The Effect of Using an Alternative Fuel (Gas/Liquid Fuel) For Diesel Engine to Reduce Exhaust Emissions

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Abstract: Emission characteristics of a heavy-duty diesel engine operating on neat gas-to-liquids GTL (1&2) of different fuel characteristics were investigated and a comparison was made with those of diesel fuel. The effect of GTL on the emissions of a heavy duty diesel engine was carried out. The results showed that the engine fueled with GTL (1) & (2) had some variations compared with the one fueled with diesel fuel. Under the load characteristics, the nitrogen oxides (NOx), carbon monoxide (CO), and hydrocarbon (HC) emissions can be decreased when operating on both GTL. Compared with GTL (1) & (2) characteristics, the results showed that the engine operating on GTL (2) can reduce NOx, CO, and HC better than the engine operating on GTL (1), these were due to its high cetane number, low aromatic content, low sulfur content, low kinematic viscosity, low density and high heating value.

Keywords: Heavy duty, Diesel engine, Alternative fuel, Gas to liquid fuel, Different percentage of GTL, NOx, CO, HC, Emissions.

1. Introduction

The shortage of petroleum resources and pollution resulting from exhaust emissions of automobiles have been major challenges with the increasing number of automobiles. Thus, it is urgent and significant to search for and investigate environment-friendly alternative fuels. Generally, diesel engines emit a great deal of nitrogen oxides (NOx) and smoke or particulate matter (PM), although it produces negligible hydrocarbon (HC) and carbon monoxide (CO). Therefore, the emission control of diesel engines focuses on reducing NOx and smoke or PM. In recent years, gas-to-liquids (GTL) fuel, as an alternative diesel fuel, has attracted considerable attention. Gas-to-liquids can be synthesized via Fischer-Tropsch (F-T) catalytic conversion process using natural gas as feedstock. Compared with conventional fossil based diesel fuel, GTL has attractive properties with high cetane rating, near zero sulfur and ultra low aromatic contents, showing its potential to reduce engine-out emissions. On the basis of this background, this paper investigates the emission characteristics of neat GTL and various diesel-GTL blends in a turbocharged diesel engine with conventional diesel fuel as a baseline. Synthetic ultra-clean diesel-type fuels can be manufactured through the Fischer-Tropsch (F-T) process. The feedstock can be either natural gas (gas-to-liquids, GTL) or biomass (biomass-to-liquids) or coal (coal-to-liquids). Shell’s Shell Middle Distillate Synthesis process can convert natural gas into GTL fuel via synthesis gas by combining a modern, improved F-T synthesis and a special hydroconversion process. The GTL fuel is characterized by a high cetane number (CN), being free of sulfur, and having an ultralow aromatics content, which are supposed to
facilitate further reductions of engine-out emissions.

Several papers have documented GTL behavior, and experiments have involved the study of engine and vehicle emissions running with GTL. A common trend observed in those studies was reductions in emissions using different kinds of GTL fuels compared to conventional fossil-based diesel fuel. Alleman and McCormick reviewed the Fischer-Tropsch diesel fuel’s properties and exhaust emissions then concluded that, in almost every case, NOx, CO, and particulate matter (PM) emissions were reduced with neat F-T diesel fuel; however, HC emissions were variable [3]. Abu-Jrai et al. performed combustion and gas reforming experiments with GTL and ultralow sulfur diesel fuels and concluded that using GTL fuel could reduce NOx emission but increase smoke for the default injection timing, yet both NOx and smoke were reduced simultaneously by optimizing the injection timing. During exhaust-gas reforming, the use of GTL fuel increased fuel conversion, while producing more hydrogen and less methane. The Fischer-Tropsch (F-T) catalytic conversion process can be used to synthesize diesel fuels from a variety of feedstocks, including coal, natural gas and biomass. Synthetic diesel fuels can have very low sulfur and aromatic content, and excellent autoignition characteristics. Moreover, Fischer-Tropsch diesel fuels may also be economically competitive with California diesel fuel if produced in large volumes. Overview of Fischer-Tropsch diesel fuel production and engine emissions testing is presented. Previous engine laboratory tests indicate that F-T diesel is a promising alternative fuel because it can be used in unmodified diesel engines, and substantial exhaust emissions reductions can be realized.

