APPLICATION OF REAL-TIME NON-SURFACTANT EMULSION FUEL SUPPLY SYSTEM FOR COMMON RAIL DIESEL ENGINE

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This thesis is dedicated to my beloved parents for making me who I am today, to my lovely wife, my sons, and my siblings for supporting me all the way

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ABSTRACT

Water-in-diesel emulsified fuel (W/D) has become an alternative fuel for diesel engines, as it minimizes harmful emissions. However, its main limitation is the stability issue, which relies on the surfactant to remain stable. Too much reliance on surfactant is more costly than conventional diesel fuel. This research highlights the application of non-surfactant emulsion fuel in a common rail direct injection diesel powered vehicle. To eliminate the dependency on surfactants, a device known as Real-Time Non-Surfactant Emulsion Fuel Supply System (RTES) was used to produce and instantaneously supply W/D into the engine. This study carried out two types of experimental methods: roller dynamometer testing and on-road testing. Exhaust emissions and fuel consumption were measured while the optimal water percentage was also analyzed. The roller dynamometer testing was conducted based on the High Speed Modified WVU 5-Peak Cycle. The base test fuel used during this experiment was Euro 2 diesel (D2), while other test fuels were W/D with different water percentages; 6.4 %, 10 %, 15 %, and 20.6 %. The results from the roller dynamometer testing reveal that the optimum water percentage for W/D in this type of engine is 10 %. The application of RTES has been demonstrated to function well in a common rail diesel engine without stability issue and at the same time has been able to maintain the benefits of emulsion fuel for the road testing and roller dynamometer testing on fuel consumption. Overall, the application of non-surfactant emulsion fuel in common rail fuel injection diesel-powered vehicles shows potential benefits to balance between environmental and economic development.

ABSTRAK

Bahan bakar emulsi diesel-air (W / D) telah menjadi bahan bakar alternatif untuk enjin diesel, kerana ia meminimumkan pelepasan berbahaya. Walau bagaimanapun, batasan utamanya adalah berkaitan dengan masalah kestabilan yang bergantung kepada surfaktan untuk kekal stabil. Pergantungan yang tinggi pada surfaktan membuatkan harga kos lebih mahal berbanding dengan bahan bakar diesel konvensional. Kajian ini menekankan tentang penggunaan bahan bakar emulsi ~~bukan~~ tanpa surfaktan dalam kenderaan berenjin diesel pengecasan turbo suntikan lansung rel biasa. Bagi menghilangkan kebergantungan pada surfaktan, peranti yang dinamakan sebagai *Real-Time Non-Surfactant Emulsion Fuel Supply System* (RTES) telah digunakan untuk menghasilkan dan serta merta membekalkan W / D ke dalam enjin. Kajian ini menjalankan dua jenis kaedah eksperimen: ujian *roller dynamometer* dan ujian di jalan raya. Pelepasan ekzos dan penggunaan bahan bakar diukur, manakala peratusan air optimum dianalisis. Ujian *roller dynamometer* telah dijalankan berdasarkan piawaian *High Speed Modified WVU 5-Peak Cycle*. Bahan bakar asas yang digunakan semasa ujian ini ialah diesel *Euro 2* (D2), manakala bahan bakar lain adalah W / D dengan peratusan air yang berbeza;6.4%, 10%, 15%, dan 20.6%. Hasil ujian *roller dynamometer* menunjukkan bahawa peratusan air optimum untuk W / D dalam enjin jenis ini ialah 10 %. Aplikasi RTES telah ditunjukkan untuk berfungsi dengan baik dalam enjin diesel rel biasa tanpa isu kestabilan dan pada masa yang sama telah dapat mengekalkan faedah bahan api emulsi untuk ujian jalan raya dan ujian dinamometer roller pada penggunaan bahan api. Secara keseluruhannya, penggunaan bahan bakar emulsi tanpa surfaktan dalam kenderaan berenjin diesel pengecasan turbo suntikan langsung rel biasa menunjukkan potensi yang bermanfaat untuk mengimbangi antara pembangunan alam sekitar dan ekonomi.

