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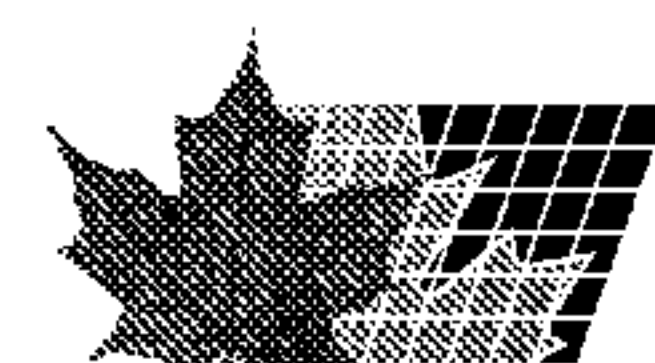
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(54) Title: LOW SULPHUR DIESEL FUEL AND AVIATION TURBINE FUEL

(57) **Abrégé/Abstract:**

A process for the production of a synthetic low sulphur diesel fuel and a low soot emission aviation fuel from a Low Temperature Fischer-Tropsch (LTFT) feedstock by the fractionation of the Low Temperature Fischer-Tropsch feedstock into a light kerosene fraction and a heavier diesel fraction in a volumetric ratio of between 1:2 and 5:4, and aviation and diesel fuels produced by said process.



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(54) Title: LOW SULPHUR DIESEL FUEL AND AVIATION TURBINE FUEL

(57) Abstract: A process for the production of a synthetic low sulphur diesel fuel and a low soot emission aviation fuel from a Low Temperature Fischer-Tropsch (LTFT) feedstock by the fractionation of the Low Temperature Fischer-Tropsch feedstock into a light kerosene fraction and a heavier diesel fraction in a volumetric ratio of between 1:2 and 5:4, and aviation and diesel fuels produced by said process.

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## LOW SULPHUR DIESEL FUEL AND AVIATION TURBINE FUEL

### Field of the Invention

- 5 The invention relates to a low sulphur diesel fuel and to an aviation fuel and a blending stock for aviation fuel.

### Background to the Invention

- 10 In this specification reference is made to Low Temperature Fischer-Tropsch (LTFT) process. This LTFT process is a well known process in which carbon monoxide and hydrogen are reacted over an iron, cobalt, nickel or ruthenium containing catalyst to produce a mixture of straight and branched chain hydrocarbons ranging from methane to waxes and smaller amounts of  
15 oxygenates. This hydrocarbon synthesis process is based on the Fischer-Tropsch reaction:

$$2 \text{H}_2 + \text{CO} \rightarrow \sim[\text{CH}_2]\sim + \text{H}_2\text{O}$$
 where  $\sim[\text{CH}_2]\sim$  is the basic building block of the hydrocarbon product molecules.

20

- The LTFT process is used industrially to convert synthesis gas, which may be derived from coal, natural gas, biomass or heavy oil streams, into hydrocarbons ranging from methane to species with molecular masses above 1400. While the term Gas-to-Liquid (GTL) process refers to schemes based on natural gas, i.e.  
25 methane, to obtain the synthesis gas, the quality of the synthetic products is essentially the same once the synthesis conditions and the product work-up are defined.

While the main products are linear paraffinic materials, other species such as branched paraffins, olefins and oxygenated components may form part of the product slate. The exact product slate depends on reactor configuration,  
5 operating conditions and the catalyst that is employed, as is evident from articles such as Catal.Rev.-Sci. Eng., 23 (1&2), 265-278 (1981) or Hydroc. Proc. 8, 121-124 (1982).

Preferred reactors for the production of heavier hydrocarbons are slurry bed or  
10 tubular fixed bed reactors, while operating conditions are preferably in the range of 160–280°C, in some cases in the 210-260°C range, and 18–50 bar, in some cases preferably between 20-30 bar.

The catalyst may comprise active metals such as iron, cobalt, nickel or  
15 ruthenium. While each catalyst will give its own unique product slate, in all cases the product slate contains some waxy, highly paraffinic material which needs to be further upgraded into usable products. The LTFT products can be hydroconverted into a range of final products, such as middle distillates, naphtha, solvents, lube oil bases, etc. Such hydroconversion, which usually consists of a  
20 range of processes such as hydrocracking, hydrotreatment and distillation, can be termed a LTFT Products Work-up process. Typically the process is normally configured in such a way that only two liquid products are transferred to storage. In most instances a small amount of light hydrocarbons containing up to four carbon atoms is also co-produced. The typical quality of the LTFT liquid  
25 products is presented in Table 1.

**Table 1      Typical Quality of the LTFT Products**

|                           | LTFT Naphtha | LTFT Diesel |
|---------------------------|--------------|-------------|
| Density, kg/l (20°C)      | 0,685        | 0.765       |
| Distillation              |              |             |
| ▪ IBP, °C                 | 54           | 151         |
| ▪ T10, °C                 | 81           | 182         |
| ▪ T50, °C                 | 101          | 249         |
| ▪ T90, °C                 | 120          | 317         |
| ▪ FBP, °C                 | 131          | 334         |
| Composition, % wt         |              |             |
| ▪ n-paraffins             | 59,0         | 31,9        |
| ▪ iso-paraffins           | 38,2         | 67,1        |
| ▪ Naphthenics             | ND           | ND          |
| ▪ Aromatics               | 0,3          | ND          |
| ▪ Olefins                 | 2,5          | ND          |
| ▪ Oxygenates              | ND           | ND          |
| Iso:Normal Paraffin ratio | 0,65         | 2,10        |

- 5 The applicant has identified a need to utilise LTFT fuel, including GTL fuel, directly, without blending with cracked stocks, as a fuel that will be interchangeable with conventional diesel fuels.

Semi-synthetic aviation fuel was approved in 1999 under British Aviation Turbine Fuel Defence Standard 91-91 (DEF STAN 91-91) specifications.

- 5 A need has thus been identified for a synthetic based fuel which meets or exceeds the above standards and which permits use of LTFT products, including GTL products, or components thereof in the aviation industry as fuels and/or as blend stocks for fuels.

## 10 Summary of the Invention

According to a first aspect of the invention there is provided a process for the production of a synthetic low sulphur diesel fuel and an aviation fuel from a Low Temperature Fischer-Tropsch (LTFT) feedstock, said process including the  
15 fractionation of the Low Temperature Fischer-Tropsch feedstock into a light kerosene fraction useable as an aviation fuel and/or an aviation fuel blend stock, and a heavier diesel fraction useable as a synthetic low sulphur diesel fuel and/or a diesel fuel blend stock, said fractions substantially complying with diesel and aviation fuel specifications.

20

Surprisingly, the diesel fuel meets the lubricity specification without the use of additives, although being highly hydrogenated. Usually those skilled in the art would expect highly hydrogenated fuel to need lubricity improvers.

25

This has been identified as one method to increase the energy density of LTFT Fuel and also adhering to the cold flow properties (CFPP – cold filter plug point test) and lubricity specifications while producing a lighter kerosene fraction that is useable either to blend with crude oil derived blending stock to produce a semi-synthetic aviation fuel or directly as a synthetic aviation fuel.

30

The process includes the fractionation and removal of at least 33 volume% of the LTFT feedstock to form said aviation fuel or blending stock having a final boiling point of about 270°C.

- 5 Typically, the process includes fractionation and removal of 45 volume%, or even 55 volume% of the feedstock.

The light kerosene fraction may be cut to meet the – 47°C freezing point of Jet A-1 at a cut point of 270°C. Again the lubricity properties measured with the ball on  
10 cylinder lubricity evaluator (BOCLE) of the kerosene fraction was above expectations.

According to a second aspect of the invention, there is provided a synthetic low sulphur fuel or blend stock for a low sulphur fuel, said fuel or blend stock having  
15 the following properties:

- from 13 mass% to 17 mass% hydrogen;
- iso:n-paraffins mass ratio of from 2 to 5
- less than 0.1% m/m aromatics;
- CFPP according to IP309 of below -5°C;
- 20 - density@20°C of at least 0.780 kg/l; and
- total oxygen content less than 80 ppm.

Typically the iso:n paraffins mass ratio is from 3 to 4.

- 25 The iso:n paraffins mass ratio may be 3.7.

The hydrogen may be about 15 mass% of the fuel or blend stock.

Typically the CFPP is below -9°C.

30

Surprisingly, the fuel meets the lubricity specification without the use of additives, although being highly hydrogenated.

Advantageously, the emission performance was not adversely affected when  
5 compared to a crude derived low sulphur fuel even though its lighter ends is removed.

The fuel or blend stock may be a LTFT diesel fraction.

10 The blend stock may have viscosity@40°C of above 2cSt.

The fuel or blend stock may have a final boiling point of above 330°C, typically about 340°C.

15 The fuel or blend stock may have an IBP of above 200°C, typically above 250°C, in some embodiments in excess of 265°C.

According to a third aspect of the invention, there is provided a synthetic aviation fuel or fuel blend stock for a semi-synthetic aviation fuel, said blend stock having  
20 the following properties:

- from 13 mass% to 17 mass% hydrogen;
- iso:n-paraffins mass ratio of 0.5 to 3;
- BOCLE lubricity wear scar less than 0.85mm;
- oxygen as oxygenates less than 50 ppm; of which
- 25 - oxygen as primary C7 – C12 alcohols is less than 50 ppm; and
- oxygen as primary C12 – C24 alcohols is less than 50 ppm.

The oxygen as oxygenates may be less than about 10 ppm.

30 The oxygen as primary C7 – C12 alcohols may be less than about 10 ppm.

The oxygen as primary C12 – C24 alcohols may be less than about 10 ppm.

5 The synthetic aviation fuel or fuel blend stock may have less than 0.1% m/m aromatics according to HPLC.

The synthetic aviation fuel or fuel blend stock may have a smoke point greater than 50mm.

10 The synthetic aviation fuel or fuel blend stock may have a density@20°C about 0.75 kg/l.

The synthetic aviation fuel or fuel blend stock may have a freezing point of below -47°C;

15

Typically the iso:n paraffins mass ratio is from 1 to 2.

The iso:n paraffins mass ratio may be 1.2, or 1.16.

20 The hydrogen may be about 15 mass%.

The blend stock may be used directly as a fully synthetic aviation fuel without blending with crude derived fuel components.

25 The blending stock may be a LTFT kerosene fraction.

The blend stock may have viscosity@-20°C less than 8cSt, typically 4cSt.

30 The blend stock may have a final boiling point of above 200°C, typically about 270°C.

According to a fourth aspect of the invention, there is provided a semi-synthetic aviation fuel including a blending stock as described above having the following properties:

- iso:n-paraffins ratio of 0.5 to 3;
- 5 - Smoke point greater than 35mm; and
- at least 8% m/m aromatics.

