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THE INFLUENCE OF WATER IN WATER-MICROEMULSIFIED-DIESEL AND ITS IMPACT ON FUEL PROPERTIES AND ENGINE PERFORMANCE

(Pengaruh Air dalam Air-Termikroemulsi-Diesel dan Kesannya ke atas Sifat-sifat Bahan Api dan Prestasi Enjin)

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Abstract

This investigation has been performed to study the effect of water on water microemulsified diesel on the fuel properties and engine performance. Selective tests of engine performance were performed in order to compare the efficiency in the engine between formulated water microemulsified diesel and conventional diesel fuel. The formulated water microemulsified diesel used were diesel/T80/1-penthanol/water 60:20:15:5 wt% (System 1), 55:20:15:10 wt% (System 2) and 50:20:15:15 wt% (System 3). These fuels withstand stability over a month in storage. The result showed that the engine brake specific fuel consumption (BSFC) increased as the water concentration in the system increased. Instead of showing higher fuel consumption than diesel fuel, System 1 and System 2 fuels show good fuel properties that meet the ASTM requirements for cloud point, calorific value and pour point for biodiesel. Further investigation in the gas emission test must be carried out in order to finding its potential as alternative fuels.

Keywords: brake specific fuel consumption, engine performance, fuel consumption, water microemulsified diesel

Abstrak

Kertas kerja ini melaporkan hasil kajian kesan kandungan air ke atas bahan api termikroemulsi air-diesel pada sifat-sifat bahan api dan prestasi enjin. Ujian prestasi enjin yang terpilih telah dilakukan bagi membandingkan kecekapan antara bahan api termikroemulsi dan diesel konvensional di dalam enjin. Formulasi bahan api termikroemulsi yang digunakan ialah diesel/T80/1-pentanol/air 60:20:15:5 wt% (Sistem 1), 55:20:15:10 wt% (Sistem 2) dan 50:20:15:15 wt% (Sistem 3). Formulasi bahan api ini adalah stabil melebihi sebulan. Keputusan menunjukkan bahawa penggunaan bahan api tentu brek (BSFC) enjin meningkat dengan peningkatan kepekatan air di dalam sistem mikroemulsi. Walaupun keputusan menunjukkan bahawa bahan api termikroemulsi air-diesel memerlukan penggunaan bahan api yang lebih tinggi berbanding dengan bahan api diesel, tetapi bahan api Sistem 1 dan Sistem 2 menunjukkan sifat-sifat bahan api yang baik dan memenuhi piawai seperti takat keruh, nilai kalori dan takat tuang. Ujian pembebasan gas mesti dilakukan pada kajian akan datang bagi mengetahui potensinya sebagai bahan api alternatif.

Kata kunci: penggunaan bahan api tentu brek, prestasi enjin, penggunaan bahan api, air-diesel termikroemulsi

Introduction

Implementation of more stringent regulation on exhaust emission drives the researcher to search for alternative fuels. The introduction of water into the fuels gave significant effect in the reduction of greenhouse gases such as nitrogen oxide (NO_x). The presence of water in the fuel may assist in fuel atomization due to microexplosion. Microexplosion phenomenon occurs during the evaporation of the water inside droplets of fuel, thus improve the combustion efficiency due to the complete combustion [1-3].

Water can be introduced into the fuels through three methods which are injection of water into cylinder using a separate injector, spraying water into inlet air and water-diesel emulsion. Among these three techniques, water-diesel emulsion has been chosen as the most effective way to introduce water into the fuel and hence for the reduction of diesel emission, for four-stroke direct injection (DI) engines [3]. The interest in water-diesel emulsion derives from the fact that water in the form of micrometer-sized droplets exerts some positive effects on the combustion of the fuel in the chamber [4]. Emulsified fuels can reduce the emission of soot and NO_x from diesel engine without any deterioration of specific fuel consumption [5]. Water-in-oil emulsion have been formulated and evaluated for most types of fuels, ranging from light hydrocarbons to triglycerides [4].