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LIST OF ABBREVIATIONS

%	-	Percentage
CO	-	Carbon Monoxides
CO_2		Carbon Dioxides
D2	-	Diesel Euro 2
EE2	-	Emulsion Euro 2
E6.4	-	6.4 % water in emulsion fuel
E10	-	10 % water in emulsion fuel
E15	-	15 % water in emulsion fuel
E20.6	-	20.6 % water in emulsion fuel
HC	-	Hydrocarbon
NO	-	Nitric Oxide
NO_2	-	Nitrogen Dioxide
NO_x	-	Nitrogen Oxides
OH	-	Hydroxyl
O/W	-	Oil-in-water
PEMS	-	Portable Emission Measurement System
PM	-	Particulate Matter
RDE	-	Real Driving Emission
RTES	-	Real-Time Non-Surfactant Emulsion Fuel Supply System
US EPA	-	United States Environmental Protection Agency
W/D	-	Water-in-diesel
WVU	-	West Virginia University
HSM WVU	-	High Speed Modified West Virginia University
NEDC	-	New European Driving Cycle
WLTP	-	Worldwide Harmonized Light-Duty Vehicles Test Procedure

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Petroleum fuel is the major contributor to energy demand that is transforming the global economy today. It is almost certain that fossil fuel will retain about 60% of the power generation, which accounts for nearly 80% of the total energy supply in 2035. In the future, this situation is likely to continue. The dominant area responsible for the energy use of fossil fuels is the transport sector, which contributes roughly two-thirds of the use [1]. The growing usage of non-renewable energy has led our world to face challenges from adverse environmental consequences and depletion of resources [2]. Total fuel resource limitations and environmental pollution regulations have driven research programs around the world to implement new techniques and methodologies that not only rationalize fuel consumption but also maintain emissions from different combustion devices at extremely low levels [3].

The diesel engine tends to survive longer with regular maintenance and give long term services. In spite of this constraint of higher maintenance, diesel engines are preferred for their robust performance, reliability and lower fuel consumption. [4]-[6]. In different industries, such as agriculture, land-based power plants, or marine transport, they are used as a source of power. Diesel vehicles, despite their many benefits, cause significant health and environmental issues due to emissions such as NO_x, CO_2 (carbon dioxide), and PM (particulate matter). The greenhouse effects, ozone layer degradation and human health concerns are significantly contributing to these emissions from diesel engines, it is one of the most significant contributors to global warming and environment change [5].

Diesel engines, by virtue of their exhaust parameters are termed as the most polluting vehicles, that gives rise to greenhouse effects, hastens the ozone layer destruction and is the key culprit for global warming and climate change. Also, the harmful exhaust gas leads to several health hazards, that is another factor that plays a major role in decrement of human life expectancy [6]. Climate change is the most challenging problem of present time due to its unpredictable nature. The fallout of this is increment of temperature of earth, increment of ocean levels and ferocious storms that endanger human life and brings in destruction. So, to control this catastrophic climate changes, the emission regulations are periodically revised by the governments to reduce the harmful toxic gases. This has led the researchers to find methodologies for cleaner fuels, which are greener in form, thereby controlling the most polluting automobile emission of diesel engines [7].The challenging emission norms has posed difficult questions for the researchers to come up with cleaner emissions from diesel-based automobiles. To meet this challenging task scientists are carrying out several different experiments to minimize these harmful emissions. It's taken including modification of the engine to the improvements of fuel technology, the implementation of after-treatment, exhaust gas recirculation, multiple fuel injection strategies. Alternative fuels such as animal fat and vegetable oil biodiesel [10]-[13]. There are challenging tasks to fulfil the stringent emission regulations, devices and systems were also devised to lower NOx and PM emissions. This requires the usage of NOx Absorber Catalysts (NAC) and Selective Catalytic Reduction (SCR) which has the capability of significantly reducing the production of NOx.

