Corrosion of aluminium in water-in-diesel-emulsion fuel

D Chandran, M Khalid, R Raviadaran and PR Jagadish

Graphene & Advanced 2D Materials Research Group (GAMRG), School of Science and Technology, Sunway University, Malaysia
Email: dchandran@sunway.edu.my

Abstract. This study aimed to determine the corrosion characteristics of water-in-diesel emulsion fuel towards aluminium. Investigation was performed by immersing aluminium coupons in emulsified diesel for 240 hours, 480 hours, 720 hours, 960 hours and 1200 hours at 25 °C. For comparison, additional aluminium coupons were immersed in diesel for 1200 hours at 25 °C. Span 80 and Tween 80 surfactants were used to prepare the emulsified diesel which consisted of 5 vol% of water and 95 vol% of diesel. Mass loss of the coupons were measured to calculate the corrosion rate. Water content, total acid number, density and viscosity of the fuel samples were measured before and after immersion. The corrosion rate of aluminium coupons exposed to emulsified diesel reduced by 97.6% between 240 hours and 1200 hours of immersion duration. The aluminium coupons immersed in emulsified diesel had 2.2 times higher corrosion rate than in diesel. The higher total acid number of emulsified diesel by 4.7 times than diesel is suggested to have influenced this. To benefit the potential reduction in harmful exhaust emission through the adoption of emulsified diesel, studies towards producing less acidic stable emulsified diesel are essential.

1. Introduction
Reduction in the harmful emission produced by vehicles are absolutely necessary to address the declining air quality. Declined air quality are among the major reason leading to respiratory diseases and may also cause neurological disorders. With regard to this, research works have demonstrated the possibilities of reducing harmful exhaust emission from diesel engine by adopting water-in-diesel emulsion fuel (emulsified diesel). Ithnin et al. [1] reported reduced nitrogen oxide and particulate matter by 41% and 35%, respectively, for using emulsified diesel with 20 vol% of water as compared to diesel. In another study, the authors reported reduction in nitrogen oxide and particulate matter by 32% and 16%, respectively, with the use of emulsified diesel consisting of 5 vol% of water as compared to neat diesel [2]. Several other studies have also exhibited similar outcome [3-5]. However, limited information is available till present concerning the compatibility of emulsified diesel with fuel delivery materials. Use of incompatible fuel could significantly reduce the components lifespan culminating in stalling the engine due to fuel leakage [6, 7]. This study therefore investigated the corrosive effect of emulsified diesel on aluminium (common material for high pressure fuel pump) under immersion investigation.

2. Materials and methods
Aluminium coupons with a diameter of 0.02 m, thickness of 0.002 m and an elemental composition of 99.59 wt% of aluminium, 0.28 wt% of iron, 0.10 wt% of silicon and 0.03 wt% of zinc were used in this study. Emulsified diesel was prepared using not additized diesel, distilled water prepared from TKA Smart2Pure and surfactants (Span 80 and Tween 80). The emulsion consisted of 5 vol% of water, 1.5 vol% of Span 80, 1.5 vol% of Tween 80 and 92 vol% of diesel. The emulsion was prepared using Silverstone LM-5 high shear mixer at a rotational speed of 3500 revolutions/min. The immersion investigations were carried out by employing ASTM G1 and ASTM G31 standard methods. Each coupon was immersed in 38 ml of emulsified diesel according to SAE J1747 standard method, stored in a closed and dark environment at 25 °C for 240 hours, 480 hours, 720 hours, 960 hours and 1200
hours. Additionally, coupons were also immersed in diesel for 1200 hours at 25 °C for comparisons. For each condition, an additional coupon was analysed as duplicate. The mass of the coupons was measured before and after the immersion. Details on coupons preparation/cleaning have been reported earlier [8]. The corrosion rate was calculated using the average mass loss. The water content, total acid number (TAN), viscosity and density of the fuels were measured before and after the immersion. The specific details concerning the analysis procedure and utilized equipment have been reported elsewhere [9, 10].

3. Results and discussion

As shown in Figure 1, the corrosion rate of aluminium exposed to emulsified diesel reduced by up to 97.6% with increasing immersion duration from 240 hours to 1200 hours. For the comparative corrosion rate of aluminium in emulsified diesel and diesel after 1200 hours of immersion at 25 °C, 2.2 times higher corrosion rate occurred to the coupon exposed to emulsified diesel at 0.000249 mm/yr than to diesel at 0.000116 mm/yr. Comparisons to the existing studies were not made possible due to the limited information available in this area. The trend of reducing corrosion rate with increasing immersion duration nevertheless corroborated with the study reported by Chandran et al. [9] in which the authors reported reduced corrosion rate of copper due to biodiesel exposure by 2.8% after 540 hours as compared to 108 hours of immersion duration. Fazal et al. [11] also reported likewise in which the corrosion rate of copper reduced by 19.5% due to biodiesel exposure between 1200 hours and 2880 hours of immersion duration.

