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# Effect of partially stabilized zirconia ($Zr_2O$) in improving the efficiency of emulsified fuel

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**Abstract**. The aim of experimental investigation is to analyze the change in performance characteristics when Partially Stabilized Zirconia (PSZ) was used as a thermal barrier coating in the combustion chamber, with emulsified fuel. Sorbitan mono elate (span 80) and PEG 20 sorbitan monooleate (tween 80) were used as the surfactants to form an emulsified fuel with diesel and water. Diesel, water and surfactants were taken in a flask; continuous stirring was done at a speed of 1000 rpm. The stability of the emulsified fuel has been checked for 8 hours for separation. It was observed that a remarkable improvement in brake thermal efficiency and specific fuel consumption. The results of the experiment proved that PSZ would be used as a performance improver as it retains the combustion temperature and increases the efficiency to a significant level.

## 1. Introduction

Partially Stabilized Zirconia (PSZ) is a ceramic material which is mostly preferred as a coating material because of its properties such as highest service temperatures (~2000$^0$C) among all of the ceramics and they retain some of their mechanical strength close to their melting point (2750 $^0$C). This results in more complete combustion of fuel and increased thermal and combustion efficiency. Sathyagnam et al [1] used PSZ as the coating material and mentioned that there was an increase of efficiency with fuel additive. PSZ has a low thermal conductivity of about 2 W/mK, which make them a good thermal insulator and thus able to reduce the heat lost to the surroundings. It also reduces the heat rejected from the working chamber of an internal combustion engine to the engine's cooling system and thus improves engine efficiency. Taymaz et al [2] used thermally insulating material PSZ, on the piston crown face and reported a 19% reduction in heat loss through the piston. During combustion only one third of heat produced is used for the effective combustion. One part of the heat is carried away by the coolant and one part to the atmosphere due to the difference in the combustion zone temperature and atmospheric temperature. Hence researchers made an attempt to insulate the combustion chamber, by various ceramic materials to retain the heat produced during combustion. Few of the coating materials tried through the experiments are PSZ, Silicon nitride, fly ash etc. Morel et al [3] conducted experiments in low heat rejection engine and found that due to ceramic coating, the heat rejection rate got reduced. Kamo et al [4] used silicon nitride as thermal coating material for insulating combustion chamber of a diesel engine. Methyl esters of vegetable oil produced higher oxides of nitrogen ($NO_x$) emission with PSZ coated combustion chambers. Many of the researches went on with transesterified vegetable oils such as Jatropha, Pongamia, Mahua, Neem, Nerium, etc. Vinay and Ravi [5] carried out experiment by applying Thermal Barrier Coatings (TBC) onto engine parts for improving engine performance when biodiesel was used as an alternative fuel. They have reported that there was improvement in the performance characteristics of the engine. Agung et al [6] attempted to study the use of diesel oil-water emulsion fuel (water in-oil type) in direct injection single cylinder diesel engine. It is observed that there was reduction in emission parameters such as oxides of nitrogen, carbon monoxide and sulpur di oxide. Selection of surfactants plays a vital role in the homogeneous mixture formation in emulsified fuel as well as the stability of the emulsions.

It was observed that when ceramic coating was applied to the engines, the efficiency was found to be increased. However the oxides of nitrogen ($NO_x$) emissions were also found to be more in most of the researches. Hence in this experimental work, it has been decided to use emulsified fuel (diesel+water) so that the micro-explosion of water during adiabatic flame temperature would reduce the temperature and it may bring down the oxides of nitrogen ($NO_x$) emission.

## 2. Preparation of Emulsified Fuel

Diesel and water are immiscible fluids. Hence to form an emulsified fuel, using diesel and water, a chemical agent called surfactants are to be added to make it miscible. “Surfactant” is an abbreviated form of “surface active agents”. The surfactants are chosen based on Hydrophilic and Liphophilic Balance number (HLB number). The most widely used to form emulsified fuels are Span and Tween. The “span” is known by its chemical name “sorbitan ester” and “tween” by its chemical name “polyethoxylated sorbitan ester”. Both span and tween are non-ironic surfactants used to form emulsification of two immiscible liquids of this experimental work, namely, diesel and water. In their research Zeng et al [7] stated that the surfactants should be so chosen that they should easily take part in the combustion and burn easily without soot.