In addition, Diesel Oxidation Catalysts (DOCs) and Diesel Particulate Filters (DPFs) are devices which are widely used to minimize PM. DOC is a low-cost, versatile system suitable for non-road applications that can minimize PM by 25 % or more. As for DPFs, they can minimize PM forming by up to 90 % and operate effectively on engines capable of sustaining high exhaust temperatures [9]. For example, large quantities of NOx emitted from the diesel engine caused upper respiratory tract irritation. Densely populated region, growing numbers of road vehicles and industrial areas are factors this exacerbate the air quality index due to released pollution [10]. The easiest way to reduce the exhaust emission of diesel-based automobiles is by using various combinations of biodiesel fuel, natural gas, and emulsion fuel. Natural gas offers advantage for diesel vehicles in term of low emissions, which has found support in industrial applications and electricity generations for its performance [11]. However, the usage of natural gas in diesel engines requires a major engine modification for the optimum performance .This includes major overhaul of the existing engine which become a constraint for the natural gas application [12]. The biodiesel obtained from particular plants or industrial waste be a warning of the form of renewable energy has a huge potential in reducing harmful air pollutants namely PM, CO, CO_2 [7]. Similarly, to the natural gas, the major constraint of biodiesel application is the overhauling and high-cost maintenance of the re-designed engine.

The emulsified fuel technology has emerged as the prime candidate to replace the existing technology in diesel engines as it offers a drastic change by reducing the harmful exhaust emissions. In contrast to other methods, water-diesel-emulsified fuel has become one of the preferred alternative fuels for diesel engines that able to reduce harmful emissions without any major changes to engine design [13]. Water-in-Diesel emulsion fuel (W/D) is a viable alternative fuel that can simultaneously reduce the production of nitrogen oxides (NOx) and particulate matter (PM) while increasing the efficiency of combustion [14]. Numerous researchers' studies on emulsified fuel technology and provides promising results across various parameters. Different methodologies adopted to test the characteristics of the emulsified fuel in multiple combinations using constant volume chamber, burner and bomb experiment [15]. It was generally analysed using the exhaust emission testing (NOx, PM, CO, and HC) and engine performance (exhaust temperature, fuel consumption, brake power, and torque) [10][16][3]. Also, various combinations of water percentage, methods of emulsification and surfactants have been reviewed by numerous researchers worldwide [17]

W/D is the immiscible liquids which consist of water and diesel, that combined with a chemical additive called surfactant, and mixed with the aid of mechanical agitation. The role of the surfactant is to hold the two immiscible liquids together to form a solution. W/D application has become popular in worldwide. The key restriction of the W/D application is the emulsified fuel's stability problem, which makes it dependent on the surfactant to maintain its stability. However, W/D stability is an important characteristic to be consider before being applied in diesel engines [18].

The process of emulsion comes with the innate difficulty of its stability as it can stay in that state for a small fraction of time. The addition of surfactants can increase its stability for up to 3 months provided the temperature, amount of surfactants, its viscosity, specific gravity and the water content are taken into consideration [19][10]. Researchers mostly chose the lipophilic and hydrophilic surfactants SPAN 80 and TWEEN 80. Nonetheless, reliance on surfactant causes the emulsion fuel to become pricey compared to the existing diesel fuel, thereby restricting the marketing of emulsion fuel [4]. The diesel engine requires the stability of emulsion for its proper operation and performance. This is because, with the destabilization of W/D, on storage or engine operation, the chance of engine failure increases. Also, the addition of surfactant to the W/D, in the case of large-scale commercialization is not feasible as the cost increases manifold on their addition.

The best way to mitigate the surging cost, is to use a novel method of supplying non-surfactant W/D. Muhsin et al has developed a concept of supplying W/D emulsion fuel without the addition of surfactant which named as Real-Time Non-Surfactant Emulsion Fuel Supply System (RTES)[14]. It is a combination of mixing devices that incorporates two types of different mixers. The idea of this concept is to continuously emulsify the diesel fuel with water and directly supplied into a diesel engine in real-time. As the system utilizes mechanical emulsification method, thus no surfactant is needed during the emulsification process.

1.2 Problem Statement

The RTES has been previously applied in a small diesel electric generator and a 1-ton diesel lorry that having a mechanical pump as the fuel system. The diesel electric generator utilizes the non-surfactant emulsion fuel and tested under a steady state condition. From the test, it can be concluded that the non-surfactant emulsion fuel has significantly improved the engine performance and the exhaust emissions by cutting down the NOx by 31.7% and the PM by 16.3% respectively. Furthermore, the specific fuel consumption sees an improvement of 3.89% compared to the normal diesel fuel[14]. Therefore, it indicates that the use of non-surfactant emulsion fuel is not only proven working but having enormous emulsion fuel effects on the diesel engine. Furthermore a 1-ton lorry with a mechanical pump direct injection engine fuelled with W/D reduced fuel consumption up to 7.39%. NOx emissions are reduced by 23%, and CO emissions are marginally higher than base diesel and smoke emissions are reduced at all operating speeds.

