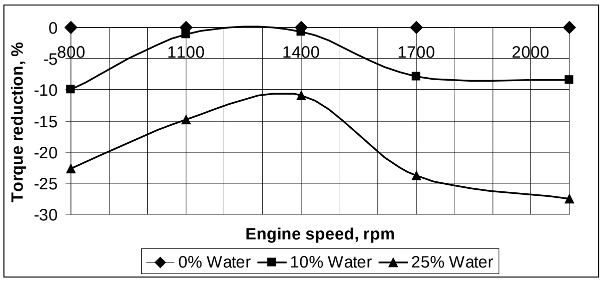


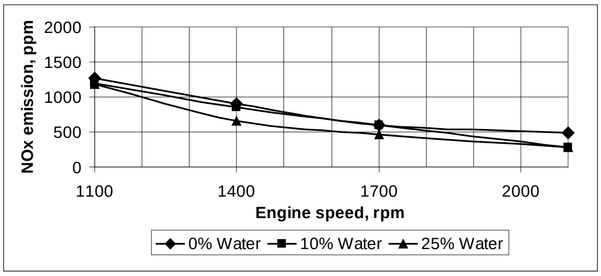
Fig. 5 *Engine torque reduction vs. speed and water ratio in emulsified fuels.*

On the other hand, it can be noticed that the engine torque reduction is not constant versus engine speed and water content. For the two tested emulsion fuels with 10 and 25% water in diesel-water emulsion, the maximum reduction is within the range of 1200-1400 rpm (fig. 5), and is far less than the water ratio in emulsified fuel. This could be explained that at these engine speed values, the best conditions for micro-explosion of water droplets in the emulsion fuel are fulfilled, due to the fact that the heat transfer rate from in-cylinder compressed air to injected emulsion fuel reaches its maximum value.

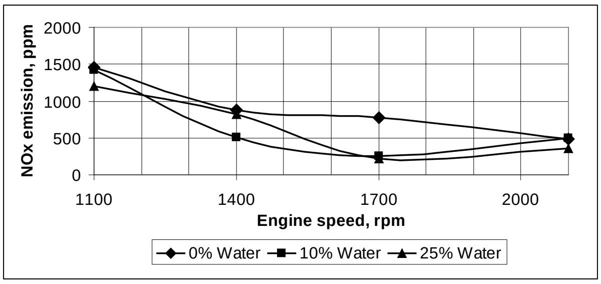
For the maximum engine speed, it can be noticed that the engine torque is decreasing as the water ratio in the emulsion fuel is increasing. However, at 10% water in diesel-water emulsion, the engine torque reduction is a little bit less than the water ratio. Conversely, at 25% water ratio, the reduction is a little bit higher than the water ratio. We can assume that the higher reduction at 25% water ratio is due to the higher heat that is necessary for water evaporation.

NOx emission

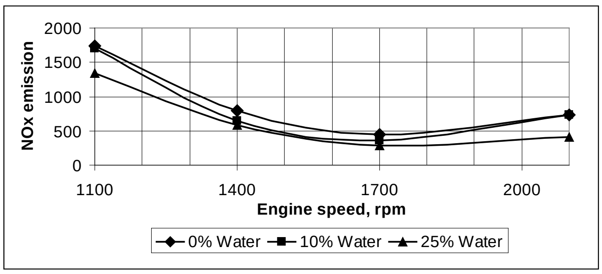
Figure 6 shows the NOx emission from the TCD2012 L04 V4 engine exhaust versus engine speed and water content in diesel-water emulsion. It can be noticed that NOx emission level is reduced for the emulsion fuels compared to neat diesel: the higher water content the smaller NOx emission.



a)



b)



c)

Fig. 6 *NOx emission of TCD2012 L04 V4 diesel engine vs. speed, water content and engine torque (**a**-150 Nm; **b**-300 Nm; **c**-450 Nm).*

As the engine load is increasing, a slighter increase of NOx emission, at the engine speed of 1100 and 2100 rpm, can be observed. At engine speed of 1700 rpm and engine load of 300 and 450 Nm, the highest NOx emission reduction was reached. The most notable reduction was of 67% for the emulsion of 10% water ratio and of 71% for the emulsion of 25% water ratio, at engine torque of 300 Nm.

Carbon balance

Exhaust emission containig solid carbon are generally known as particulate matter (PM). To have a global view on PM emission (soot, smoke), we propose to evaluate the carbon balance from exhaust gases. In this respect, the PM emission accounts along with gaseous emission of CO and CO_2 for total carbon from exhaust emission.