**Table 1.** Surfactants and their HLB value

| S. No. | Name of the surfactant | HLB value |
|---|---|---|
| 1 | Span20 | 8.6 |
| 2 | Span80 | 4.3 |
| 3 | Tween20 | 16.7 |
| 4 | Tween80 | 15.6 |
| 5 | Tween60 | 14.9 |

HLB number is known as Hydrophilic Liphophilic Balance number which decides the suitable surfactant to form an emulsion. **Table 1** shows the name of the surfactant and its HLB number. In general low value of HLB number forms water-in-oil emulsion and high value of HLB number forms oil-in-water emulsion. The range of HLB number varies from 1 to 20.

The surfactants span80 and tween80 were chosen because their $HLB_{resultant}$ (Hydrophilic Liphophilic Balance) value is 9.95, which is suitable for water-in-oil emulsion. The calculation for the $HLB_{resultant}$ has been given below.

$HLB_{resultant}$ = ($HLB_1$ value x weight percentage) + ($HLB_2$ x weight percentage)

Where,

$HLB_1$ = HLB number of Span80 (4.3)

$HLB_2$ = HLB number of Tween80 (15.6)

## 3. Experimental Setup and Methodology

A Kirloskar brand AV1 model water cooled engine has been used. For plotting the performance based curves, a data acquisition system with powerful windows OS has been used. Diesel has been used as reference fuel and emulsified fuels have been used as test fuel. DWM1 refers to the percentage of diesel/water/surfactant and the proportion to 94%/5%/1%. DWM2 refers to 89/10%/1%, and DWM3 refers to 84/15%/1%. After the usage of every test fuel, the engine has been flushed out with reference fuel, for obtaining the precise reading. The properties of fuel used where tested for the various properties and listed in **Table 2** and **Table 3**.

**Table 2.** Composition of diesel-water emulsion

| | DWM1 | DWM2 | DWM3 |
|---|---|---|---|
| Diesel | 94% | 89% | 84% |
| Water | 5% | 10% | 15% |
| Span80 | 0.5% | 0.5% | 0.5% |
| Tween80 | 0.5% | 0.5% | 0.5% |

**Table 3.** Comparison of fuel properties of diesel and diesel-water emulsion

| | Diesel | DWM1 | DWM2 | DWM3 |
|---|---|---|---|---|
| Density (kg/m$^3$) | 830 | 833 | 836 | 841 |
| Calorific value (MJ/kg) | 43.2 | 40.72 | 38.48 | 36.32 |
| Flash point ($^o$C) | 56 | 58 | 60 | 62 |
| Fire point ($^o$C) | 64 | 65 | 66 | 68 |

## 4. Results and Discussion

### *4.1Brake thermal efficiency*

The maximum brake thermal efficiency obtained with diesel fuel at three fourths of the load was found to be 26.481%. The increase in efficiency was found to be 0.72%, 0.89%, and 0.93% for DWM1, DWM2, and DWM3 respectively when compared to diesel. On comparing uncoated and ceramic coated engine, it was seen that there was increase in the efficiency of diesel, and emulsified fuels. Ceramic coated engines operate at a higher temperature than the conventional engine as it is insulated with thermal barrier coating and heat retained during combustion is more than the conventional engine.