The semi synthetic aviation fuel may have a density@15°C of at least 0.775 kg/l.

10 The semi synthetic aviation fuel may have a smoke point greater than 50mm.

The semi synthetic aviation fuel may have a freezing point of below -47°C;

Typically the iso:n paraffins mass ratio is from 1 to 2.

15

The iso:n paraffins mass ratio may be 1.8.

The blend stock may have viscosity@-20°C of below 8cSt, or even below 4 cSt.

20 With a 50 vol-% blend of LTFT kerosene and crude derived sweetened and severely hydrotreated kerosene, the minimum density and aromatic content requirements according to the American Society for Testing and Material (ASTM D1655) and the British Aviation Turbine Fuel Defence Standard 91-91 for Jet A-1 were met.

25

Since LTFT fuel is composed almost only of normal and isoparaffins, a LTFT kerosene fraction may be utilised as an aviation turbine fuel blending component. The virtual absence of aromatics and naphthenes from LTFT kerosene may provide it with a very good smoke point number (i.e. it produces very little soot).

30

According to a fifth aspect of the invention there is provided a thermally stable

aviation fuel with low deposition tendency when combusted, said fuel including one or more fuel selected from a fully synthetic aviation fuel, a semi synthetic aviation fuel, and a synthetic aviation fuel blend stock, as described above.

- 5 Typically the aviation fuel and blend stock has a thermal stability tube deposit rating at 260°C less than 1.

Typically the aviation fuel has a Quartz Crystal Microbalance (QCM) deposition less than 3  $\mu\text{g}/\text{cm}^2$ .

10

More typically, the aviation fuel has QCM deposition of less than 2  $\mu\text{g}/\text{cm}^2$  for a 15h QCM test @ 140°C without addition of an anti-oxidant.

- 15 According to a sixth aspect of the invention there is provided a low soot emission aviation fuel, said fuel including one or more fuel selected from a fully synthetic aviation fuel, a semi- synthetic aviation fuel, and a synthetic aviation fuel blend stock, as described above.

- 20 Typically the aviation fuel blend stock has about a 33% reduction in the normalized particulate number density under cruise conditions, more typically a 60% reduction under cruise conditions and a 67% reduction in the normalized particulate number density under idle conditions, more typically a 83% reduction under idle conditions compared to typical conventional aviation fuel.

## 25 **Description of Embodiments of the Invention**

The invention will now be described with reference to specific embodiments which illustrate the invention but are not intended to limit its application.

## Examples

### Low Sulphur Diesel Fuel

- 5 Sasol Slurry Phase Distillate<sup>TM</sup> diesel or Sasol SPD<sup>TM</sup> diesel was fractionated targeting a freezing point requirement for Jet A-1 of -47°C with a final boiling point of 270°C. The resultant diesel fuel properties and kerosene properties are shown in Table 2 and include density, viscosity, high-frequency reciprocating rig (HFRR) and ball-on-cylinder evaluator (BOCLE) lubricity test and cold filter
- 10 plugging point (CFPP) of diesel and freezing point of kerosene.

**Table 2: Selected fuel properties of Sasol SPD™ diesel, the heavier diesel fraction and the lighter kerosene cut obtained through fractionation.**

|                                |                       |               | <i>Sasol SPD™<br/>Diesel</i> | <i>Sasol SPD™<br/>Diesel 1</i> | <i>Sasol SPD™<br/>kerosene 1</i> | <i>Sasol SPD™<br/>Diesel 2</i> | <i>Sasol SPD™<br/>kerosene<br/>2</i> |
|--------------------------------|-----------------------|---------------|------------------------------|--------------------------------|----------------------------------|--------------------------------|--------------------------------------|
| <i>Product Yield</i>           |                       | <i>vol %</i>  | 100%                         | 45%                            | 55%                              | 55%                            | 45%                                  |
| <i>Density @ 15°C</i>          | <i>ASTM<br/>D4052</i> | <i>kg/l</i>   | 0.769                        | 0.790                          | 0.752                            | 0.786                          | 0.747                                |
| <i>Density @ 20°C</i>          | <i>ASTM<br/>D4052</i> | <i>kg/l</i>   | 0.765                        | 0.786                          | 0.748                            | 0.782                          | 0.743                                |
| <i>H<sub>2</sub> content</i>   | <i>ASTM<br/>D5291</i> | <i>mass %</i> | 14.97                        | 14.62                          | 15.00                            | 14.68                          | 14.87                                |
| <i>Distillation</i>            | <i>IBP</i>            | <i>°C</i>     | 151                          | 268                            | 157                              | 246                            | 154                                  |
| <i>ASTM D86</i>                | 10%                   | <i>°C</i>     | 182                          | 282                            | 172                              | 262                            | 168                                  |
|                                | 50%                   | <i>°C</i>     | 249                          | 300                            | 203                              | 289                            | 191                                  |
|                                | 95%                   | <i>°C</i>     | 325                          | 336                            | 267                              | 333                            | 254                                  |
|                                | <i>FBP</i>            | <i>°C</i>     | 334                          | 341                            | 278                              | 339                            | 267                                  |
| <i>Flash point</i>             | <i>ASTM<br/>D93</i>   | <i>°C</i>     | 58                           | 114                            | 50                               | 122                            | 45                                   |
| <i>Freezing point</i>          | <i>ASTM<br/>5901</i>  | <i>°C</i>     | -15                          |                                | -42                              |                                | -48                                  |
| <i>CFPP</i>                    | <i>IP 309</i>         | <i>°C</i>     | -19                          | -9                             |                                  | -12                            |                                      |
| <i>Viscosity @ -20°C</i>       | <i>ASTM<br/>D445</i>  | <i>cSt</i>    |                              |                                | 4.26                             |                                | 4.17                                 |
| <i>Viscosity @ 40 °C</i>       | <i>ASTM<br/>D445</i>  | <i>cSt</i>    | 2.00                         | 3.90                           |                                  | 3.31                           |                                      |
| <i>Lubricity (HFRR)</i>        | <i>ASTM<br/>D6079</i> | <i>µm</i>     | 617                          | 450                            | 751                              | 446                            | 781                                  |
| <i>Lubricity<br/>(BOCLE)</i>   | <i>ASTM<br/>D5001</i> | <i>mm</i>     |                              |                                | 0.81                             |                                | 0.83                                 |
| <i>Cetane number</i>           | <i>ASTM<br/>D613</i>  |               | 72                           | 76                             |                                  | 75                             |                                      |
| <i>Gross Heating<br/>Value</i> | <i>ASTM<br/>D240</i>  | <i>MJ/kg</i>  | 46.96                        | 46.55                          | 47.13                            | 46.97                          | 47.24                                |
| <i>Net Heating</i>             | <i>ASTM</i>           | <i>MJ/kg</i>  | 43.79                        | 43.44                          | 43.95                            | 43.86                          | 44.09                                |

| <i>Value</i>                               | <i>D240</i>      |             |               |               |               |               |               |
|--------------------------------------------|------------------|-------------|---------------|---------------|---------------|---------------|---------------|
| <i>Net Heating Value</i>                   | <i>ASTM D240</i> | <i>MJ/l</i> | <i>33.50</i>  | <i>34.13</i>  | <i>32.88</i>  | <i>34.25</i>  | <i>32.75</i>  |
| <i>Oxygen as oxygenates</i>                | <i>GC-MS</i>     | <i>ppm</i>  | <i>&lt;6</i>  | <i>&lt;6</i>  | <i>&lt;6</i>  | <i>&lt;6</i>  | <i>&lt;6</i>  |
| <i>Oxygen as primary C7 – C12 alcohols</i> | <i>GC-MS</i>     | <i>ppm</i>  | <i>&lt;6</i>  | <i>&lt;6</i>  | <i>&lt;6</i>  | <i>&lt;6</i>  | <i>&lt;6</i>  |
| <i>Oxygen as primary C12– C24 alcohols</i> | <i>GC-MS</i>     | <i>ppm</i>  | <i>&lt;6</i>  | <i>&lt;6</i>  | <i>&lt;6</i>  | <i>&lt;6</i>  | <i>&lt;6</i>  |
| <i>Total oxygen</i>                        | <i>GC-TCD</i>    | <i>ppm</i>  | <i>&lt;80</i> | <i>&lt;80</i> | <i>&lt;80</i> | <i>&lt;80</i> | <i>&lt;80</i> |

In table 2:

Sasol SPD™ diesel is the full distillation range LTFT diesel

Sasol SPD™ diesel 1 is a 45% heavy end LTFT diesel

5 Sasol SPD™ diesel 2 is a 55% heavy end LTFT diesel

Sasol SPD™ kerosene 1 is a 55% light end LTFT kerosene cut

Sasol SPD™ kerosene 2 is a 45% light end LTFT kerosene cut

10 Table 3: Selected fuel properties of the Sasol SPD™ kerosene fraction blends with crude derived sweetened and hydrotreated kerosene.

| <i>Property</i>          | <i>Units</i>   | <i>Sasol SPD™ kerosene</i> | <i>Kero Merox™ kerosene</i> | <i>50/50 Kero Merox blend</i> | <i>DHC Kerosene</i> | <i>50/50 DHC kerosene blend</i> | <i>DEF STAN 91-91</i> |              |
|--------------------------|----------------|----------------------------|-----------------------------|-------------------------------|---------------------|---------------------------------|-----------------------|--------------|
|                          |                |                            |                             |                               |                     |                                 | <i>min</i>            | <i>max</i>   |
| <i>Total Aromatics</i>   | <i>vol%</i>    | <i>0</i>                   | <i>19.8</i>                 | <i>9.9</i>                    | <i>12.7</i>         | <i>6.5</i>                      | <i>8</i>              | <i>25</i>    |
| <i>Olefins</i>           | <i>vol%</i>    | <i>0</i>                   | <i>0</i>                    | <i>0</i>                      | <i>0</i>            | <i>0</i>                        |                       |              |
| <i>Paraffins</i>         | <i>vol%</i>    | <i>99.9</i>                | <i>80.2</i>                 | <i>90.1</i>                   | <i>87.3</i>         | <i>93.5</i>                     |                       |              |
| <i>Total Sulphur</i>     | <i>Mass%</i>   | <i>&lt;0.01</i>            | <i>0.14</i>                 | <i>0.07</i>                   | <i>&lt;0.01</i>     | <i>&lt;0.01</i>                 |                       | <i>0.3</i>   |
| <i>Mercaptan Sulphur</i> | <i>Mass%</i>   | <i>0.0002</i>              | <i>0.0006</i>               | <i>0.0004</i>                 | <i>0.0005</i>       | <i>0.0003</i>                   |                       | <i>0.003</i> |
| <i>Doctor test</i>       |                | <i>Negative</i>            | <i>Negative</i>             | <i>Negative</i>               | <i>Negative</i>     | <i>Negative</i>                 | <i>Negative</i>       |              |
| <i>Total acid</i>        | <i>mgKOH.g</i> | <i>0.009</i>               | <i>0.002</i>                | <i>0.009</i>                  | <i>&lt;0.001</i>    | <i>0.01</i>                     |                       | <i>0.015</i> |
| <i>Density</i>           |                |                            |                             |                               |                     |                                 |                       |              |
| <i>@ 15°C</i>            | <i>kg/l</i>    | <i>0.747</i>               | <i>0.809</i>                | <i>0.776</i>                  | <i>0.820</i>        | <i>0.784</i>                    | <i>0.775</i>          | <i>0.840</i> |
| <i>@ 20°C</i>            | <i>kg/l</i>    | <i>0.743</i>               | <i>0.805</i>                | <i>0.772</i>                  | <i>0.817</i>        | <i>0.780</i>                    |                       |              |
| <i>Distillation D86</i>  |                |                            |                             |                               |                     |                                 |                       |              |

