PAPER • OPEN ACCESS

Integration of real-time non-surfactant emulsion fuel system on light duty lorry

View the article online for updates and enhancements.

Integration of real-time non-surfactant emulsion fuel system on light duty lorry

Muhammad Adib Abdul Rashid[*], Ahmad Muhsin Ithnin, Wira Jazair Yahya, Nur Atiqah Ramlan, Nurul Aiyshah Mazlan, Dhani Avianto Sugeng

Vehicle System Engineering, Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, 54100 Kuala Lumpur, Wilayah Persekutuan Kuala Lumpur, Malaysia

*Corresponding author email: madib52@live.utm.my

Abstract. Interest in water-in-diesel emulsion fuel (W/D) grows because of its advantages in improving fuel efficiency, reducing greenhouse emissions and retaining the quality of the lubrication oil. Recently, a device called Real-Time Non-Surfactant Emulsion Fuel System (RTES) have successfully created an emulsion without surfactant for a 5kW single-cylinder diesel engine generator. This study integrates the RTES into a light duty lorry, and the effect of the integration is investigated. The lorry was tested on a chassis dynamometer with a controlled 16.6% water ratio. The results show how fuel consumption is reduced by 7.1% compared to neat diesel. Moreover, the exhaust emission of Nitrogen Oxides (NO_x) is reduced by 52%, while as observed in other works, carbon monoxides (CO) emission also increased, in this case by 41.6%. This integration concluded to retain similar benefits and disadvantages as tested on the 5.5kW diesel generator.

1. Introduction

Documentation of ideas in water-in-diesel (W/D) emulsion fuel dated back from as early as 1931. Among its advantages are the improvement of fuel efficiency, the reduction of greenhouse gases emissions and the retainment of the quality of lubrication oil [1-4].Transportation is the main contributor of NO_x emission so integrating W/D into this sector will significantly reduce it [5].

Micro-explosion phenomena are the main reason for the improvement of the fuel efficiency and the reduction of the particulate matter (PM). It causes a "second atomization" by rapid evaporation of the water, so the diesel droplets become finer and more evenly distributed inside the combustion chamber [6-8]. Despite the benefits, emulsion fuel has not taken off in the industry because of its dependency on additives to mix the two immiscible liquids. In solving this problem, a study on a new emulsification technology was performed; it is called the Real-Time Non-Surfactant Emulsion Fuel System (RTES). This RTES was originally designed for a stationary 5kW diesel electric generator, and it has been proven to retain the similar benefits of conventional emulsion fuels [3]. It eliminates the dependency of additives by supplying freshly produced emulsion fuel to the vehicle. RTES mixes diesel and water by using three primary mechanisms; (1) water atomization, (2) high shear mixer and (3) ultrasonic transducer. Figure 1 shows the configurations of RTES.

In this research, the feasibility of RTES integrated into a 2.8L four-cylinder diesel engine vehicle was investigated. Its goal was to include it into the fuel supply system, to run the vehicle continuously without stalling, and to operate the system at different vehicle speed. Furthermore, the effect of this

integration in term of the fuel consumption and exhaust emission were also studied using WVU-5 peak drive cycle on a chassis dynamometer.
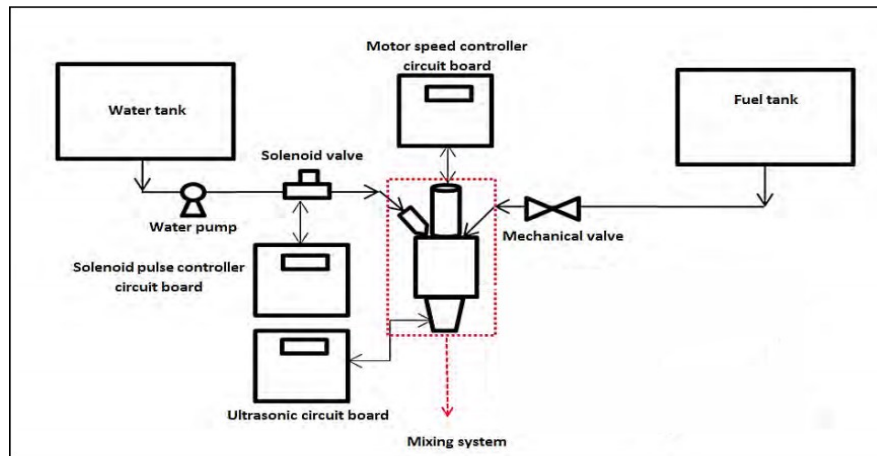

Figure 1. Real-Time Non-Surfactant Emulsion Fuel System (RTES*)* [3].