Figure 1. Corrosion rate of aluminium in emulsified diesel with respect to immersion duration at 25 °C.

Figure 2 shows the TAN of emulsified diesel due to aluminium coupon exposure for 240 hours, 480 hours, 720 hours, 960 hours and 1200 hours. The TAN of the emulsified diesel is observed to reduce with increasing immersion duration. 12% reduction in TAN was measured between 240 hour and 1200 hours of immersion duration. As shown in Figure 3, the water content of the emulsified diesel remained similar (< 0.03% change) after exposed to aluminium coupon for 240 hours, 480 hours, 720 hours, 960 hours and 1200 hours. From Figure 4, it is noticed that the viscosity of the emulsified diesel increased with increasing immersion duration of aluminium coupons. The viscosity value increased by 20.3% between 240 hour and 1200 hours of immersion duration. As shown in Figure 5, the density of the emulsified diesel is observed to increase with increasing immersion duration. The density of the emulsified diesel increased by 0.7% between 240 hours and 1200 hours of aluminium coupon exposure.
As shown in Table 1, the prepared emulsified diesel has 4.7 times higher TAN than diesel. The surfactants Span 80 and Tween 80 which has a TAN of 13.90 mgKOH/g and 2.65 mgKOH/g, respectively, used in the preparation of emulsified diesel is suggested to have influenced the rise. After exposed to aluminium, the TAN reduced by 18% for emulsified diesel, while it increased by 39% for the diesel. The reduction in TAN for the emulsified diesel suggest the involvement of the acidic substances in the corrosion process. The prepared emulsified diesel has 23% higher viscosity value than diesel. The presence of water in the form of emulsion in
could have caused this rise. Existing studies have reported up to 50% rise in viscosity value to formation of emulsified diesel with 5 vol% of water [12, 13]. 18% increase in the viscosity value occurred for the emulsified diesel after exposed to aluminium while it did not change for diesel. The increase in the water droplets size could have influenced this rise for the emulsified diesel. The emulsified diesel has 2% higher density than diesel. The presence of 5 vol% of water in the emulsified diesel could have caused this rise since water has a higher density value by 19% than diesel. Existing studies have reported increased density value by up to 3.5% for emulsified diesel with 5 vol% of water than diesel [12, 13]. After exposed to aluminium, < 1% increase in density occurred for emulsified diesel while it remained close to as-received for diesel.

Table 1. Changes in the properties of diesel and emulsified diesel due to exposure to aluminium.

|                        | Diesel          | Emulsified diesel |
|------------------------|-----------------|-------------------|
|                        | Before          | After             | Before          | After             |
| **Mean**               | **SD**          | **Mean**          | **SD**          | **Mean**          | **SD**          |
| TAN (mgKOH/g)          | 0.21            | 1.29E-02          | 0.29            | 5.77E-03          | 0.96            | 5.00E-03          | 0.79            | 9.57E-03          |
| Water content (%)      | 0.007           | 5.77E-04          | 0.008           | 5.77E-04          | 4.994           | 7.63E-03          | 4.990           | 4.54E-03          |
| Viscosity (mm²/s)      | 3.358           | 7.41E-04          | 3.361           | 7.39E-04          | 3.952           | 7.41E-04          | 4.859           | 1.56E-03          |
| Density (kg/m³)        | 838.1           | 1.26E-01          | 838.7           | 3.51E-01          | 853.9           | 3.30E-01          | 860.3           | 3.50E-01          |

By relating the properties of the fuels to the corrosion rate, the increased acidity of the emulsified diesel as compared to diesel is suggested to have influenced the higher corrosion rate. This suggestion corroborates to the trend of reduced corrosion rate with reduced TAN observed in this study, which also agrees to an existing study [14]. Emulsified diesel with lower TAN should therefore be formulated in order to prevent accelerated metal corrosion. The effect of water towards corrosion rate can be ruled out in this study since free water did not form during the investigation. Nevertheless, taking into account the de-emulsification of emulsified diesel which could culminate in the formation of free water [12], stable emulsified diesel are equivalently necessary to prevent accelerated metal corrosion.