|                               |        |       |      |      |      |      |      |      |
|-------------------------------|--------|-------|------|------|------|------|------|------|
| <i>IBP</i>                    | °C     | 154   | 158  | 152  | 184  | 156  |      |      |
| <i>10%</i>                    | °C     | 168   | 176  | 169  | 195  | 179  |      | 205  |
| <i>50%</i>                    | °C     | 191   | 206  | 194  | 218  | 204  |      |      |
| <i>95%</i>                    | °C     | 254   | 259  | 253  | 274  | 268  |      |      |
| <i>FBP</i>                    | °C     | 267   | 267  | 267  | 280  | 278  |      | 300  |
| <i>Flash point</i>            | °C     | 45    | 55   | 48   | 52   | 53   | 38   |      |
| <i>Viscosity @ -20°C</i>      | cSt    |       | 4.51 | 3.65 | 5.33 | 4.61 |      | 8    |
| <i>Freezing point</i>         | °C     | -48   | -48  | -51  | -51  | -50  |      | -47  |
| <i>Lubricity (BOCLE)</i>      | mm     | 0.83  | 0.48 | 0.79 | 0.68 | 0.85 |      | 0.85 |
| <i>Thermal Stability</i>      |        |       |      |      |      |      |      |      |
| <i>Filter pressure drop</i>   | mmHg   | 0     | 0    | 0    | 0    | 0    |      | 25   |
| <i>Tube deposit rating</i>    | visual | <1    | <1   | <1   | <1   | <1   |      | <3   |
| <i>Contaminants</i>           |        |       |      |      |      |      |      |      |
| <i>Microsep without SDA</i>   | rating | 75    | 95   | 74   | 84   | 80   | 85   |      |
| <i>Water interfase rating</i> | rating | 1b    | 1b   | 1b   | 1b   | 1b   |      | 1b   |
| <i>Combustion</i>             |        |       |      |      |      |      |      |      |
| <i>Smoke point</i>            | mm     | >50   | 25   | 36   | 27   | 37   | 25   |      |
| <i>Specific energy</i>        | MJ/kg  | 44.09 |      |      |      |      | 42.8 |      |

### ***Diesel fractions***

The 45 vol-% heavy end diesel fraction has excellent properties for use as a neat  
5 Sasol SPD™ diesel without the use of additives

A maximum wear scar diameter (WSD) of 460 µm is allowed according to the EN  
590:1999 Diesel Fuel Specifications. The lubricity of the Sasol SPD™ diesel  
fractions with a total oxygen content less than 80ppm increased considerably and  
10 meets the current specification requirement because of the higher viscosity of the  
diesel fractions, which improve the hydrodynamic lubrication without the use of a  
lubricity improver.

The flash points of the Sasol SPD™ diesel fractions are high because of its  
15 higher initial boiling point whereas the cold flow properties of the diesel fraction  
remained good.

According to Gas Chromatograph Mass Spectrometry (GC MS) and Gas Chromatograph Flame Ionisation Detection (GC-FID) results Sasol SPD™ diesel, prior to fractionation to kerosene and a diesel, has an isoparaffin to normal paraffin ratio of 2.2:1 (see Figure 1). The 55% heavy end diesel cut has a

5 isoparaffin to normal paraffin ratio of 3.71.

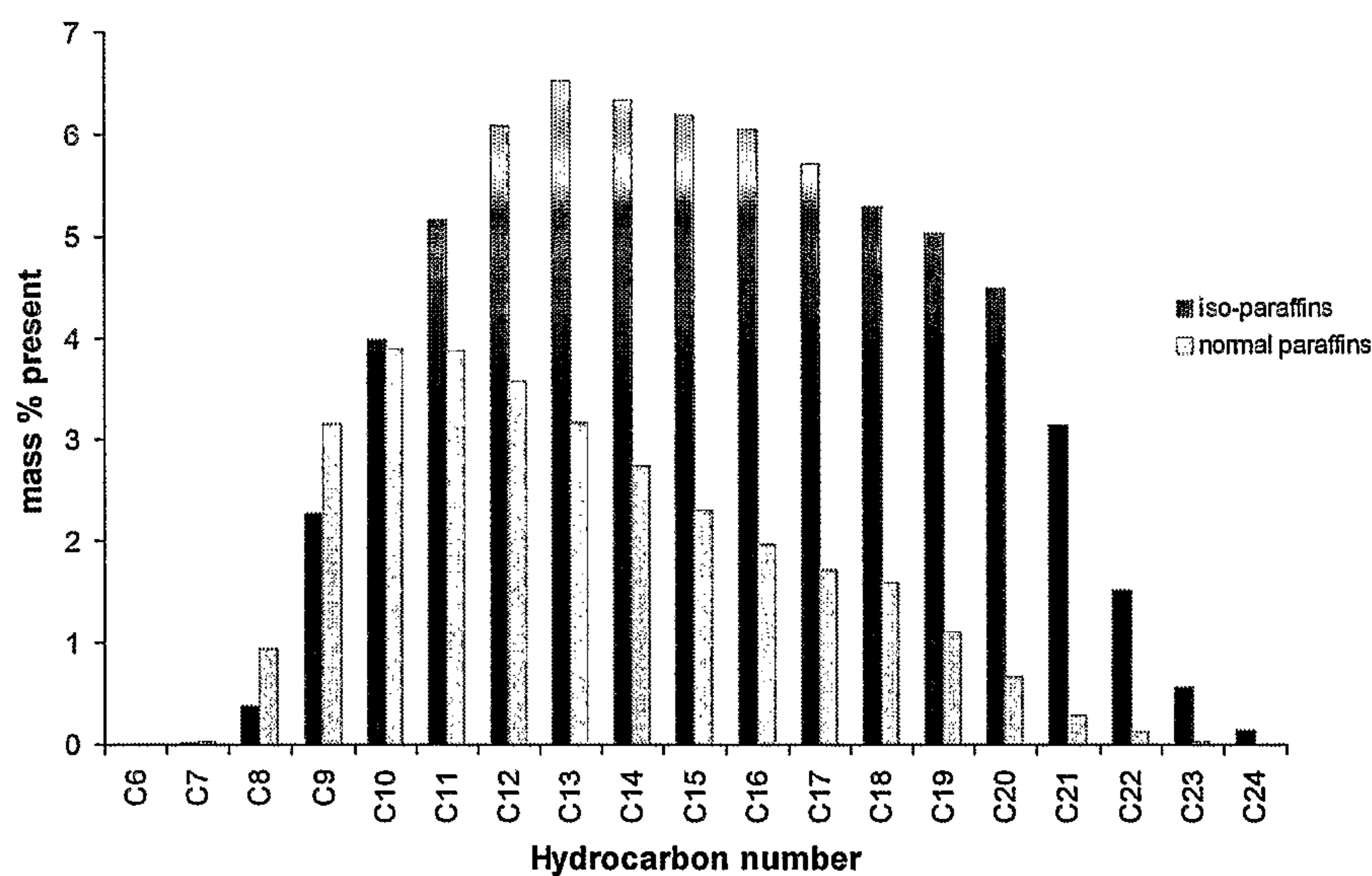
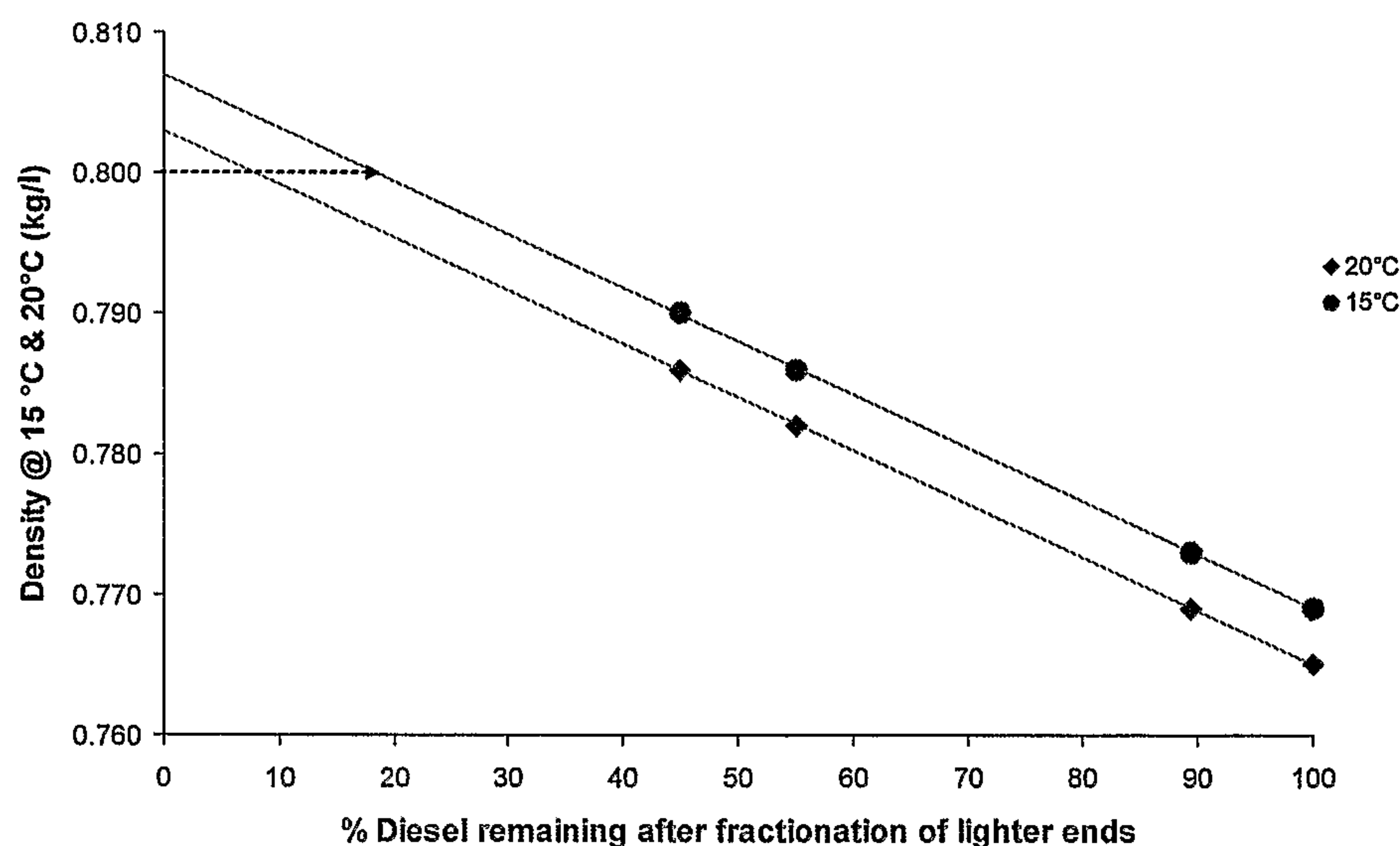