2.   Experiment method

2.1. Test vehicle
In this study, a 1-ton lorry vehicle model Isuzu NHR categorised as a light-duty lorry was used as the test vehicle. The engine of this vehicle is a 2.8L 4-cylinder diesel engine. The truck was designed to fulfil Euro 2 emission regulation, and its overall specifications are given in Table 1.

Table 1. Test Vehicle Specifications.

Parameter	Specification
Model	Isuzu NHR 55E (4JB1)
Fuel injection system	Direct injection
Cylinder	4 cylinders, in-line
Cooling system	Water-cooled
Displacement (L)	2.8
Bore x stroke (mm)	93 x 102
Compression ratio	18.2:1
Fuel tank capacity (L)	75

2.2. Test fuel
Diesel and water were the only components for the emulsion fuel. Tap water was used, and its characteristics are presented in Table 2 [9]. Euro 2 diesel was used with its characteristics tabulated in Table 3 [10]. The percentage of water for emulsion utilised a controller to control the amount of water supplied. The actual average water percentage is defined with a flow rate sensor during the testing. The emulsion used in the testing is with 16.6% water percentage.

Table 2 Characteristics of tap water. [9]

Specification	Tap water
Density, g/cm³, 25 °C	1.02412
Specific conductivity, µS/cm, 25 °C	0.0532
Viscosity, milipoise, 25 °C	9.02
Vapour pressure, mm Hg, 20 °C	17.4
Isothermal compressibility, vol/atm, 0 °C	46.4 E-6
Surface tension, dyne/cm, 0 °C	72.74
Specific heat, J/g °C, 17.5 °C	3.898
Temperature of Maximum Density, °C	-3.25
Freezing point, °C	-1.91

Table 3. Malaysian Euro 2 Diesel characteristics [10].

Properties	Unit	Value
Calorific Value	MJ/kg	45.28
Cloud Point	°C	18
Density @15°C	kg/L	0.8538
Total Sulphur	mass %	0.28
Viscosity	cSt	7.6 @20°C
		5.1 @40°C
		4.0 @60°C
Distillation Temperature, 90% recovery	°C	367.9
Flashpoint	°C	93.0
Pour Point	°C	12
Cetane Number		54.6
Carbon	wt %	84.1
Hydrogen	wt %	12.8
Sulphur	wt %	0.2
Nitrogen	wt %	< 0.1
Oxygen	wt %	3.9
Dielectric constant		2.1

2.3. Integration of RTES

Throughout the integration of RTES, there were three main factors considered. Firstly, the non-surfactant emulsion stability. The produced emulsion fuel only lasted a short time before the water started to visually separate from diesel. Therefore, the distance of the RTES from the engine was the major factor affecting the integration design. Secondly, the space availability and RTES form factor. The engine compartment has limited space, but RTES small form factor made it possible to mount it as close possible to the engine. Thirdly, the fuel return line. The short life span of the produced emulsion prevents the return of emulsion fuel to the fuel tank. Returning the fuel to its tank was not possible because separated water from the emulsion fuel might ultimately damage the vehicle engine. Therefore, the return line was routed back to RTES. The fuel line of the vehicle with RTES is shown in Figure 2. This integration only modified the fuel line and electrical wiring without any modifications on the engine. Addressing the short stability period of emulsion fuel, after integration based on the three factors, samples of fuel from the return fuel line were withdrawn. A quick

observation concluded that the emulsion was still intact with no apparent water layer. This showed that the emulsion fuel was stable enough even after the injector pump and engine.
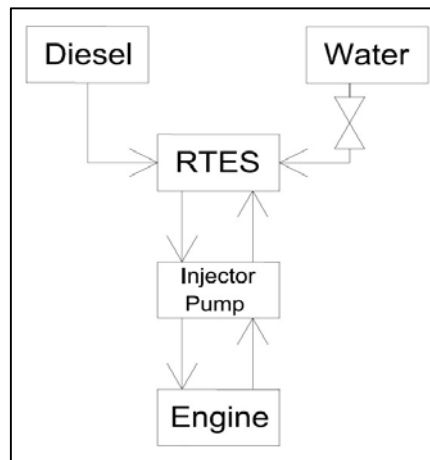

Figure 2. Vehicle fuel line with RTES.