Many works had been reported on emulsified fuels. These include works dealing with the development of the emulsion systems, emulsified fuel properties, engine performance and at present the new post-treatment devices [6]. The fact that emulsion is used as fuel in diesel engine requires significant observation on the stability of the emulsified fuel. Fuel instability is an obvious problem when the technique of emulsion system was used in the introduction of water in the fuel [7]. This is due to the fact that emulsion system is thermodynamically unstable and easily separates [1-3]. The instability of the emulsified fuel can deteriorate the diesel engine [8]. It is compulsory to select the suitable emulsification technique, optimized speed and agitation time in order to achieve stable emulsified fuel [7].

Microemulsions technique which is thermodynamically stable has been proposed as the solution for the instability of the emulsified fuel [3]. Microemulsions are defined as transparent, thermodynamically stable colloidal dispersions of oil and water stabilized by a surfactant and/or co-surfactant. The diameter of the dispersed-phase droplet is less than one-fourth the wavelength of the visible light which is the reason for their transparency and microemulsions is low in viscosity which make it more profitable than emulsion [9-11]. In contrast, emulsion is milky white in colour, high in viscosity, its viscosity dependent on temperature, relatively in large droplets and static system, and slightly unstable system, which is will eventually separate [4].

Very few studies of water-in-diesel microemulsions fuels have been reported in the literature. This study is the extended investigation from the previous work, which focused on the effect of water content on partial ternary phase diagram and physicochemical part. The main objective of this present work is to investigate the effect of water content on fuel properties and engine performance of microemulsified diesel. The percentage of water content in the system was varied from 5% to 15%. The optimal formulation for microemulsified diesel that was used in this study was taken from the previous work.

Materials and Methods

Commercial diesel was purchased from local petrol station (kinematic viscosity, η =3.6095 mm^2/s. The non-ionic surfactant, polyoxyethylene sorbitan monooleate (T80) with hydrophile-lipophile balance (HLB) value of ~15.0 was supplied by Merck (M) Sdn Bhd. Selangor, Malaysia. The co-surfactant used was 1-penthanol and was manufactured by Fluka Sdn. Bhd. Distilled water was used to obtain the microemulsion systems.

The preparation of microemulsions was adopted from a published procedure applying constant composition method [12]. The components used were T80, 1-penthanol and water + oil phase (W + O) with total mass of 10 g in a screwed cap test tube. Composition of T80 and 1-penthanol were varied from 5 to 50% with 5% interval. The portion of water in the system was varied at 5, 10 and 15%. These mixtures were mixed by vortex and left for 1 to 2 days at ambient condition. The same mixture undergone microemulsion stability study at 45°C and was observed for a month. These formulated microemulsions were qualitatively analyzed using polarized light sheets to distinguish isotropic from anisotropic phases. The selected microemulsions were characterized for fuel properties i.e. viscosity, calorific value, cloud point, pour point and flash point and selected engine performance.

Fuel Properties

The kinematic viscosity of the formulated microemulsions fuel was determined using viscosity analyzer model HVM 472 Herzog and was conducted at 40°C. The density was measured following EN ISO 12185. The calorific value of the formulated microemulsions fuel was determined using Parr bomb calorimeter model 6100EF at 25°C. The pour point of the formulated microemulsions fuel was measured using a Pour Point Analyzer model ISL-CPP97-2, according to the ASTM D-97 standard method. The cloud point was determined following ASTM D2500, in which these fuels were observed for the first sign of turbidity and cloudiness in a cooling water bath as the temperature was decreased in increments of 5°C.

Diesel Engine Setup

A single cylinder, direct injection diesel engine coupled with dynamometer was used to evaluate fuel performance. The diesel engine was manufactured by YANMAR with specifications listed in Table 1 (source: single cylinder engine manual test, K.L Sdn Bhd).