“Gas-to-liquids” (GTL) process technology is one promising approach for achieving energy diversity. There has been heightened interest in GTL technology in recent years, as researchers and industrial firms are demonstrating good production economics. GTL fuel and chemical plants are emerging in developing countries. GTL pilot plants are also being developed for remote and off-shore applications to liberate remote and stranded natural gas reserves. Fischer-Tropsch (F-T) is a GTL chemical conversion process that is being successfully used to produce high quality gasoline and diesel fuel products from coal, natural gas and biomass feedstocks. The process originates from Franz Fischer and Hans Tropsch who patented the synthesis of petroleum at normal pressure using metal catalysts. Fischer-Tropsch synthetic diesel fuel is typically synthesized using a three-step procedure.

1. A synthesis gas containing mostly carbon monoxide and hydrogen is produced. Natural gas is reformed with pure oxygen or air, or coal is gasified in the presence of oxygen and steam.
2. Through F-T catalysis, the synthesis gas is converted into liquid hydrocarbons. The lengths of the hydrocarbon chains are determined by catalyst selectivity and reaction conditions. The process can be tuned to yield lighter or heavier hydrocarbons.
3. The resulting waxy synthetic crude is upgraded using standard hydrocracking and isomerization processes and fractionated into middle distillate fuels.

This process can be used to create a variety of fuel properties depending on the process technology. Generally, synthetic diesel fuels have favorable characteristics for use in compression ignition engines including:
- Liquid phase at ambient conditions
- Miscible in conventional petroleum-derived diesel
- Good auto-ignition characteristics
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- Low sulfur (typically less than 10 ppm)
- Low aromatics (near zero)
- Energy density comparable to conventional diesel
- Fuel tank flammability similar to conventional diesel
- Suitable for use in unmodified diesel engines
- Transportable as a liquid in existing petroleum infrastructure.

GTL (Gas to Liquid) synthetic diesel fuel is hydrocarbon compounds made from natural gas through the process of gasification and synthesis. It is recommended as the high quality vehicle fuel to realize super low emission due to its excellent chemical characters of low sulfur content, low aromatic hydrocarbon content and high cetane number. The GTL is finding its role in the global energy supply due to the increasing production capability in the near future. There have been studies on the effect of GTL on the engine performances since 1998. Until 2008, the Society of Automotive Engineer (SAE) of American has published more than 50 papers about GTL on fuel character, engine and vehicle performance. The fuel includes neat GTL and its blend with diesel by different proportion, and the vehicle/engine includes the passenger car, truck and bus, and corresponding engines. The results showed that the GTL or its blend with diesel fuel could improve the engine or vehicle performances compared with petroleum-based diesel fuel, especially the reduction of pollution emissions from vehicle tail pipe.

The study on one turbocharged and intercooled diesel engine showed that the using of GTL or its blend with traditional diesel could reduce the emission of NOx, smoke and PM effectively in any operating condition, and the reduction ratio increases with the GTL proportion. The study on a heavy duty on-road engine with exhaust gas after treatment indicates that GTL shows a better performance than traditional diesel in terms of NOx and HC emission. The study on a diesel engine operated with reformed EGR indicates the relationship between emission and EGR rate. Similar research has been done on other alternative fuels such as methyl ester, rapeseed oil, and biodiesel. Although there are some studies as mentioned above, but it is necessary to do more experiment about the GTL on engine performance with different technologies (such as injection timing) and compared with different fuels. In this study, the effect of GTL on the exhaust emissions of a heavy duty diesel engine with common rail fuel system and a kind of clean conventional diesel fuel with sulfur less than 50 ppm will be carried out.

2. Fuel Characteristics

GTL (Gas to Liquid) synthetic diesel fuel is the hydrocarbon compounds derived from natural gas. On the other hand, conventional diesel is derived from petroleum crude oil through some complex physical and chemical processes, and the composition of diesel is complicated and usually composed of thousands of compounds. Because of the difference in composition, the character of GTL differs from that of diesel. Table 1 shows the characteristics of GTL produced by Shell Corporation.

According to Table 1, the following conclusions of the main difference between GTL and diesel can be made:

- The aromatics content and sulfur content of GTL (1) & (2) are near zero, which can decrease the emission of HC and PM.
- The kinematic viscosity of GTL (1) & (2) are lower which has advantage on fuel spraying optimization.
- The cetane number of GTL (1) & (2) and the heating value are higher than the diesel fuel used in this study, which offers the benefits of better combustion performance.