2.4. Drive cycle

The drive cycle selected to test the vehicle followed the West Virginia University (WVU) 5-Peak drive cycle. The cycle was designed specifically for truck testing [11] with a drive cycle of 900 seconds and 8 km equivalent distance. The cycle peaks at 5 points e.g. 32.19, 40.23, 48.28, 56.33 and 64.37 km/h. Figure 3 shows the 5-peak drive cycle graph.
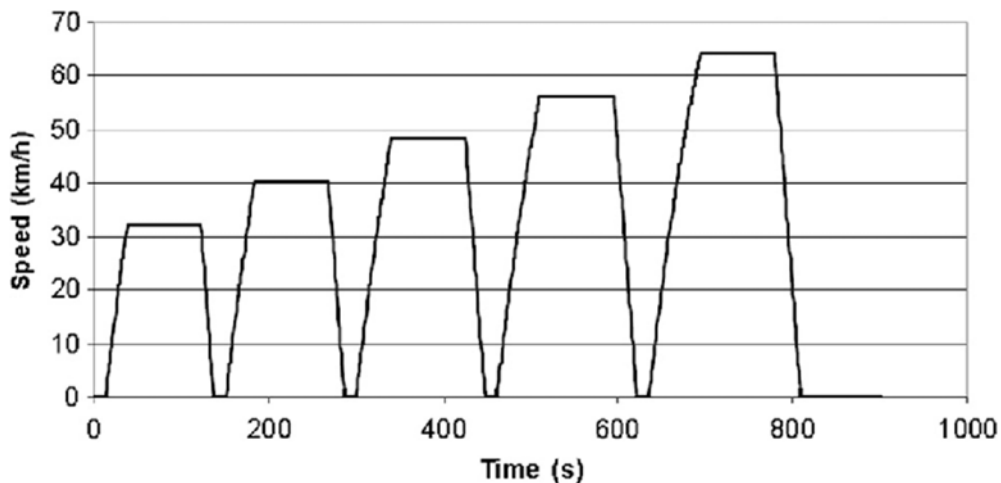

Figure 3. WVU 5-Peak drive cycle. [11]

2.5. Measurements setup

Ono Sokki FP-2240H volumetric flow detector was used to measure the fuel consumption of both fuels, and the device measured the flow located after the diesel tank. Only the diesel consumption of both fuels was taken account as the fuel consumption, thus in the case for emulsion, water was not considered. As for the exhaust emission, a Testo 350 emission analyser was used to record it. The probe of the emission analyser was placed at the tailpipe. The emission analyser measured Nitrogen Oxides (NO_x) and Carbon Monoxide (CO) in parts per million (ppm). All measuring devices simultaneously began and ended recording data with the drive cycle.

3. Results and discussion

During the testing period, RTES system supplied the non-surfactant W/D emulsion fuel to the engine, and the vehicle completed the WVU 5-peak drive cycle on a chassis dynamometer with speed ranges from 0 – 64.37 km/h without stalling or unusual behaviour.

3.1. Fuel Consumption

The result of the fuel consumption of both fuels is shown in Figure 4. The non-surfactant emulsion fuel with 16.6% of water (Emulsion 16.6) had a lower fuel consumption by 7.1% compared to neat Euro 2 diesel. This result complied with the previous study of RTES on a 5kW diesel generator which yielded a reduction of the specific fuel consumption by 3.89% [10]. The reduction of fuel consumption was mainly believed to be caused by the micro-explosion phenomenon.
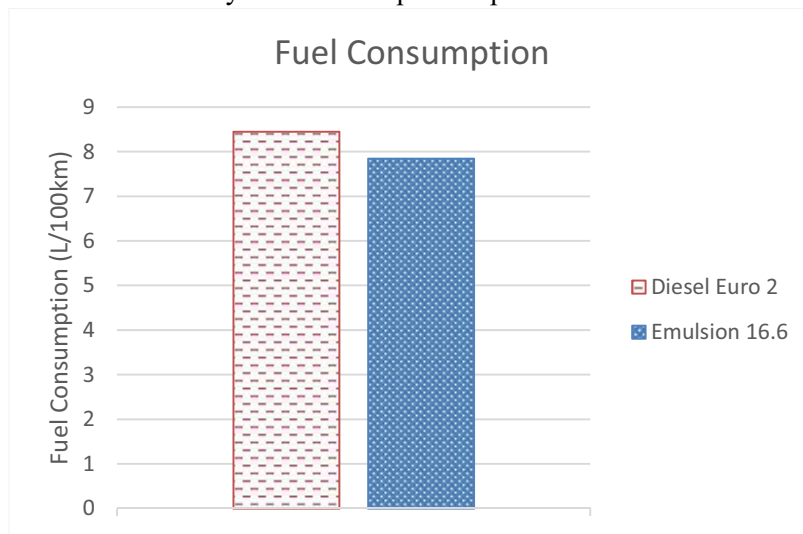

Figure 4. Fuel consumption of both fuel.