Figure 7 shows the gaseous emission of CO and CO_2 versus engine speed and water content in diesel-water emulsion, for torque value of 300 Nm. It can be noticed that, in general, the level of cumulated emission of CO and CO_2 of emulsified fuels is higher than the same cumulated emission of standard diesel fuel: the higher water ratio the higher level of cumulated emission of CO and CO2 of emulsified fuels. The same behavior is for the torque values of 150 and 450 Nm.

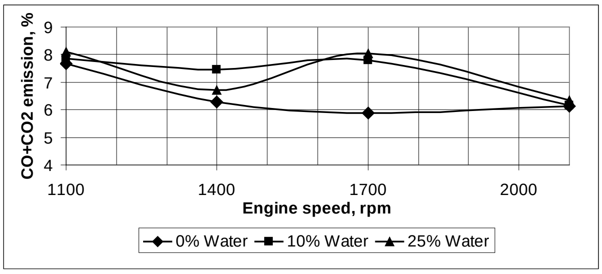


Fig. 7 *CO and CO2 emission vs. speed and water ratio in emulsified fuels, at engine torque of 300 Nm.*

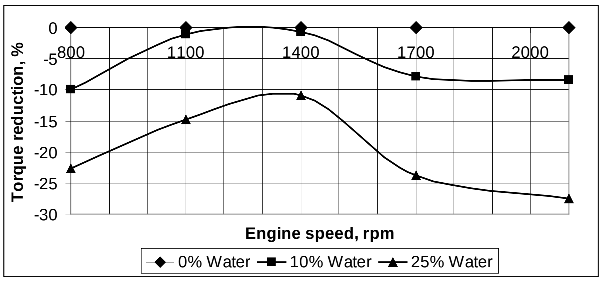


Fig. 8 *O2 level vs. speed and water ratio in emulsified fuels, at engine torque of 300 Nm.*

The increased level of cumulated emission of CO and CO_2 of emulsified fuels accounts for a reduced level of solid carbon emission. This could be explained by a higher carbon oxidation due to water droplet micro-explosion that provide a better mixing of fuel and in-cylinder air. This assumption is supported by the reduced level of O_2 (fig. 8).

4. Conclusion

Diesel engines are still the most fuel-efficient internal combustion engines and the pollutants exhausted from diesel engines are considered as one of the major sources of air pollution.

The heterogeneous results regarding the use of diesel-water emulsion as fuel for diesel engines suggested that more experimental work is recommended. In this paper, an experimental investigation was conducted on an agricultural tractor diesel engine fueled with diesel-water emulsion at different engine load and speed. The engine testing was perfor-med at engine torque of 10, 150, 300, 450 Nm and at maximum fuel supply. For every engine torque, the engine speed was set at 800, 1100, 1400, 1700 and 2100 rpm, and the water ratio of diesel-water emulsion was set at 0 (standard commercial diesel fuel), 15 and 25%.

The engine torque decreases as the emulsion water content is increasing. This behavior is according to reduction of heating value of the emulsion fuel due to water content in emulsion. For the emulsion fuels, the maximum reduction is within the range of 1200-1400 rpm, and is far less than the water ratio in emulsified fuel, which could be explained by reaching the best conditions for micro-explosion of water droplets in the emulsion fuel.

The NOx emission level is reduced for the emulsion fuels compared to neat diesel: the higher water content the smaller NOx emission. As the engine load is increasing, a slighter increase of NOx emission, at the engine speed of 1100 and 2100 rpm, can be observed. At engine speed of 1700 rpm and engine load of 300 and 450 Nm, the highest NOx emission reduction was reached. The most notable reduction was of 67% for the emulsion of 10% water ratio and of 71% for the emulsion of 25% water ratio, at engine torque of 300 Nm.

To have a global view on PM emission (soot, smoke), we proposed to evaluate the carbon balance from exhaust gases: PM emission accounts along with gaseous emission of CO and CO_2 for total carbon from exhaust emission. In general, the level of cumulated emission of CO and CO_2 of emulsified fuels is higher than the same cumulated emission of standard diesel fuel: the higher water ratio the higher level of cumulated emission of CO and CO_2 of emulsified fuels. This could be explained by a higher carbon oxidation due to water droplet micro-explosion that provide a better mixing of fuel and in-cylinder air. This assumption is supported by the reduced level of O_2.

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