Table 1. Single cylinder diesel engine specification

Model	**TF90**
Type	Horizontal, water cooled
Combustion system	Direct injection
Bore × stroke	102 mm × 105 mm
Compression ratio	17.8
Cooling system	Water-radiator
Oil injection pump	Bosch

Engine Test Procedure

Engine test was performed for conventional diesel fuel as the baseline and for three microemulsion fuels. For all test runs, the engine was warmed up for approximately 10 min so that the operating conditions were stabilized prior to testing. Engine performance was evaluated under two operating conditions: low load and high load. Engine speed varied from 1000 to 1800 RPM. The time taken for the engine to burn 10 mL of fuel was recorded, yielding average fuel consumption. Before each test, the line was drained and new fuel to be tested was flushed. The engine performance analysis has included: torque, power, brake specific fuel consumption and brake thermal efficiency.

Results and Discussion

Fuel Properties

The kinematic viscosity, density, cloud point, pour point and calorific value of commercial diesel and microemulsion fuels with various percentage of water were measured and presented in Table 2.

Table 2. Fuel properties of diesel and microemulsified diesel fuels.

Properties	**Diesel**	**System 1 (5% H_2O)**	**System 2 (10% H_2O)**	**System 3 (15% H_2O)**
Kinematic viscosity, mm^2/s	3.61	10.37	12.88	16.31
Density at 20°C, g/cm^3	0.8545	0.8953	0.9036	0.9120
Cloud point, °C	5.9	7.4	7.7	8.3
Pour point, °C	0	3	5	9
Calorific value, kJ/g	43.7	37.4	34.8	32.5

The kinematic viscosity of all microemulsion fuels is higher than diesel fuel. As water content in the microemulsion system increased, the droplet size and number of disperse phase increased, led to more complex micelle structure formed in the system resulting in increment in viscosity [13-16]. The density of microemulsion fuels also increased as the amount of water in the system increased [13, 16]. This is attributed to the higher density of water than diesel that has been added into the system of microemulsion diesel [13]. As the water composition increased, the cloud point and pour point of the microemulsified fuels also increased. This is in relation to the increase in viscosity [17]. The calorific value of microemulsion fuels was much lower than diesel fuel. As the percentage of water content in the system increased, the calorific value decreased [13, 16]. The systems encountered heat sink phenomenon. When heat sink occurs, the heat releases from the combustion reaction is partially absorbed by water molecules and hence reduces the calorific value [13].

Engine Performance

Engine Torque

Water concentration effect in water microemulsified diesel on engine torque for two load conditions are shown in Figure 1 and Figure 2. The torque produced increased gradually as the engine speed increased, under both low and high loading conditions. Also, the microemulsified diesel with 10% water produced the highest torque at all engine speeds. As the water concentration in the system of microemulsified diesel was increased to 15%, engine torque is observed to deteriorate particularly at lower engine speeds. This is contributed by the additional force on top of the piston provided by the vapour from microemulsified diesel. When the cylinder is fired by the charge, the water in the microemulsified diesel would produce high pressure vapour thus provided additional force on the piston [13, 18, 19]. Besides, the presence of water droplet in the fuels promote a finer cloud which leads to the atomization of the microemulsified mixture during injection [18]. In addition, higher density of microemulsion fuels resulted in higher mass flow rate for the same fuel volume pumping into the combustion chamber [20].

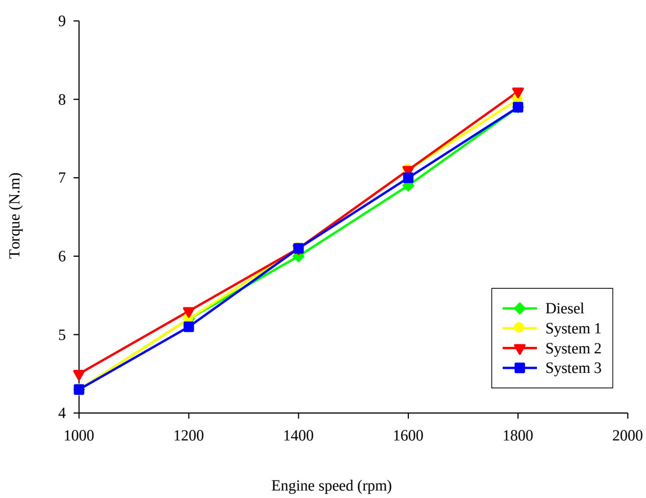

Figure 1. Engine torque at varying engine speed of the water microemulsified diesel at low load