3.2. Emission Analysis

Comparison of Nitrogen Oxides (NO_x) and Carbon Monoxide (CO) of both fuels are shown in Figure 5 and Figure 6 respectively. The non-surfactant emulsion from RTES significantly reduced the NO_x emission. Under the WVU 5-peak drive cycle, 52% of average NO_x reduction for Euro 2 diesel was achieved. Bertrand D. also had a similar finding with the NO_x reduction of 50% [12]. The reduction of NO_x is primarily caused by lower peak temperature of the combustion [13]. The emulsion fuel yields lower peak temperatures because the water has the high latent heat of vaporisation that absorbs the heat inside the combustion chamber during phase transition. However, the lower combustion temperature also leads to the increase in CO emission [8]. In Figure 6, a notable increase of CO by an average of 41.6% is shown. Several other researchers also observed the similar increase in CO emission [14-15].
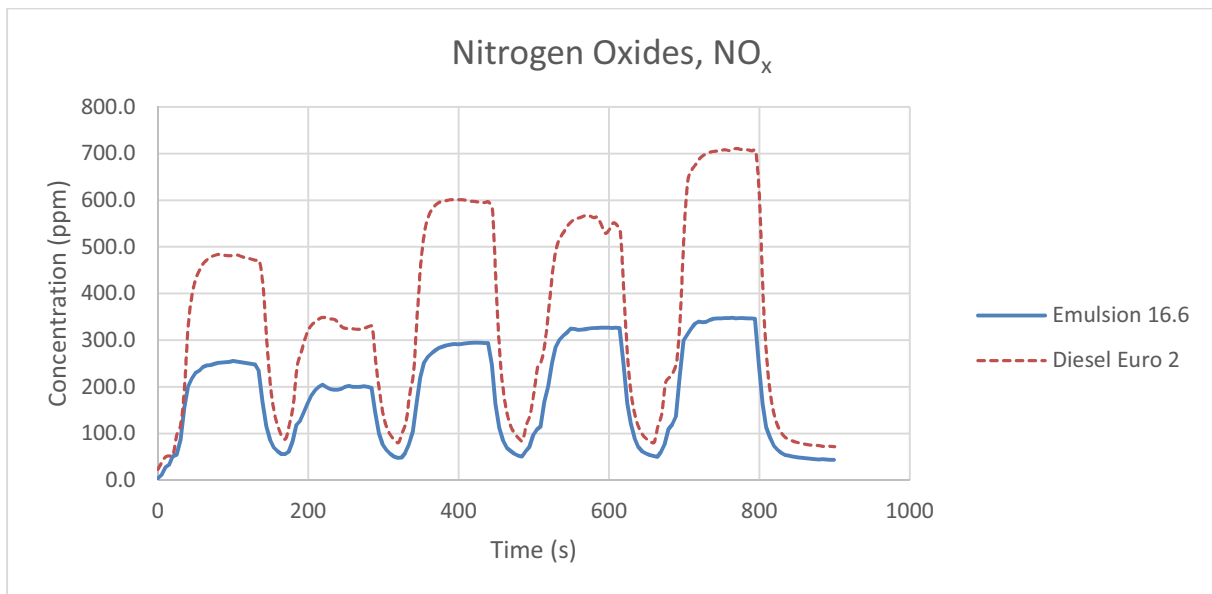
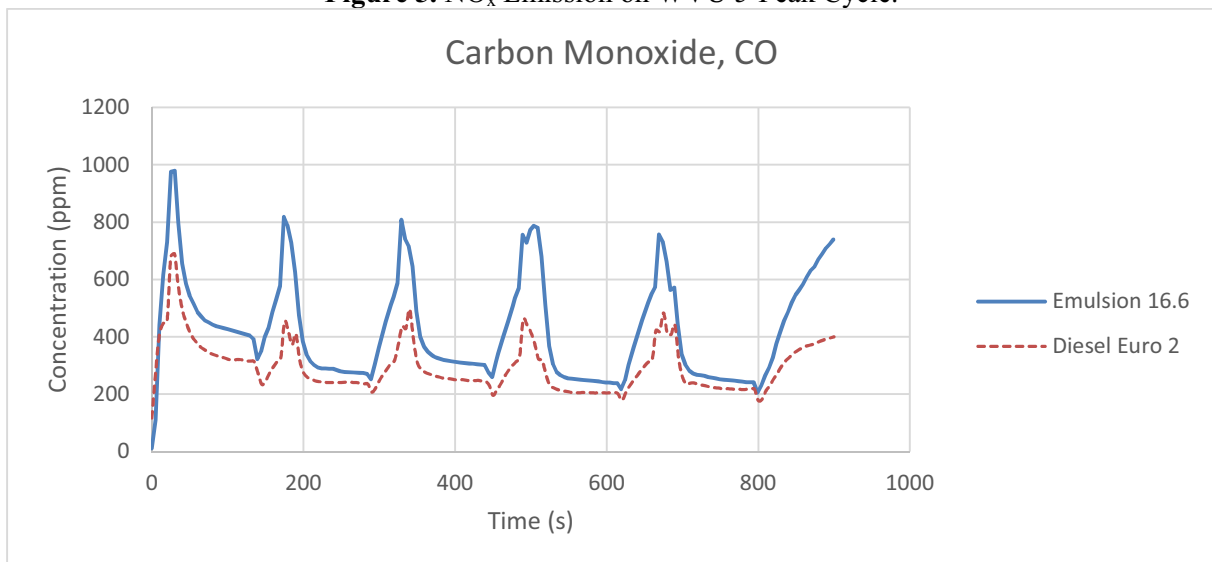**Figure 5.** NO_x Emission on WVU 5-Peak Cycle.