Figure 1: Carbon distribution of Sasol SPD™ diesel



10 Figure 2: Graph of Sasol SPD™ diesel densities at various degrees of fractionation

Fractionation of Sasol SPD™ diesel results in a diesel having a higher density (see Figure 2) and energy density which results in better fuel economy or more power. It also revealed other changes after fractionation including an improvement in its lubricity, a much higher viscosity and flash point. The good cold flow properties did not decreased dramatically although the diesel fraction is much heavier.

## 10 Exhaust Emission Performance Of the Heavy Cut diesel

The exhaust emissions of a heavy cut of Sasol SPD™ diesel fuel were compared with those of the full boiling range Sasol SPD™ diesel, as well as a European reference diesel fuel. The tests were performed using a late model European passenger car. It was found that the emission performance was not adversely affected when compared to the conventional diesel conforming to current EN590 fuel specifications, although unburned hydrocarbons, carbon monoxide, and particulate matter emissions deteriorated when compared with the full boiling range Sasol SPD™ diesel. The higher volumetric energy content of the heavy cut Sasol SPD™ diesel resulted in an improvement of 2% in the measured fuel consumption when compared to the full boiling range Sasol SPD™ diesel.

### Test vehicle

|    |                       |                       |
|----|-----------------------|-----------------------|
| 25 | Model :               | 2002 BMW 320d sedan   |
|    | Test Mass :           | 1 474 kg              |
|    | Engine displacement : | 1 995 cm <sup>3</sup> |
|    | Bore / stroke :       | 84 / 90 mm            |
|    | Compression ratio :   | 17 : 1                |
| 30 | Power output :        | 110 kW @ 4000 rev/min |
|    | Maximum torque :      | 330 Nm @ 2000 rev/min |

Fuel injection system : Bosch common rail  
Exhaust aftertreatment : Dual oxidation catalysts  
Emission certification : EU 3 (2000)

## 5 Test Fuels

Three fuels were tested for the comparison:

10 EN590 : A conventional diesel fuel meeting the European EN 590 specification, and with a sulphur content of < 10 mg/kg.

Full boiling range Sasol SPD™ diesel: Sasol SPD™ diesel with an IBP of 150°C and FBP of 335°C.

15 55 vol-% heavy Sasol SPD™ diesel cut: A heavy cut of Sasol SPD™ diesel, comprising of the remainder after a 45 vol-% kerosene fraction had been removed by fractionation.

Relevant fuel specifications are provided in Table 2 above:

20

The emission tests performed according to European EC/ECE test method, and using the NEDC test cycle. Two pre-conditioning runs were performed in preparation for each test. Three tests were performed with each of the EN590 and full boiling range Sasol SPD™ diesel, and two tests were performed with the  
25 55 vol-% heavy Sasol SPD™ diesel cut. The fuels were tested sequentially, and the vehicle was warmed up and run at a speed of 120 km/h for a period of 5 minutes after each fuel change.

30 The results for the ECE R15 urban cycle, the EUDC highway cycle, and the combined ECE R15 + EUDC cycle, are presented in Tables 4, 5, and 6 below.

**Table 4 : ECE R15 Urban Cycle Emissions and Fuel Consumption**

| <b>Fuel</b>                                         |                 | <b>Exhaust Emissions (g/km)</b> |              |                       |                     |                       | <b>FC<br/>(l/100km<br/>)</b> |
|-----------------------------------------------------|-----------------|---------------------------------|--------------|-----------------------|---------------------|-----------------------|------------------------------|
|                                                     |                 | <b>CO</b>                       | <b>HC</b>    | <b>NO<sub>x</sub></b> | <b>PM</b>           | <b>CO<sub>2</sub></b> |                              |
| <b>EN590</b>                                        | <b>Avg.</b>     | <b>0.419</b>                    | <b>0.077</b> | <b>0.391</b>          | <b>Not measured</b> | <b>220.4</b>          | <b>8.40</b>                  |
|                                                     | <b>Std Dev</b>  | <b>0.078</b>                    | <b>0.019</b> | <b>0.012</b>          |                     | <b>3.611</b>          | <b>0.141</b>                 |
|                                                     | <b>COV (%)</b>  | <b>18.6</b>                     | <b>25.2</b>  | <b>3.0</b>            |                     | <b>1.6</b>            | <b>1.7</b>                   |
| <b>Full<br/>range<br/>Sasol<br/>SPD™<br/>diesel</b> | <b>Avg..</b>    | <b>0.113</b>                    | <b>0.031</b> | <b>0.388</b>          |                     | <b>212.7</b>          | <b>8.89</b>                  |
|                                                     | <b>Std Dev.</b> | <b>0.011</b>                    | <b>0.005</b> | <b>0.011</b>          |                     | <b>1.246</b>          | <b>0.051</b>                 |
|                                                     | <b>COV (%)</b>  | <b>9.4</b>                      | <b>14.8</b>  | <b>2.9</b>            |                     | <b>0.06</b>           | <b>0.6</b>                   |
| <b>Heavy<br/>Sasol<br/>SPD™<br/>diesel</b>          | <b>Avg.</b>     | <b>0.152</b>                    | <b>0.035</b> | <b>0.371</b>          |                     | <b>211.7</b>          | <b>8.64</b>                  |
|                                                     | <b>Std Dev</b>  | <b>0.003</b>                    | <b>0.001</b> | <b>0.000</b>          |                     | <b>0.896</b>          | <b>0.037</b>                 |
|                                                     | <b>COV (%)</b>  | <b>1.7</b>                      | <b>3.8</b>   | <b>0.1</b>            |                     | <b>0.4</b>            | <b>0.4</b>                   |

**Table 5 : EUDC Highway Cycle Emissions and Fuel Consumption**

| Fuel                         |          | Exhaust Emissions (g/km) |       |                 |              |                 | FC<br>( $\ell/100\text{km}$ ) |
|------------------------------|----------|--------------------------|-------|-----------------|--------------|-----------------|-------------------------------|
|                              |          | CO                       | HC    | NO <sub>x</sub> | PM           | CO <sub>2</sub> |                               |
| EN590                        | Avg.     | 0.008                    | 0.003 | 0.295           | Not measured | 127.2           | 4.84                          |
|                              | Std Dev  | 0.001                    | 0.000 | 0.001           |              | 1.363           | 0.052                         |
|                              | COV (%)  | 15.6                     | 12.4  | 0.4             |              | 1.1             | 1.1                           |
| Full range Sasol SPD™ diesel | Avg..    | 0.010                    | 0.003 | 0.283           |              | 123.1           | 5.14                          |
|                              | Std Dev. | 0.004                    | 0.000 | 0.008           |              | 1.071           | 0.045                         |
|                              | COV (%)  | 35.3                     | 10.8  | 2.9             |              | 0.9             | 0.9                           |
| Heavy SPD™ diesel            | Avg.     | 0.008                    | 0.003 | 0.279           |              | 123.2           | 5.03                          |
|                              | Std Dev  | 0.000                    | 0.000 | 0.009           |              | 0.097           | 0.004                         |
|                              | COV (%)  | 5.2                      | 15.7  | 3.1             |              | 0.1             | 0.1                           |

**Table 6 : Composite ECE + EUDC Cycle Emissions and Fuel Consumption**

5

| Fuel                         |          | Exhaust Emissions (g/km) |       |                 |       |                 | FC<br>( $\ell/100\text{km}$ ) |
|------------------------------|----------|--------------------------|-------|-----------------|-------|-----------------|-------------------------------|
|                              |          | CO                       | HC    | NO <sub>x</sub> | PM    | CO <sub>2</sub> |                               |
| EN590                        | Avg.     | 0.159                    | 0.030 | 0.330           | 0.025 | 161.4           | 6.15                          |
|                              | Std Dev  | 0.029                    | 0.007 | 0.004           | 0.000 | 2.064           | 0.080                         |
|                              | COV (%)  | 18.1                     | 23.9  | 1.3             | 1.6   | 2.2             | 1.3                           |
| Full range Sasol SPD™ diesel | Avg..    | 0.048                    | 0.013 | 0.322           | 0.020 | 156.0           | 6.52                          |
|                              | Std Dev. | 0.002                    | 0.002 | 0.009           | 0.001 | 1.118           | 0.047                         |
|                              | COV (%)  | 3.3                      | 14.8  | 2.9             | 4.4   | 3.0             | 0.7                           |

|                         |         |       |       |       |       |       |       |
|-------------------------|---------|-------|-------|-------|-------|-------|-------|
| Heavy<br>SPD™<br>diesel | Avg.    | 0.061 | 0.015 | 0.313 | 0.027 | 155.8 | 6.36  |
|                         | Std Dev | 0.000 | 0.000 | 0.005 | 0.000 | 0.378 | 0.015 |
|                         | COV (%) | 0.7   | 1.3   | 1.7   | 1.0   | 1.7   | 0.2   |

The results are also presented graphically in Figures 3 to 8.

The following may be concluded from the emission tests performed:

5

- Use of the heavy cut of Sasol SPD™ diesel fuel did not adversely affect the exhaust emissions of the test vehicle, when compared to a European EN590 reference diesel fuel. HC and CO emissions were lower than the EN590 fuel, while NOx and particulate emissions were similar. All regulated emissions were well within the Euro 3 limits for which the test vehicle is certified.

10

- Removing the lighter 45% of the diesel results in increases in HC, CO and PM emissions, when compared to the full boiling range diesel. While HC and CO emissions are still lower than with the EN590 reference fuel, PM emissions were similar to the EN590 fuel, and some 30% higher than the full boiling range diesel.