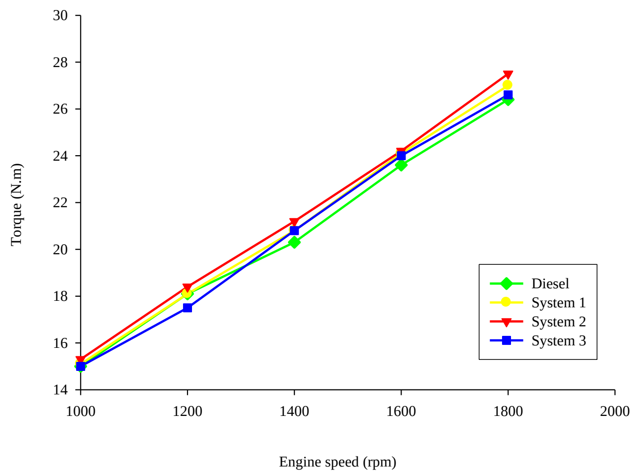

Figure 2. Engine torque at varying engine speed of the water microemulsified diesel at high load

Engine power

The engine power produced by the engine using microemulsified diesel and diesel fuel under low and high loading conditions at various speeds is presented in Figure 3 and 4, respectively. The figures illustrated that the engine power produced increased as the engine speed increased, under both loading conditions. Also, there was a slight increase in engine power when using microemulsified fuel compared to commercial diesel fuel. The presence of water in the system, prolonged the ignition delay. The ignition delay is the period between the injection of fuel into the cylinder and the fuel start to combust. Due to longer ignition delay, microemulsion fuels require less compression work than the diesel fuel during the compression stroke. This helps to reach a higher peak pressure after top dead centre (TDC) to produce more power output during the expansion stroke [13, 18, 19]. As indicated, the engine power produced was higher at high loading condition than low loading condition.

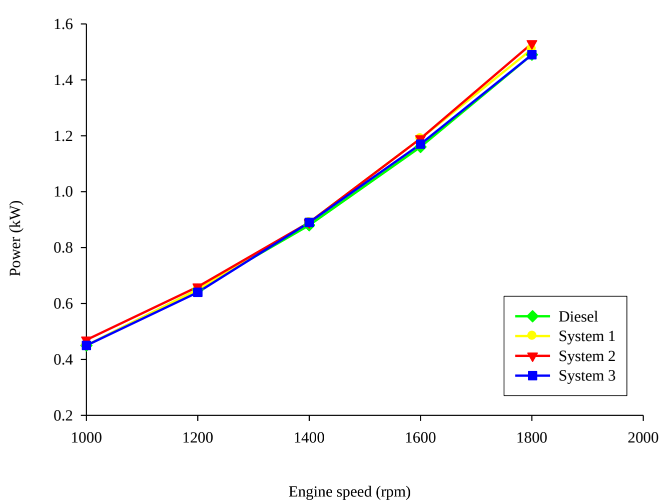

Figure 3. Engine power at varying engine speed of the water microemulsified diesel at low load