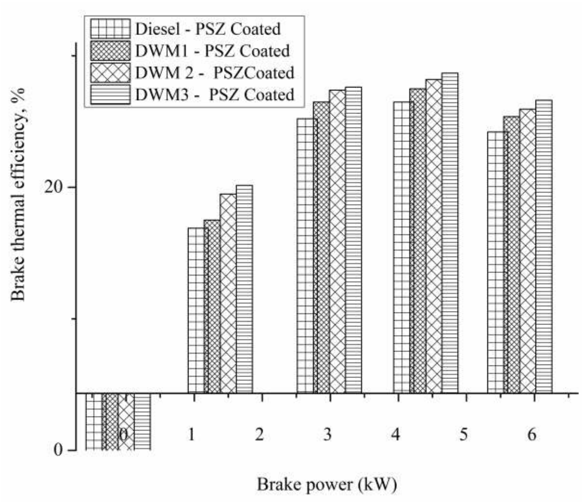


**Figure 1.** Brake power Vs Brake thermal efficiency

**Figure 1** shows the graph between brake power and brake thermal efficiency. The maximum efficiency for diesel fuel in coated engine at three fourths of the load was found to be 26.798% which was 0.31% higher than uncoated engine. The increase in efficiency was found to be 0.5396%, 0.57%, and 0.58% for DWM1, DWM2, and DWM3 respectively when compared to uncoated engine. At the high temperature, and due to the difference in the boiling point of water and diesel, micro-explosion occurred at adiabatic flame temperature. During micro-explosion, water droplets converted into steam which created an additional thrust on the piston. Walavalkar [8], in his thesis, stated that the presence of oil-water interface with very low interfacial tension which further leads to finer atomization of fuel during injection would be another reason for the improvement of combustion efficiency.

*4.2 Specific energy consumption*

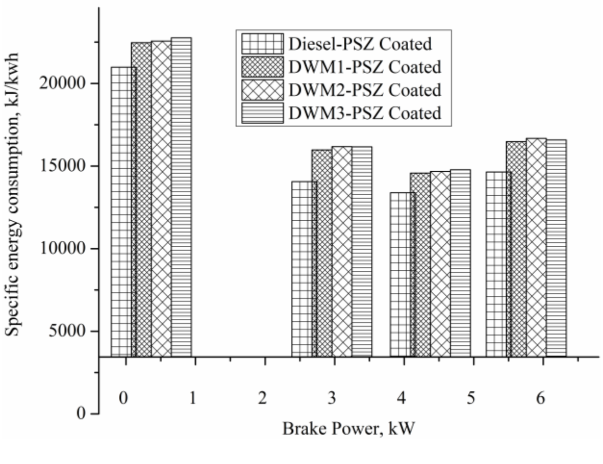


**Figure 2.** Brake power Vs Specific energy consumption

The meaningful factors to be considered as the cause in increase or decrease of SEC are calorific value of the fuel and specific gravity. The specific energy consumption of diesel at maximum load was found to be 14868.8 kJ/kWh, whereas the increase in the SEC was found to be 11.14%, 12.19%, and

12.50% with DWM1, DWM2, and DWM3 respectively. The increasing content of water reduced the calorific value of the fuel and caused more specific fuel consumption at higher loads. Longer ignition delay period increases more premixed combustion and lowers in-cylinder temperature. **Figure 2** shows the trend between brake power and specific energy consumption. Nitesh [9] in his research mentioned that when the percentage of water increased equal amount of diesel was displaced with water which had no calorific value and hence energy was absorbed by water for vaporization which caused more fuel consumption.

*4.3 Heat release rate*

The trend for the heat release rate curve shows displacement for diesel-water emulsion from the top dead centre than diesel. The reason for this might be due to increased premixed combustion and longer ignition delay.