15

- The increased density of the heavy cut of the Sasol SPD™ diesel results in an improvement in volumetric fuel consumption of 2%, when compared to the full boiling range diesel. Fuel consumption is still some 3% higher than with the EN590 diesel fuel, however.

20

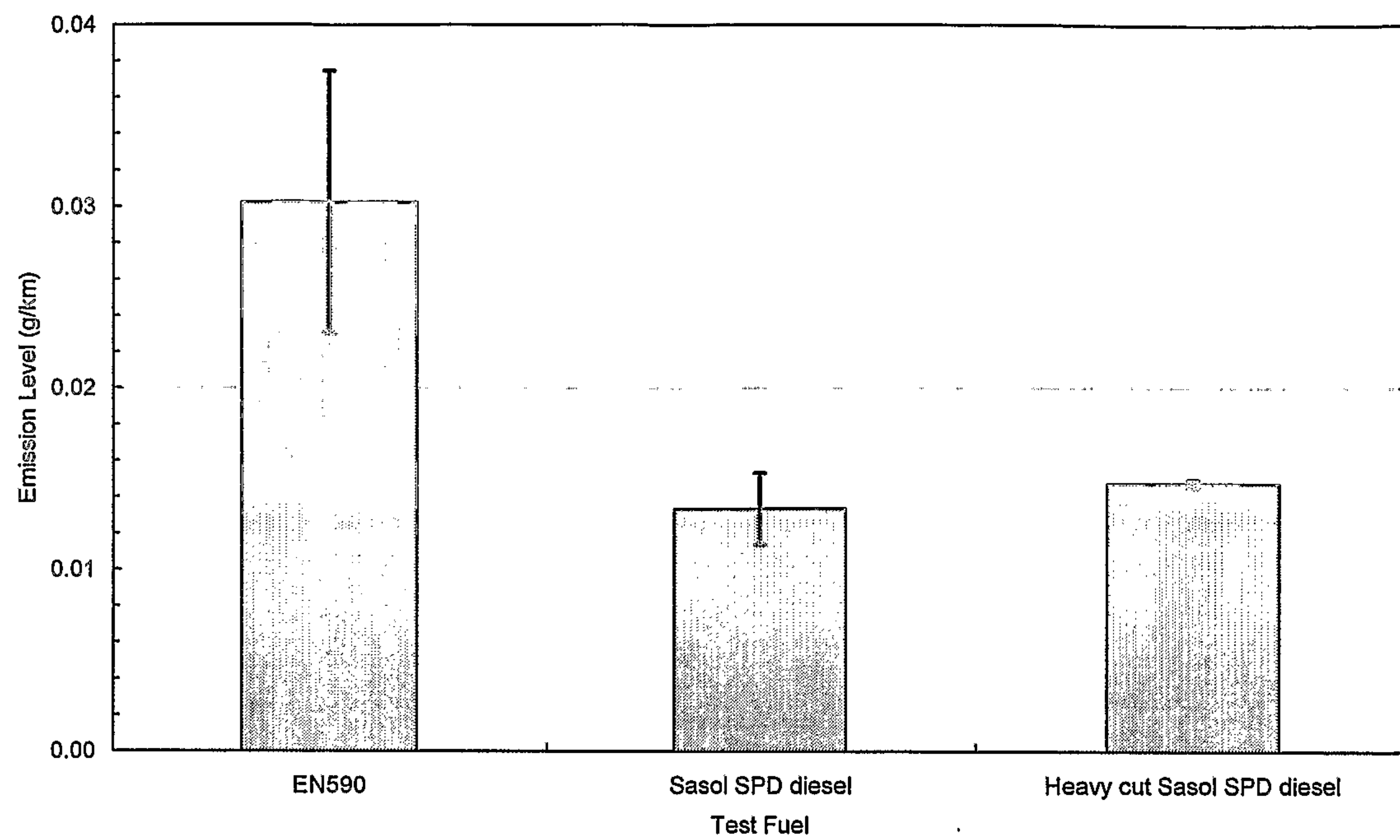


Figure 3 : Composite HC Emissions