4. Conclusion

The corrosive characteristics of emulsified diesel was investigated in this work. The corrosion rate of aluminium coupons exposed to emulsified diesel reduced by 97.6% with increasing immersion duration from 240 hours to 1200 hours. 2.2 times higher corrosion rate occurred for the aluminium coupons exposed to emulsified diesel than to diesel. Considering the influence of water could be overruled since free water did not form during the investigations, the higher acidic value of emulsified diesel by 4.7 times than diesel is suggested to have influenced the higher corrosion rate for the aluminium exposed to emulsified diesel than diesel. The surfactants used to formulate stable water-in-diesel emulsion to prevent free water formation are suggested to have increased the acidic value of the emulsified diesel thus adversely affected the metal corrosion. Studies towards producing stable emulsified diesel with lower acidic value are required to prevent metals failure due to accelerated corrosion. More studies in the area are required to establish the compatibility of emulsified diesel with fuel delivery materials.
5. References

[1] Ithnin A M, Ahmad M A, Bakar M A A, Rajoo S and Yahya W J 2015 Combustion performance and emission analysis of diesel engine fuelled with water-in-diesel emulsion fuel made from low-grade diesel fuel Energy Conv. Manage. 90 375-82

[2] Ithnin A M, Yahya W J, Ahmad M A, Ramlan N A, Kadir H A, Sidik N A C and Koga T 2018 Emulsifier-free Water-in-Diesel emulsion fuel: Its stability behaviour, engine performance and exhaust emission Fuel 215 454-62

[3] Hasannuddin A, Yahya W, Sarah S, Ithnin A, Syahrullail S, Sugeng D, Razak I, Fatah A A, Aqma W and Rahman A 2018 Performance, emissions and carbon deposit characteristics of diesel engine operating on emulsion fuel Energy 142 496-506

[4] Ogunkoya D, Li S, Rojas O J and Fang T 2015 Performance, combustion, and emissions in a diesel engine operated with fuel-in-water emulsions based on lignin Appl. Energy 154 851-61

[5] Perumal V and Ilangkumaran M 2018 Water emulsified hybrid pongamia biodiesel as a modified fuel for the experimental analysis of performance, combustion and emission characteristics of a direct injection diesel engine Renew. Energy 121 623-31

[6] Chandran D, Ng H, Harrison L, Gan S, Choo Y and Jahis S 2016 Compatibility of biodiesel fuel with metals and elastomers in fuel delivery system of a diesel engine J. Oil Palm Res. 28 64-73

[7] Chandran D 2017 Experimental investigation into the physico-chemical properties changes of palm biodiesel under common rail diesel engine operation for the elucidation of metal corrosion and elastomer degradation in fuel delivery system (Doctoral dissertation). University of Nottingham

[8] Chandran D, Gan S, Lau H L N, Raviadaran R, Salim M and Khalid M 2018 Critical relationship between biodiesel fuel properties and degradation of fuel delivery materials of a diesel engine Therm. Sci. Eng. Prog. 7 20-6

[9] Chandran D, Ng H K, Lau H L N, Gan S and Choo Y M 2016 Investigation of the effects of palm biodiesel dissolved oxygen and conductivity on metal corrosion and elastomer degradation under novel immersion method Appl. Therm. Eng. 104 294-308

[10] Chandran D, Ng H K, Lau H L N, Gan S and Choo Y M 2017 Deterioration of palm biodiesel fuel under common rail diesel engine operation Energy 120 854-63

[11] Fazal M A, Haseeb A S M A and Masjuki H H 2013 Corrosion mechanism of copper in palm biodiesel Corrosion Sci. 67 50-9

[12] Ismael M A, Heikal M R, Aziz A R A, Syah F and Crua C 2018 The effect of fuel injection equipment on the dispersed phase of water-in-diesel emulsions Appl. Energy 222 762-71

[13] Elsanusi O A, Roy M M and Sidhu M S 2017 Experimental investigation on a diesel engine fueled by diesel-biodiesel blends and their emulsions at various engine operating conditions Appl. Energy 203 582-93

[14] Tsuchiya T, Shiotani H, Goto S, Sugiyama G and Maeda A 2006 Japanese standards for diesel fuel containing 5% FAME: Investigation of acid generation in FAME blended diesel fuels and its impact on corrosion SAE Technical Paper, 2006-01-3303

Acknowledgements
The authors acknowledge the financial support provided by Sunway University through the grant INT-2018-SST-RCNMET-05 to facilitate this study.