### Table 1: Characteristics of GTL (1), (2) and diesel

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>GTL(1)</th>
<th>GTL(2)</th>
<th>Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (15 °C)</td>
<td>kg/m³</td>
<td>777.3</td>
<td>798.2</td>
<td>824.1</td>
</tr>
<tr>
<td>Kinematic viscosity (40 °C)</td>
<td>mm/s</td>
<td>2.568</td>
<td>2.864</td>
<td>3.728</td>
</tr>
<tr>
<td>Cetane number</td>
<td></td>
<td>74.7</td>
<td>83.4</td>
<td>53.4</td>
</tr>
<tr>
<td>Lower heating value (net)</td>
<td>kJ/kg</td>
<td>43,709</td>
<td>49,810</td>
<td>42,500</td>
</tr>
<tr>
<td>Carbon/hydrogen ratio</td>
<td></td>
<td>5.68:1</td>
<td>6.18:1</td>
<td>6.45:1</td>
</tr>
<tr>
<td>Sulfur</td>
<td>mg/kg</td>
<td>&lt;1</td>
<td>&lt;1.2</td>
<td>50</td>
</tr>
<tr>
<td>Aromatics</td>
<td>%</td>
<td>&lt;0.1</td>
<td>&lt;0.12</td>
<td>17.4</td>
</tr>
</tbody>
</table>

### 3. Experimental Apparatus

#### 3.1 Engine Type

The turbocharged and intercooled diesel engine is chosen for the test, without any modification on the engine. The main parameters of the engine are shown in Table 2.

### Table 2: Main parameters of the engine

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of cylinder</td>
<td>6</td>
</tr>
<tr>
<td>Bore × stroke (mm)</td>
<td>102 × 120</td>
</tr>
<tr>
<td>Displacement (L)</td>
<td>5.9</td>
</tr>
<tr>
<td>Compression ratio</td>
<td>17.5</td>
</tr>
<tr>
<td>Rated power/speed (kW/r min⁻¹)</td>
<td>136/2500</td>
</tr>
<tr>
<td>Max. torque/speed (N m/r min⁻¹)</td>
<td>690/1500</td>
</tr>
<tr>
<td>Air system</td>
<td>Inter cooling turbocharged</td>
</tr>
<tr>
<td>Fuel system</td>
<td>High pressure common rail</td>
</tr>
</tbody>
</table>

### 4. Emission Characteristics

#### 4.1 NOx Emission

As shown in Figure 1 the NOx emission is reduced when engine fueled with GTL under any condition. This comes from different combustion in the cylinder. Higher cetane number and lower aromatic content of GTL are beneficial to a shorter ignition delay period, thus less premixed charge. Less premixed charge results in the lower combustion temperature, leading to less NOx formation in the cylinder according to the highly temperature dependent thermal NOx formation mechanism. Also it is shown that the engine fueled with GTL (2) has better results in reducing the NOx emission than the engine fueled with GTL (1) , and both are better than diesel. This comes from good auto-ignition characteristics and higher cetane number of GTL (2) compared with GTL (1).
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4.2 CO Emission

Figure 2 shows the CO emission of engine fueled with GTL and diesel. The results indicate that CO emission is decreased when engine fueled with GTL under any condition. This is mainly due to the lower aromatic content and carbon–hydrogen ratio of GTL which indicated in the Table 1. The aromatic hydrocarbons are more stable, which results in not only the more PM and HC, but also more CO formation due to the more HC. The higher carbon content results in more CO emission during incomplete combustion. Also Figure 2 shows that the engine fueled with GTL (2) has better results in reducing the CO emission than the engine fueled with GTL (1), and both are better than diesel. This comes from good auto-ignition characteristics and higher cetane number of GTL (2) compared with GTL (1).
4.3 HC Emission

Figure 3 shows HC emissions of engine fueled with GTL and diesel. The results indicate that HC emission of GTL fuel is lower than that of diesel. This also caused by the near zero aromatic hydrocarbon content of GTL. Also it is shown that the engine fueled with GTL (2) has better results in reducing the HC emission than the engine fueled with GTL (1), and both are better than diesel. This comes from good auto-ignition characteristics and higher cetane number of GTL (2) compared with GTL (1).

![Figure 3: HC emission of the engine fueled with GTL and diesel](image)

5. Conclusions

The results showed that the engine fueled with GTL (1) & (2) had some variations compared with the one fueled with diesel fuel. Under the load characteristics, the nitrogen oxides (NOx), carbon monoxide (CO), and hydrocarbon (HC) emissions can be decreased when operating on both GTL. This came due to its high cetane number, low aromatic content, low sulfur content, low kinematic viscosity, low density and high heating value. Compared with GTL (1) & (2) characteristics, the results showed that the engine operating on GTL (2) can reduce NOx, CO, and HC better than the engine operating on GTL (1). This came due to good auto-ignition characteristics and higher cetane number of GTL (2) compared with GTL (1).

6. References


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