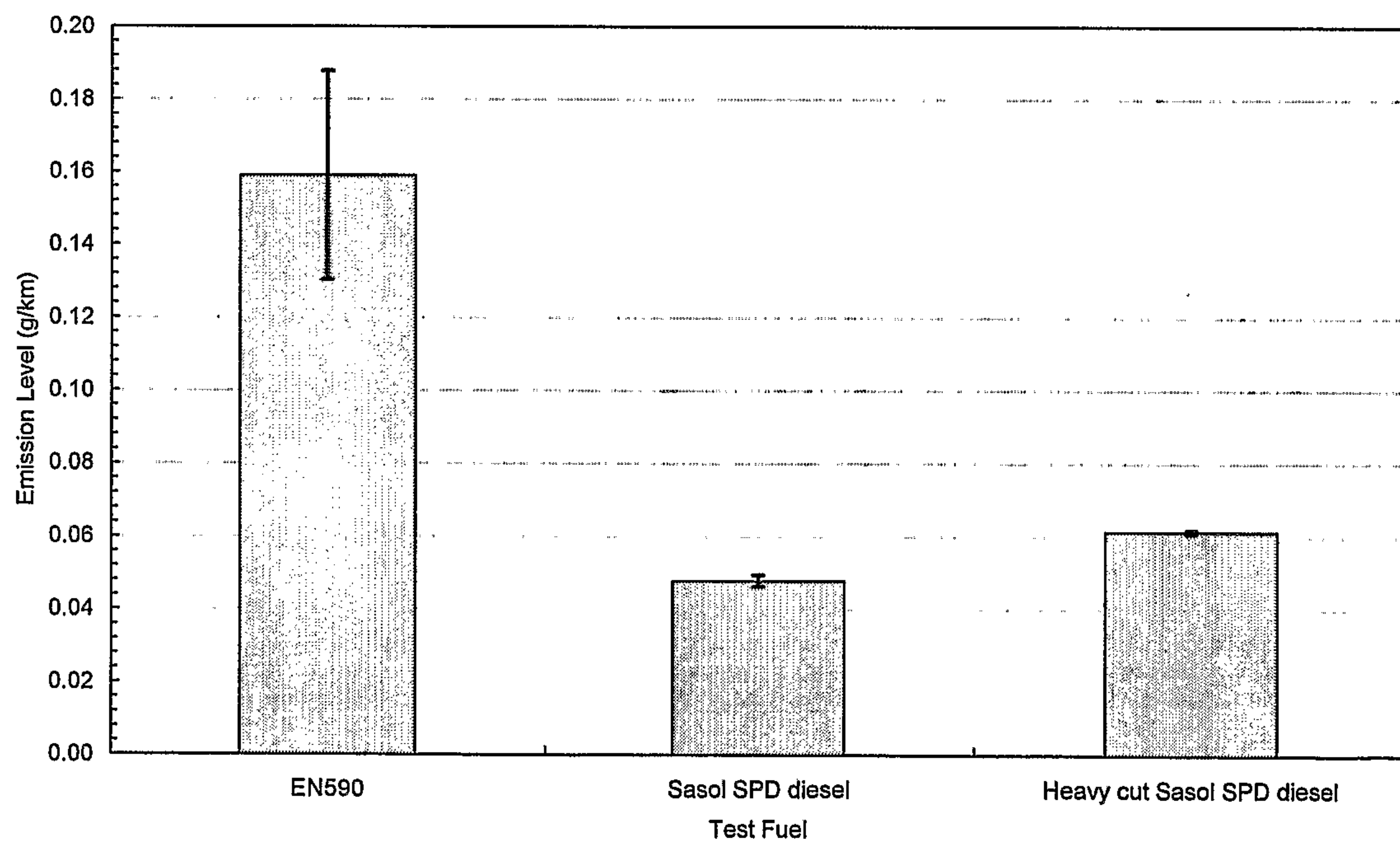


Figure 4 : Composite CO Emissions

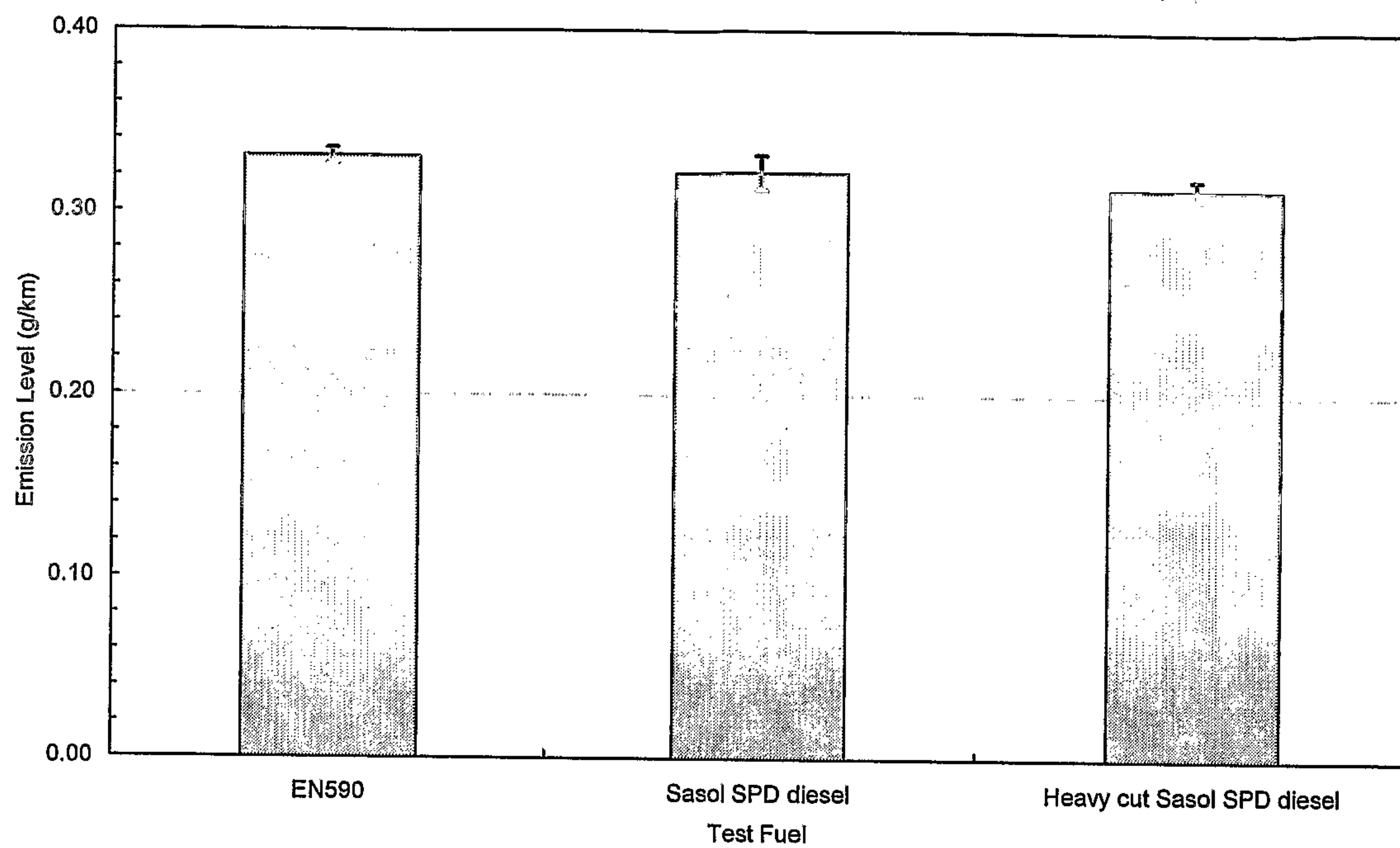


Figure 5 : Composite NOx Emissions

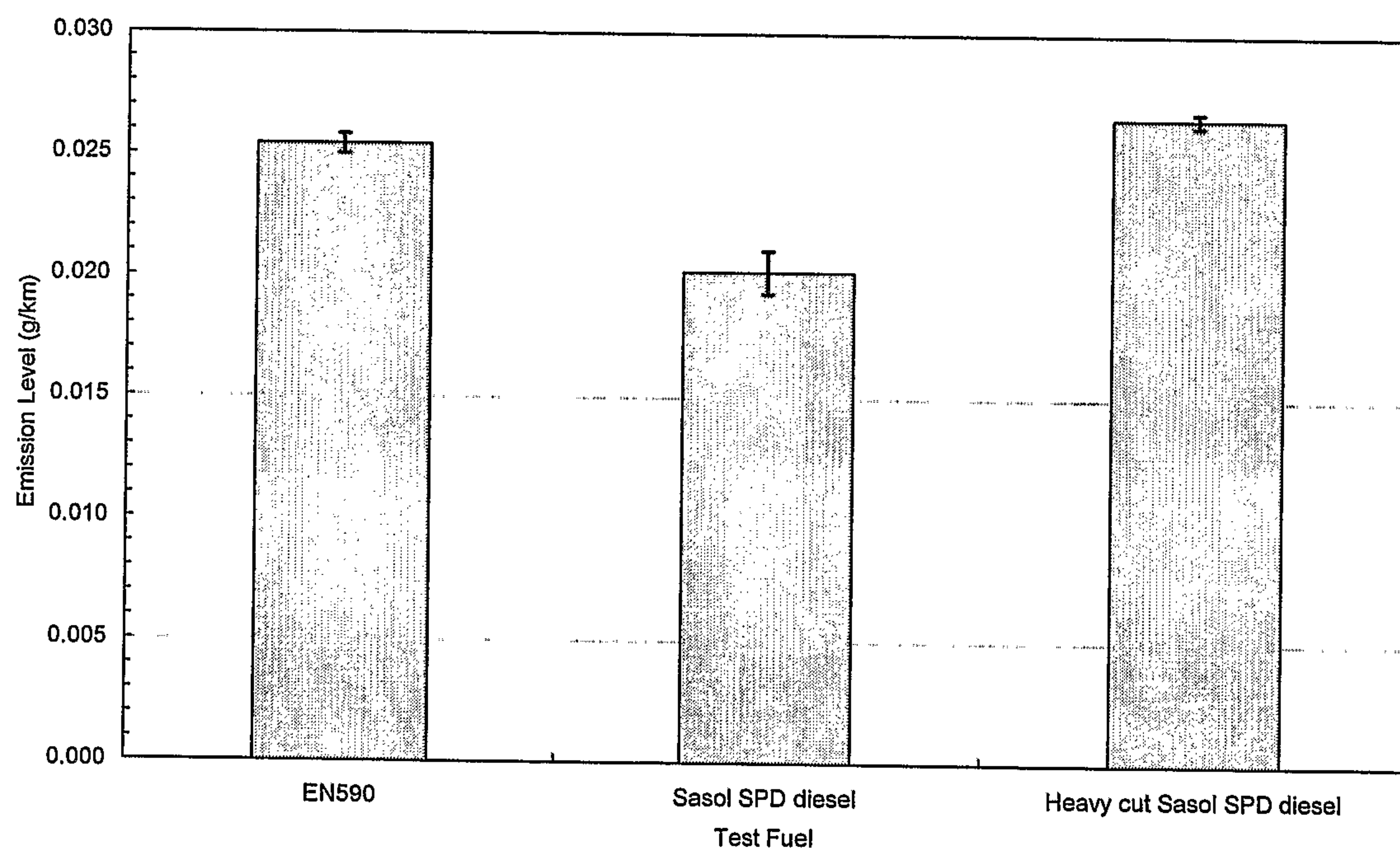


Figure 6 : Composite PM Emissions

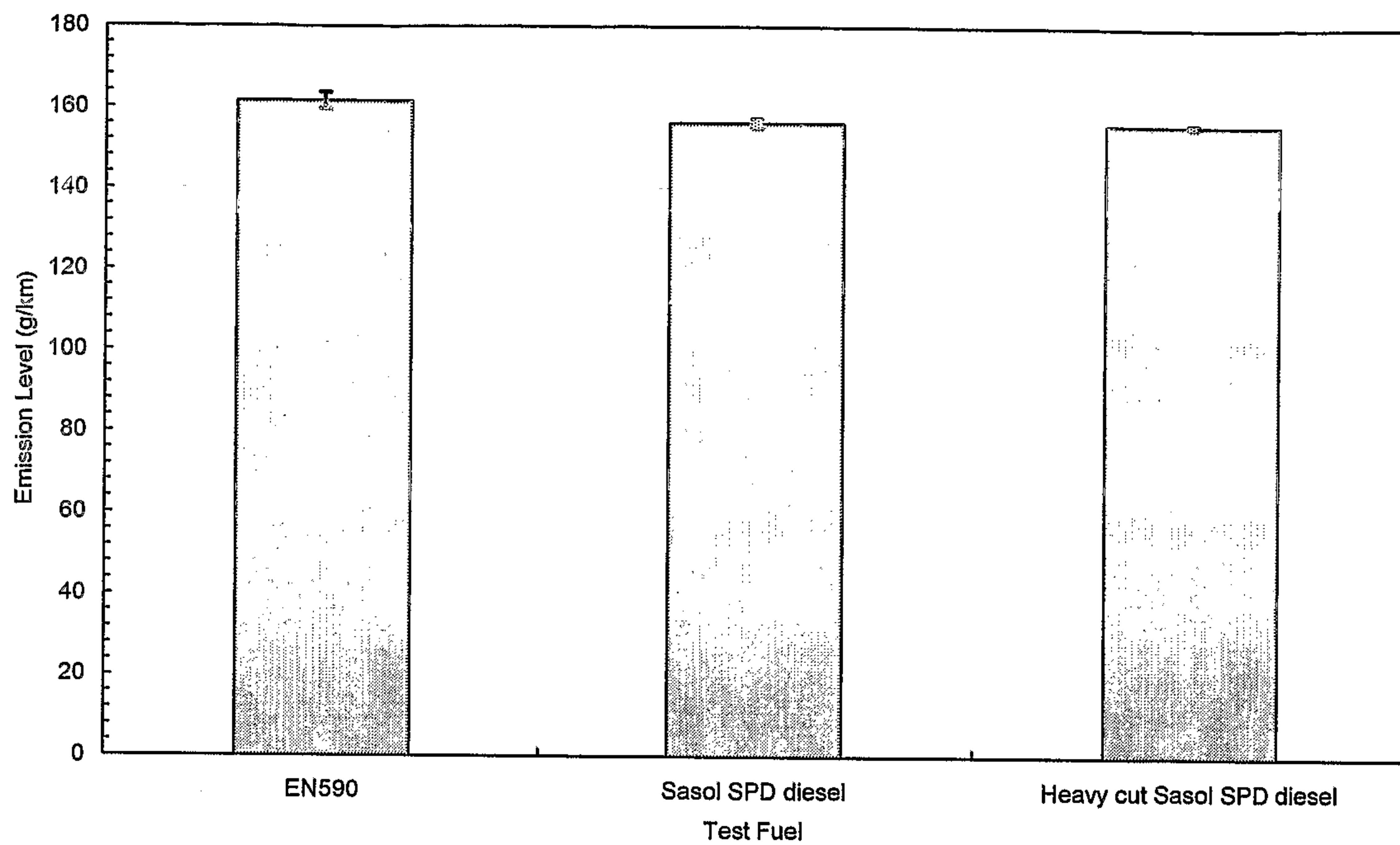
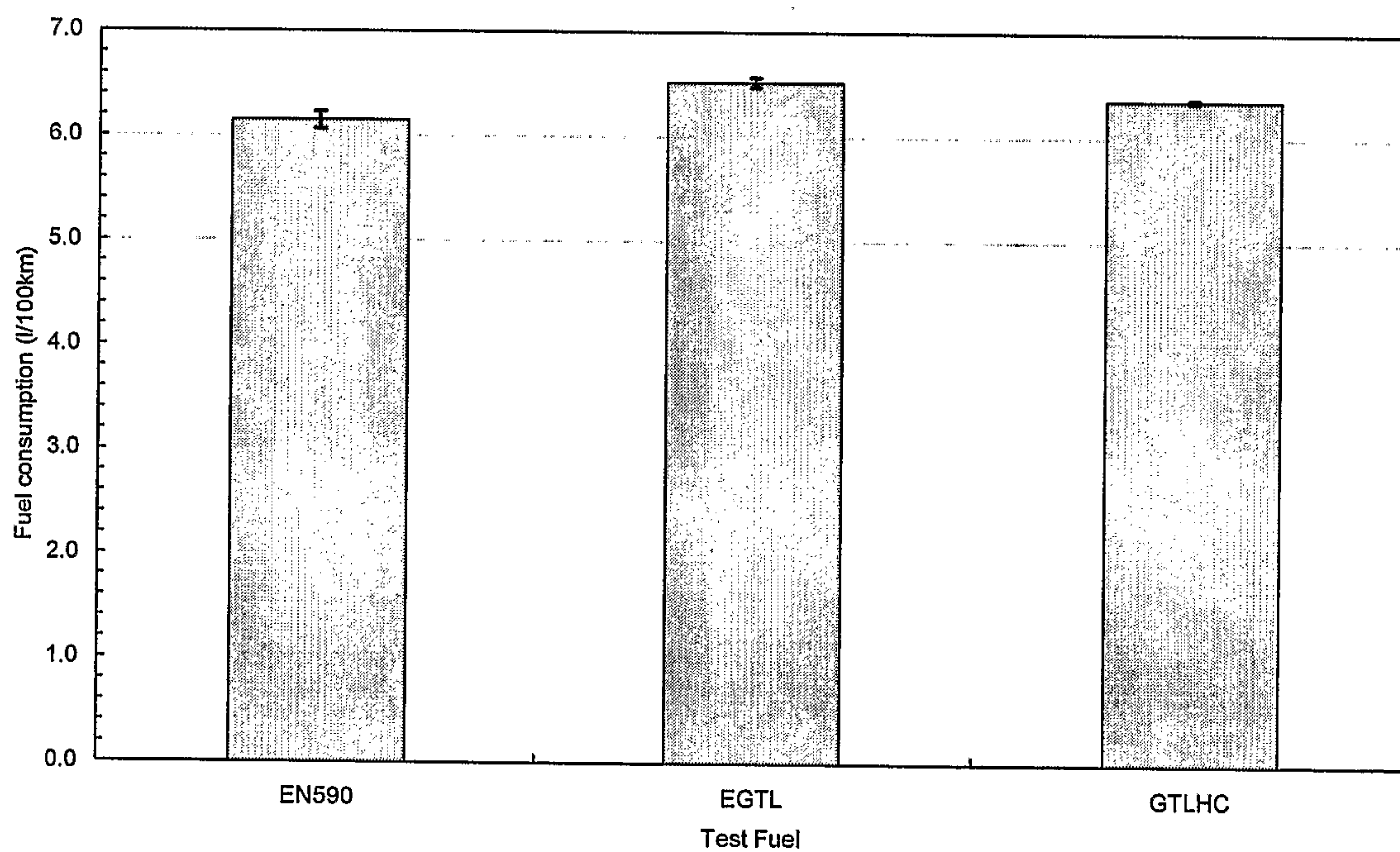
Figure 7 : Composite CO<sub>2</sub> Emissions