A small modern diesel engine is equipped with a common rail fuel injection system that cause the diesel engine performs better, silent, has less emissions and more fuel efficient than the regular mechanical injection diesel engines. A typical mechanical injection diesel engine has a fuel pump that builds up the pressure of the fuel, which is then sent to mechanical injectors, where the fuel pump's pressure is used to open the injectors, allowing the fuel to simply spray into the cylinder. On the other hand, common rail diesel engine consists of a high-pressure accumulator called rail is used to deliver fuel to the injectors. A high-pressure fuel pump supplies fuel to the rail. Pressure in the rail is controlled electronically, the common rail fuel injection system stores and supplies fuel constantly at the needed pressure on the solenoid valve injectors. The RTES never been installed and tested in a common rail diesel engine. Higher pressure developed in the common rail system might have different effect towards diesel engine performance and emissions. It is unknown on the optimum water percentage should be introduced into the W/D for the use of common rail diesel engine. Overall performance and exhaust emissions of common rail diesel engine fuelled with W/D should be measured and analysed.

1.3 Research Objective

To diversify the utilization of non-surfactant emulsion fuel made by the RTES, there is a need to test the device into a common rail injection system-based automobile diesel engine.

The objectives of this research are:

1. To suggest the optimum water percentage of non-surfactant emulsion fuel for the use of a common rail diesel engine.
2. To analyse the performance and exhaust emissions of a common rail diesel engine equipped with RTES for on-road operating condition.

1.4 Research Scope

(a) The test vehicle was an SUV with 2.2 litre displacement, 4-cylinder, common rail fuel injection system, turbo-charged, water-cooled diesel engine. (Hyundai Santa Fe, 2009)

(b) The vehicle speed for roller dynamometer testing varies from 50km/h to 90km/h using W/D emulsion compliance with SAE J1082 standard.

(c) On-road testing, the vehicle speed lies between 80km/h to 120km/h.

(d) The exhaust emissions consist of NO_x, CO, CO_2, and smoke number, the exhaust temperature and the fuel consumption are measured in L/100 km unit.

The water percentage for RTES applications in road vehicles is determined by the optimum water percentage from the results of exhaust emissions and fuel consumption of roller dynamometer testing.

1.5 Research significance

I. Water % age in non-surfactant W/D emulsion made by RTES that is suitable for common rail fuel injection diesel vehicles can be suggested.

II. The RTES was also installed in a car to assess the effects on exhaust emissions and fuel consumption of non-surfactant emulsion fuel produced with low-grade diesel.

1.6 Thesis outline

This thesis is divided into five chapters, namely, introduction, literature review, methodology, result and discussion and conclusion. The detail flowchart is described below.

Chapter 1: This chapter corroborates the background study related to emulsion fuel and non-surfactant emulsion fuel produced by virtue of RTES. This chapter also sheds the light on research question, research objective, research scope and outline of the whole thesis.

Chapter 2: This chapter discusses the key facts of literature studies related to the present research. which can throw insight on the understanding of the operation of the diesel engine, use of surfactant and the micro-explosion phenomenon and effect of emulsion fuel on fuel consumption and engine exhaust. The critical review of RTES technology is carried out based on the design aspect and working principle, with specific insight on the previous studies. Also, this chapter encompasses the literature review related to roller dynamometer testing that forms the core testing methodology of this research.

Chapter 3: This chapter clarifies the methodology adopted for this experimental work for RTES testing. It details the work carried out from installation stage to the roller dynamometer test leading to the on-road testing, thus giving a detailed specification insight.

Chapter 4: This chapter details the results and discussion of the thesis pertaining to the experimental work carried out for the RTES methodology with critical understanding of the experimental knowhow.

Chapter 5: This chapter lays down the basis of the conclusion section, which gives a firsthand knowledge of the experimental goals achieved and their implications, together with recommendations and future research work.

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