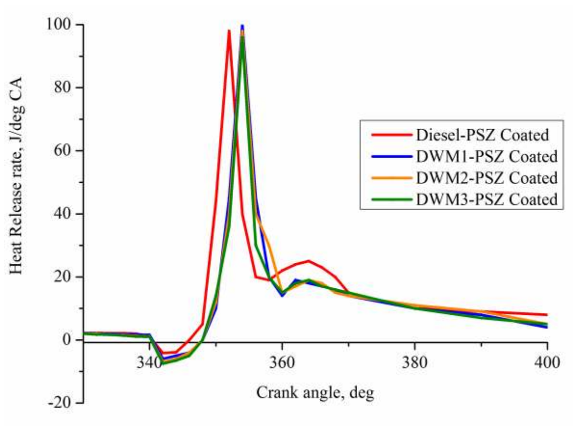


**Figure 3.** Heat release rate Vs Crank angle

**Figure 3** shows the trend of heat release rate in the test engine. It was observed that the premixed combustion for diesel-water emulsion was more than diesel. The heat release rate was found to be 81.3 J/deg CA, 85.3 J/deg CA, and 78 J/deg CA for DWM1, DWM2, and DWM3 respectively. Sudden quenching of flame due to explosion of water droplets reduced the peak heat release when the content of water increased in diesel water emulsions. Due to the evaporation of water droplets and conversion into steam increased the premixed combustion because of the increased surface area of the fuel. The heat release rate for DWM3 was less than diesel and N20 biodiesel in LHR engine.

*4.4 In-cylinder pressure*

**Figure 4** shows the graph between in-cylinder pressure and crank angle. In a compression ignition engine, the cylinder pressure developed was mainly due to the fuel burning rate during the premixed combustion. In LHR engine, it was observed that the pressure developed by both test fuel and reference fuels were more when compared with the conventional engine. The peak pressure developed by diesel in LHR engine was found to be 72 bar.

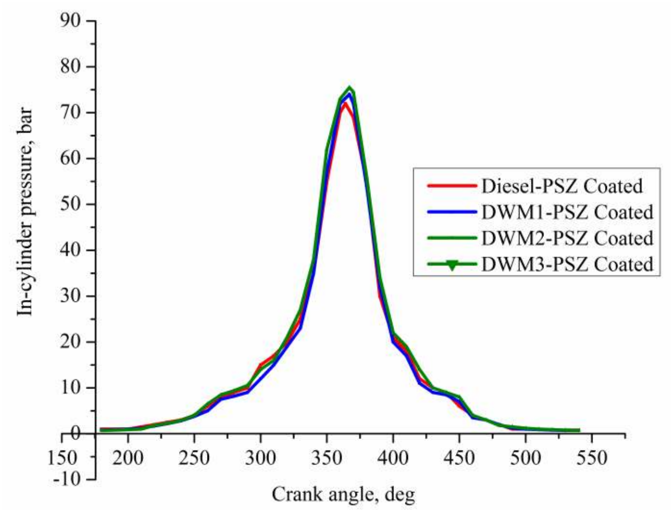


**Figure 4.** In-cylinder pressure Vs Crank angle

There was an increase in peak pressure by 1.12%, 2.91%, and 4.72% for DWM1, DWM2, and DWM3 compared with diesel respectively. More surface contact area of fuel due to secondary atomization made the primary fuel break into very fine droplets which led to smoother combustion and developed more pressure with emulsified fuel. Availability of additional temperature during combustion accelerated this reaction better than in the conventional engine.

## 5. Conclusion

The experimental results showed that brake thermal efficiency got increased with DWM3 with the water content of 15% and the reason was attributed to the micro-explosion reaction which was further accelerated due to the thermal barrier coating with Partial Stabilized Zirconia (PSZ). The specific energy consumption was more for all emulsified fuels, when compared to diesel, as there is no calorific value for water. The in-cylinder pressure developed by emulsified fuels was slightly higher than diesel fuel and it is due to the conversion of water droplets into steam, which created additional force on the piston. There was a shift in the heat release rate trend for emulsified fuel, which might be due to the longer ignition delay. At the outset, it can be concluded that emulsified fuels can be comfortably used in the conventional diesel engine, without any modification, as there was an improved performance.

## 6. Scope for future work

Cetane improver diethyl ether (DEE) could be added with fuel, for better performance. As water is used in emulsified fuel the behaviour of injector, wear and tear of other parts of the engine can be studied.

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