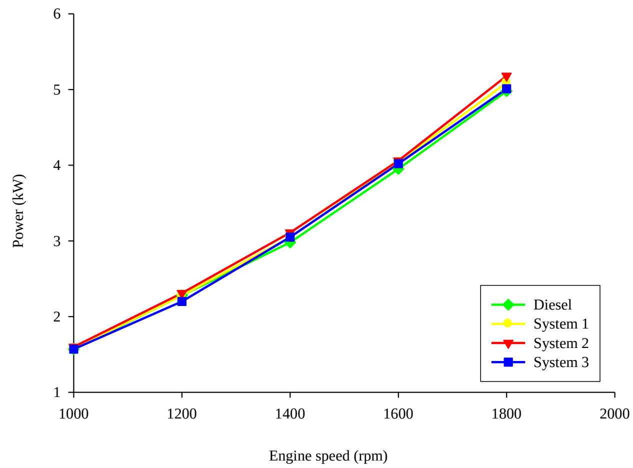

Figure 4. Engine power at varying engine speed of the water microemulsified diesel at high load

Brake Specific fuel consumption (BSFC)

Figure 5 and 6 shows BSFC values of the microemulsified diesel system by considering diesel + water as total fuel; under low and high loading conditions at various engine speeds. All fuels indicated that the BSFC value decreased as engine speed increased. These figures also illustrated that BSFC values for microemulsified diesel fuels was much higher compared to commercial diesel fuel due to the lower energy content of microemulsified diesel fuels. As the water content in the system increased, the energy content decreased, resulted in high BSFC values [16, 18, 19].

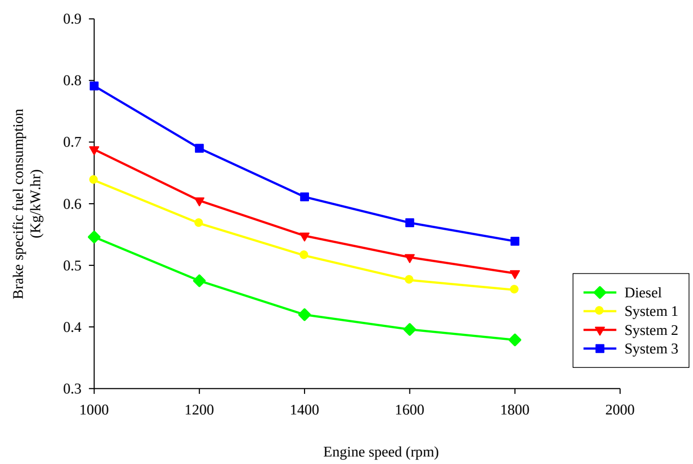

Figure 5. Brake specific fuel consumption at varying engine speed of the water microemulsified diesel considering diesel + water as total fuel; at low load

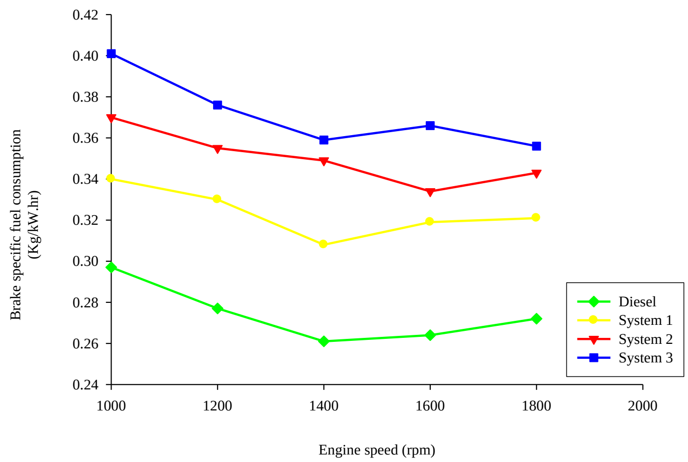

Figure 6. Brake specific fuel consumption at varying engine speed of the water microemulsified diesel considering diesel + water as total fuel; at high load

While, Figure 7 and 8 show BSFC values of the microemulsified diesel system by considering diesel as total fuel; under low and high loading conditions at various engine speeds. Both figures show that as the percentage of water in the system increased, the BSFC decreased. As the percentage of water in the system increased, a larger amount of diesel was displaced by an equal amount of water thus reduced the consumption of diesel fuel in the microemulsified diesel fuel. As a result, more diesel fuel can be preserved when microemulsified diesel fuels were used.