Figure 6. CO Emission on WVU 5-Peak Cycle.

4. Conclusions

The integration of RTES into a light duty lorry was successfully performed, and the concept was proven. This integration made it possible for a vehicle to take advantage of an emulsion fuel without the dependency on surfactant. This research also showed that the integration retained the same benefits of previous works on W/D of reducing the fuel consumption by 7.1% and NO_x emission by 52%. However, the significant increase of CO by 41.6% needs to be addressed. These results were similar with the previous study done on the 5.5kW diesel generator. Further research on non-surfactant emulsion fuel with innovative technology to reduce the CO emission and better integration designs for different kinds of application are recommended.

Acknowledgments

References

[1]   Joseph A Vance 1931 *Liquid fuel* US1926071A.
[2]   A. K. Hasannuddin, J. Y. Wira, S. Sarah, W. M. N. Wan, S. Aqma, A. R. A. Hadi, N. Hirofumi, S. A. Aizam, M. A. B. Aiman, S. Watanabe, M. I. Ahmad, and M. A. Azrin, "Performance, emissions and lubricant oil analysis of diesel engine running on emulsion fuel," 2016.
[3]   N. A. Mazlan, W. J. Yahya, A. M. Ithnin, and M. A. Ahmad, "The effect of tap water emulsified fuel on exhaust emission of single cylinder compression ignition engine."
[4]   A. K. Hasannuddin, J. Y. Wira, S. Sarah, M. I. Ahmad, S. A. Aizam, M. A. B. Aiman, S. Watanabe, N. Hirofumi, and M. A. Azrin 2016 *Energy* **94** 557–568.
[5]   O. V Lozhkina and V. N. Lozhkin 2016 *Transp. Res. Part D*, vol. **47** 251–264.
[6]   F. Y. Hagos, A. R. A. Aziz, and I. M. Tan, "Water-in-diesel emulsion and its micro-explosion phenomenon-review," in *2011 IEEE 3rd International Conference on Communication Software and Networks*, 2011, pp. 314–318.
[7]   M. E. A. Fahd, Y. Wenming, P. S. Lee, S. K. Chou, and C. R. Yap 2013 *Appl. Energy* **102** 1042–1049.
[8]   A. M. Ithnin, H. Noge, H. Abdul Kadir, and W. Jazair 2014 *J. Energy Inst.* **87** 273–288.
[9]   N. A. Ramlan, W. J. Yahya, A. M. Ithnin, A. K. Hasannuddin, S. A. Norazni, N. A. Mazlan, D. A. Sugeng, N. D. Bahar, and T. Koga 2016 *Energy Convers. Manag.* **130** 192–199.
[10]   A. M. Ithnin 2015 *Real-Time Water-In-Diesel Emulsion Fuel Production System for Diesel Electric Generator* (Universiti Teknologi Malaysia).
[11]   N. Clark, J. T. Messer, D. L. McKain, W. Wang, R. M. Bata, M. Gautam, and D. W. Lyons 1995 *Use of the West Virginia University Truck Test Cycle to Evaluate Emissions from Class 8 Trucks*.
[12]   B. D. Hsu 1986 Combustion of Water-in-Diesel Emulsion in an Experimental Medium Speed Diesel Engine.
[13]   A. Alahmer, J. Yamin, A. Sakhrieh, and M. A. Hamdan *Energy Convers. Manag.* **51** 1708–1713.
[14]   K. A. Subramanian 2011 *Energy Convers. Manag.* **52** 849–857.
[15]   A. B. Koc and M. Abdullah 2013 *Fuel Process. Technol.* **109** 70–77.