Figure 8 : Fuel Consumption

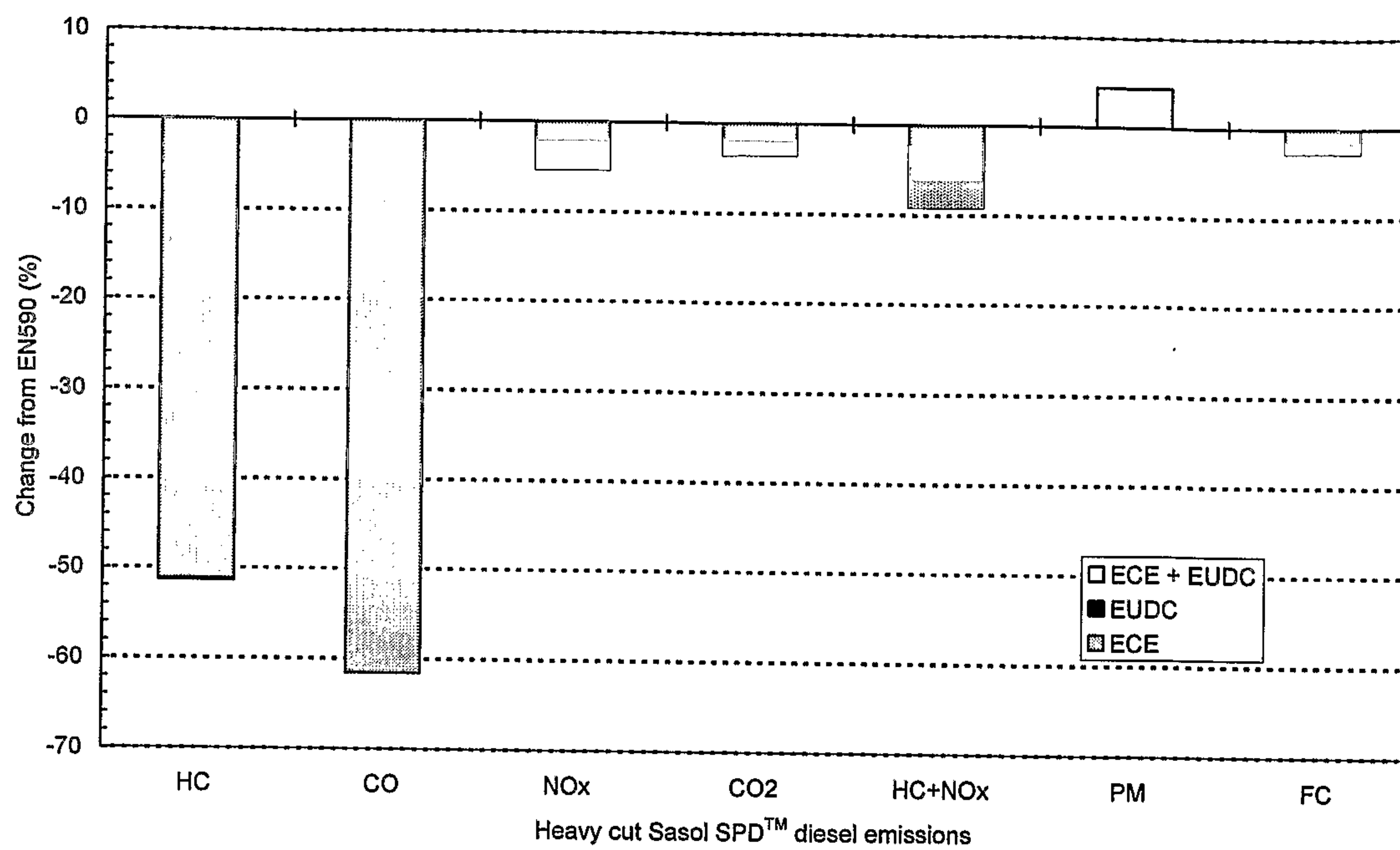
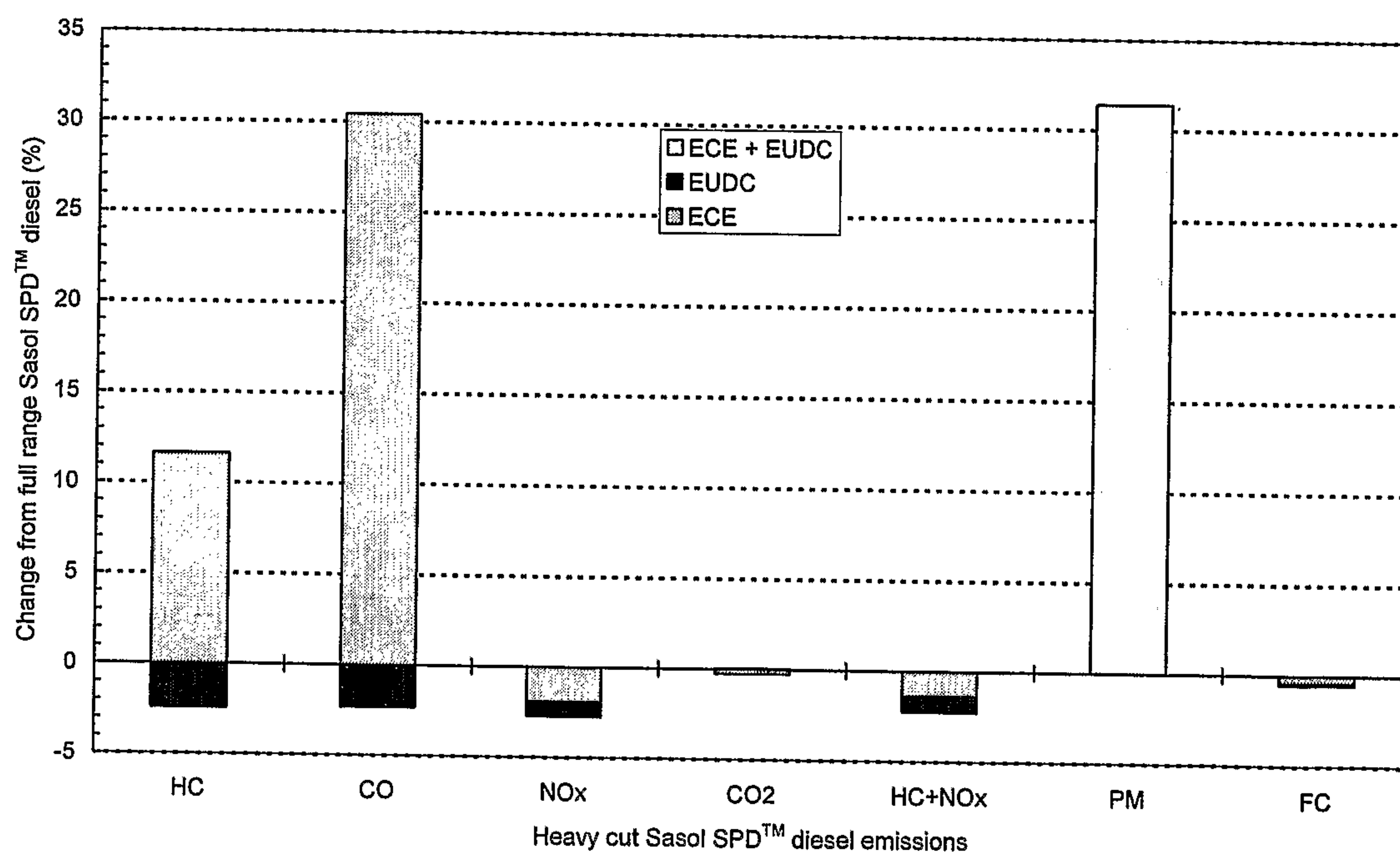


Figure 9 : 55 vol-% Heavy cut Sasol SPD™ diesel emissions vs EN590



5 Figure 10 : 55 vol-% Heavy cut Sasol SPD™ diesel emissions vs full range Sasol SPD™ diesel

## Aviation Fuel

The above tables and discussion regarding the low sulphur diesel fuel refer.

- 5 Viscosity and freezing point are the physical properties used to quantitatively characterise aviation fuel fluidity and only an upper viscosity limit is therefore specified for aviation fuel to which the fully synthetic Sasol SPD™ kerosene fractions conform. The light 45 vol-% Sasol SPD™ fully synthetic kerosene fraction met the required freezing point of  $-47^{\circ}\text{C}$  for Jet A-1 according to the DEF
- 10 STAN 91-91 with a freezing point of  $-48^{\circ}\text{C}$  (see Table 2). The low freezing point, determined in accordance with the automated ASTM 5901 test method, is believed to be attributable to the more than 60 mass-% iso-paraffins present in the full range Sasol SPD™ diesel and more than 50 mass-% iso-paraffin present in the fully synthetic Sasol SPD™ kerosene cut.

15

- The amount of energy contained in a given quantity of fuel is important since space comes at a premium in an aircraft. A fuel with a high volumetric energy content maximised the energy that can be stored in a fixed volume and thus provides the longest flight range. The specified net gravimetric energy content
- 20 of the Sasol SPD™ kerosene fractions are greater than the specified 42.8MJ/kg (see Table 3).