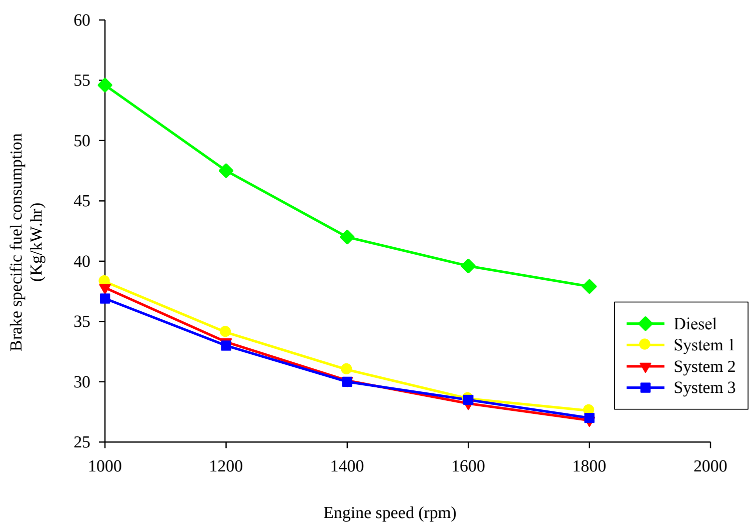

Figure 7. Brake specific fuel consumption at varying engine speed of the water microemulsified diesel considering diesel as total fuel; at low load

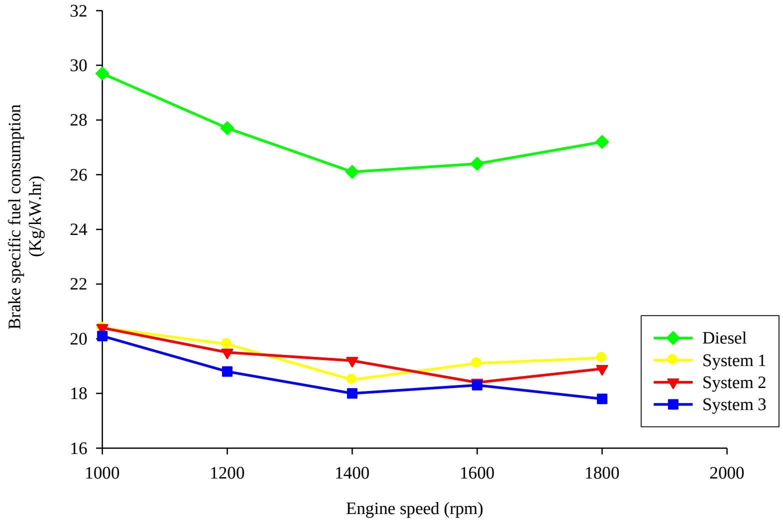

Figure 8. Brake specific fuel consumption at varying engine speed of the water microemulsified diesel considering diesel as total fuel; at high load

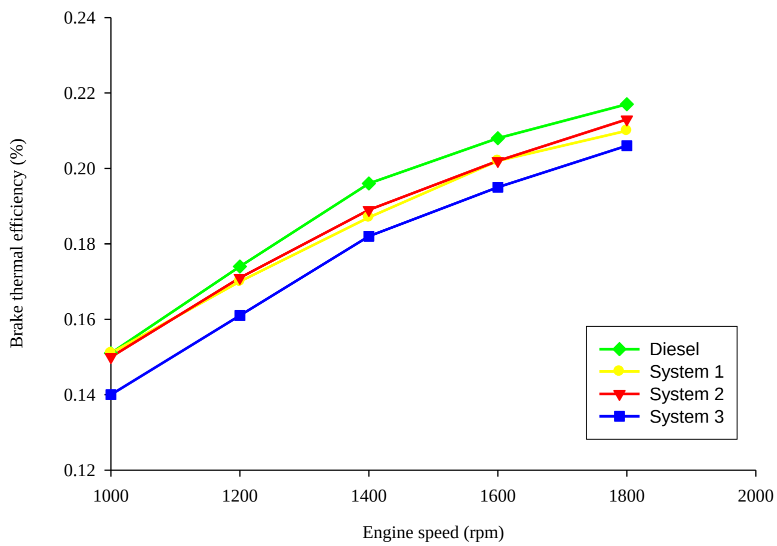

Figure 9. Brake thermal efficiency at varying engine speed of the water microemulsified diesel at low load

Brake thermal efficiency

The brake thermal efficiency versus engine speed for all fuels under low and high loading conditions are shown in Figure 9 and 10. The figures show that the thermal efficiency increases as the engine speed increases. But in Figure 8, the thermal efficiency decreases after reaching a maximum value. At low speed, a long time is available for heat to be transferred to the cylinder walls, and hence significant amount for a greater proportion of heat loss occur. As speed increases the brake power increases, which implies a higher thermal efficiency is obtained. At higher speeds, the thermal efficiency is decreasing due to rapidly increasing friction power and greater inertia in the moving parts. As anticipated, the brake thermal efficiency of microemulsified diesel fuels is lower than commercial diesel fuel, under both loading conditions. This is because of low energy content of microemulsified fuels due to the introduction of water in the system [13, 19, 20].

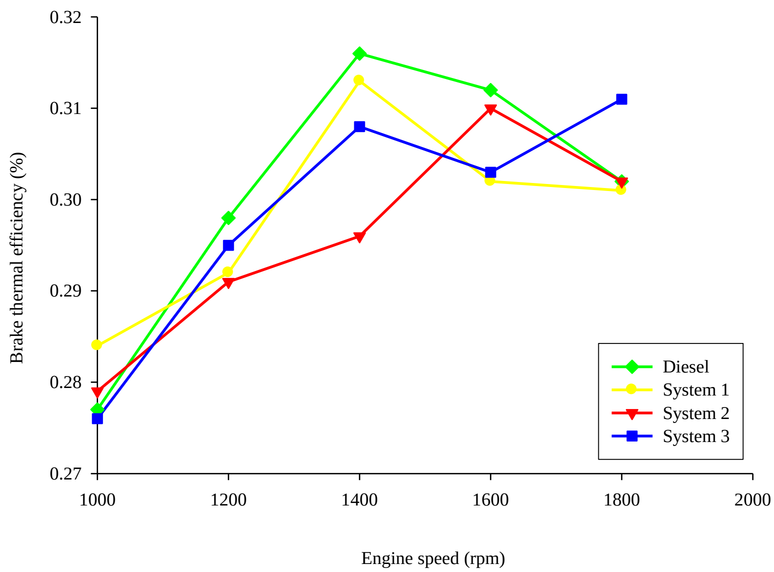

Figure 10. Brake thermal efficiency at varying engine speed of the water microemulsified diesel at high load

Conclusion

Water effect in microemulsified diesel fuel onto the fuel properties and engine performance was successfully evaluated. Microemulsified diesel fuels of 5, 10 and 15 % (w/w) were used in a single cylinder, direct injection diesel engine, operated between 1000 to 1800 rpm under low and high loads. The kinematic viscosity, density and cloud point of the microemulsified diesel fuel increased as the water concentration in the system increased, but the calorific value of the microemulsified diesel fuel decreased as the water concentration in the system increased. The density, cloud point and calorific value of System 1 and System 2 adhere to ASTM requirements. The engine torque and power produced were comparable for the commercial and microemulsified diesel fuels. The specific fuel consumption (BSFC) of all microemulsified diesels was higher than the commercial diesel fuel by considering diesel + water as the total fuel. However, by considering diesel only as the total fuel, the specific fuel consumption (BSFC) decreased when the percentage of water in the system increased. Further investigation in the gas emission test must be carried out in order to find its potential as alternative fuels.

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