- The lubricity of the fully synthetic Sasol SPD™ kerosene cut, evaluated with the Ball-on-Cylinder Evaluator (BOCLE) (ASTM D5001 test method), has an
- 25 unexpected wear scar diameter less than the maximum wear scar diameter that is specified for Jet A-1.

### Sweetened crude derived kerosene blend with Sasol SPD™ kerosene

- 30 According to the specific approval of semi-synthetic jet fuel as Jet A-1, its aromatic content must not be less than 8 vol-%. With Sasol SPD™ diesel

containing no aromatics (<0.001 mass-%), the 45 vol-% Sasol SPD™ kerosene cut was blended in a 50/50 ratio with sweetened crude derived kerosene from Merox™. The properties of the fully synthetic Sasol SPD™ kerosene as blending stock (see Table 3) and an example of sweetened kerosene, Kero Merox™, and a blend thereof are also summarised in Table 3.

The sweetened Merox treated crude derived kerosene used for the blend had a density of 0.809kg/l @ 15°C and the semi-synthetic blend had a boundary specified density of 0.776kg/l @ 15°C. The aromatic content of the blend was beyond the 8 vol-% limit (see Table 3).

The composition, volatility, fluidity, water separation characteristics, lubricity and thermal stability (JFTOT) requirements for semi-synthetic jet fuel are met with up to a 50 vol-% sweetened crude derived kerosene stream – Sasol SPD™ kerosene blend. The distillation profile of the blend is shown in Figure 11.

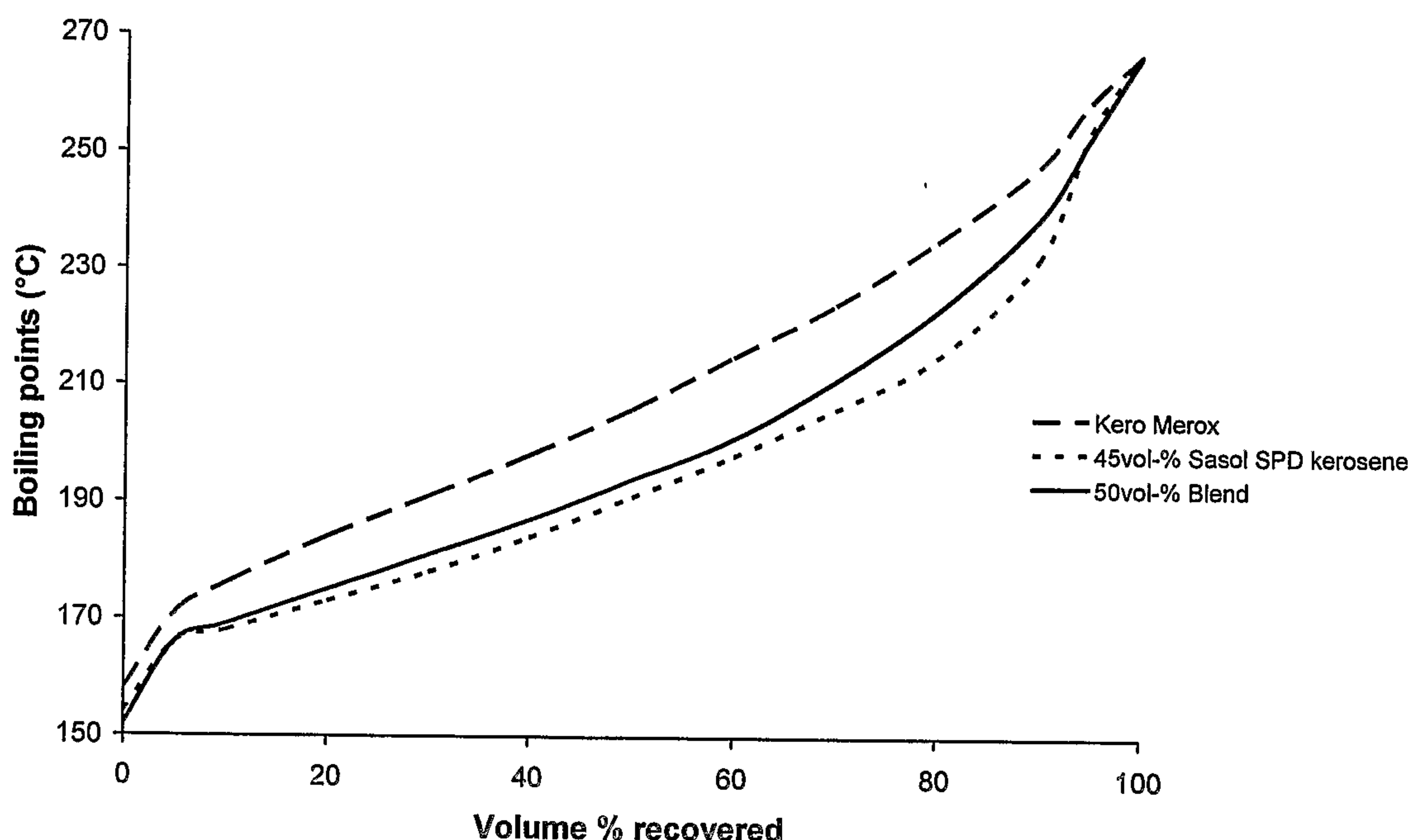


Figure 11: Distillation profiles of sweetened Kero Merox™ kerosene, the 45% Sasol SPD™ kerosene fraction and a 50% blend thereof

Synthetic kerosene blends with crude derived jet fuel have already been approved with certain limitations. These include synthetic kerosene derived solely from the Fischer-Tropsch process without the inclusion of synthetic aromatic compounds. The light Sasol SPD™ kerosene with a final boiling point of 270°C conforms to these limitations and also to the freezing point requirement for Jet A-1 of -47°C. As a blend, its density and aromatic content will also conform to the minimum requirement of 0.775 kg/l @ 15°C and an 8 vol-% aromatic content.

10 Severely hydrotreated crude derived kerosene blend with Sasol SPD™ kerosene

Up to 50 vol-% blends of Sasol SPD™ diesel with severely hydrotreated crude derived kerosene were also prepared to demonstrate a thermally stable semi-synthetic jet fuel conforming to Jet A-1 requirements such as freezing point, density and lubricity. The properties of a 50 vol-% blend with a severely hydrotreated kerosene, a Distillate Hydrocracked kerosene as example, is shown in Table 3.

20 **THERMAL STABILITY**

The thermal oxidation stability of the fully synthetic aviation fuel and semi synthetic aviation fuel (blends of the light Sasol SPD™ kerosene fractions with sweetened and severely hydrotreated crude derived kerosene) were determined according to the jet fuel thermal oxidation tester (JFTOT) ASTM D3241 test method. The visual tube deposit rating for the fully as well as the semi-synthetic aviation fuel were less than 1 with no pressure drop across the filter.

Thermal stability results with the Quartz Crystal Microbalance (QCM) confirmed the JFTOT results with only 2 µg/cm<sup>2</sup> deposition observed after the 15 hour test at 140°C without the presence of anti-oxidants.

Tests with the JP-8+100 thermal stability improving additive did not improve the stability of the synthetic aviation fuel and blends thereof since the fuel is such a low depositor.

## 5 Soot Emissions

Gas turbine engine tests results on particulates (soot) of the fully synthetic aviation fuel and blends thereof under idle and cruise conditions were compared with that of typical convention aviation fuel. The fully synthetic Sasol SPD™ light kerosene cut formed 40% less soot under cruise conditions than conventional JP-8 aviation fuel whereas a blend thereof formed 33% less soot under cruise conditions.

Under idle conditions, the Sasol SPD™ kerosene blend stock formed 83% less soot compared to typical convention aviation fuel, whereas blends thereof formed 67% less soot.

**Claims**

1. A process for the production of a synthetic low sulphur diesel fuel and a low soot emission aviation fuel from a Low Temperature Fischer-Tropsch (LTFT) feedstock, said process including the fractionation of the Low Temperature Fischer-Tropsch feedstock into a light kerosene fraction and a heavier diesel fraction in a volumetric ratio of at least 1:2 to form the light kerosene fraction having a smoke point greater than 50 mm, a freezing point of below -47°C, a BOCLE lubricity wear scar less than 0.85 mm, and an anti-oxidant additiveless thermal stability tube deposit rating at 260°C of less than 1 useable as a low soot emission aviation fuel and/or an aviation fuel blend stock, and the heavier diesel fraction having CFPP according to IP309 of below -5°C, a density@20°C of at least 0.78 kg/l, and a viscosity@40°C of above 2 cSt useable as a synthetic low sulphur diesel fuel and/or a diesel fuel blend stock.
2. A process as claimed in claim 1, wherein at least 33 volume% of the LTFT feedstock is separated to form said aviation fuel or blending stock having a final boiling point of about 270°C.
3. A process as claimed in claim 1 or claim 2, wherein the process includes fractionation and removal of 45 volume% of the feedstock to form said aviation fuel or blending stock.
4. A process as claimed in claim 3, wherein the process includes the fractionation and removal of 55 volume% of the feedstock.
5. A process as claimed in any one of claims 1 to 3, wherein the light kerosene fraction has a density@20°C of at least 0.75 kg/l.
6. A process as claimed in any one of the preceding claims, wherein the light kerosene fraction produced by the process has An iso:n paraffins mass ratio of from 1:1 to 1:2.

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7. A process as claimed in any one of the preceding claims, wherein the light kerosene fraction produced by the process has an iso:n paraffins mass ratio is from 1 to 2.
- 5 8. A process as claimed in any one of the preceding claims, wherein the light kerosene fraction produced by the process has an iso:n paraffins mass ratio is from 1.16 to 1.2.
9. A process as claimed in any one of the preceding claims, wherein the light  
10 kerosene fraction produced by the process has a hydrogen content of from 13 mass% to 17 mass%.
10. A process as claimed in any one of the preceding claims, wherein the light  
15 kerosene fraction produced by the process has a hydrogen content of about 15 mass%.
11. A process as claimed in any one of the preceding claims, wherein the light kerosene fraction produced by the process is a LTFT kerosene fraction.
- 20 12. A process as claimed in any one of the preceding claims, wherein the light kerosene fraction produced by the process has a viscosity@-20°C of less than 8cSt.
13. A process as claimed in any one of the preceding claims, wherein the light  
25 kerosene fraction produced by the process has a final boiling point of above 200°C, typically about 270°C.
14. A process as claimed in any one of the preceding claims, wherein the light kerosene fraction produced by the process has Quartz Crystal Microbalance  
30 (QCM) deposition of less than 3 µg/cm<sup>2</sup>.