**Food, fuel and fatty acids**

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**ABSTRACT**

Globally, there are around 1400 plant species that produce seed oil. The seeds of some species are harvested for various uses or markets. Different species require different environments for optimum oil production. However, for most it may not be an economically viable proposition to grow them for fuel or food and quantity may not be the only limiting factor. The seed oils of the various species are composed of a range of fatty acids which determine the oils potential characteristics and uses. Generally the fatty acids can be divided into 3 major groups:

Saturated fatty acids (SFA) are usually solid at room temperature and have to be heated to flow. However, they are very stable and have a high energy content and cetane number (65 or above) and a low iodine value (40 – 60), eg as in Palm oil, coconut oil and animal fats. These have good potential for providing energy for a fuel but the high calorific content is considered undesirable in a food and some tend to increase levels of cholesterol in the blood.

Mono-unsaturated fatty acids (MUFA) have a lower melting point (13.5 to 33°C), are less stable than the saturated fatty acids and possibly require an anti-oxidant to ensure shelf life. The energy content is less and the cetane number is generally between 55 and 60. The iodine value is higher (75 – 115), as in Olive oil and Canola. Good prospects as a fuel source, however, only the shorter chain MUFA’s such as Oleic acid are considered to be desirable in a food oil.

Poly-unsaturated fatty acids (PUFA) have an even lower melting point (-5 to -18°C), are very unstable and can oxidize and form polymers under heat and pressure. The energy content is further reduced, the cetane number is 52 – 53 and the iodine value is high (125 and above). Linseed has a high proportion of the long chain polyunsaturated fatty acid, alpha linolenic acid (C18:3) and probably is the least desirable as a fuel but has value in the health food market as a source of the essential, Omega -3 fatty acid, and in industry as a drying oil in paints and varnishes.

**Keywords:** Biodiesel, Poly-unsaturated, Mono-unsaturated, Saturated Fatty acids, Oil.

**INTRODUCTION**

For the past 10 years, the oilseed industry in Australia has been dominated by canola, currently grown for seed for export and for the production of food oil for domestic use. In the 2004 – 2005 growing season 1,500 kt of canola was produced with smaller amounts of seed of cottonseed (850 kt), soybean (70 kt), sunflower (62 kt), safflower and linseed also being produced. Most, of the seed produced was for the production of oil for human consumption or for export. To be acceptable as a food, the oil should be composed of particular fatty acids. The different food oils are characterized by containing the fatty acids in varying proportions: The major fatty acid in canola oil is oleic acid, an Omega-9 fatty acid and in soybean, sunflower and safflower oils, it is linoleic acid, an Omega-6 fatty acid.

Biodiesel is chemically refined vegetable or animal oil or fat. Converting the fat or oil to biodiesel reduces the viscosity and the melting point closer to that of mineral diesel. Biodiesel can be blended with mineral diesel in any proportion and could help to extend the dwindling reserves of mineral diesel. Biodiesel can be used to replace mineral diesel and has the potential to be an economically viable, renewable, sustainable source of fuel; for transport, heat and energy. Almost any vegetable or animal oil or fat can be used to make Biodiesel. However, the composition of the oil or fat will affect the characteristics of the Biodiesel.
Many plant species produce seed oil, but for most it is not an economically viable proposition to grow them specifically for food, fuel or energy. Different species require particular environments for optimum oil production. Some crops are grown for different markets and the oil, as a by-product can become a viable feedstock for biodiesel as with cotton and soybean. Other oilseeds produce a particular quality of oil that has a greater value than food or fuel.

**FATS, OILS AND FATTY ACIDS**

Fats (and butters) are generally solid and oils are liquid at room temperature. Animal and vegetable fats and oils are composed of a variety of fatty acids. Fatty acids consist of carbon, hydrogen and oxygen atoms linked into a variety of fatty acids. Fatty acids consist of carbon, hydrogen and oxygen atoms linked into a hydrocarbon chain with a carboxyl group (-COOH) at one end as in Figure 1. Butyric acid, shown as an example contains 4 carbon atoms.

Fig.1. Structure of Butyric Acid, a saturated fatty acid with 4 carbon atoms (C4)

![Figure 1. Structure of Butyric Acid](image)

Around seventy different fatty acids have been isolated from cells. Usually, the fatty acids contain an even number of carbon atoms in the chain and most often the fatty acids are bound in groups of three by a glycerol molecule to form triglycerides. However, diglycerides and monoglycerides do exist in cells. The major differences between the fatty acids are in the number of carbon atoms in the hydrocarbon chain and the number and positions of the double bonds. These differences affect characteristics such as viscosity, melting point, boiling point, energy content and oxidative stability. The most common fatty acids contain either 16 or 18 carbon atoms, designated as C16 or C18 fatty acids. The fatty acids can be classified into 3 groups; saturated, mono-unsaturated and poly-unsaturated, depending on the number of double bonds present in the chain.

**Saturated fatty acids** (SFA) have no double bonds between carbon atoms in the chain. They are stable, have high energy content and are usually solid at room temperature. As shown in Table I, the melting point increases with the length of the hydrocarbon chain. Palmitic (C16) and stearic (C18) acids are the most commonly occurring saturated fatty acids. Palmitic acid comprises 45% of palm oil and is present in smaller amounts in most fats and oils. Animal fats contain greater amounts of stearic acid than plant oils. Coconut oil contains a number of the shorter chain fatty acids, see Table 2.

**Mono-unsaturated fatty acids** (MUFA) have one double bond in the chain. In oleic acid, which has 18 carbon atoms in the chain (C18:1), the double bond is between the ninth and tenth carbon atoms along the chain from the carboxyl end. This places oleic acid in the Omega-9 group of unsaturated acids. MUFAs are less stable and have less calorific value than SFAs. They are usually liquid at room temperatures. The most common MUFAs include oleic acid found in olive and canola oils, eicosenoic acid (C20:1) present in concentrations of up to 15% in various cruciferous herbs and erucic acid (C22:1) prominent in crambe and the mustards.

**Poly-unsaturated fatty acids** (PUFA) have two or more double bonds in the chain. They are increasingly unstable and more prone to oxidize with increases in the number of double bonds. Under conditions of heat and pressure, PUFAs with 3 or more double bonds can polymerize, irreversibly forming plastic polymers. The melting point of PUFAs is below 0°C. The essential fatty acids, necessary for good health, are all PUFAs. Linoleic acid, with 2 double bonds (C18:2), is the major fatty acid found in cottonseed, soyabean, safflower and sunflower oils. Alpha linolenic acid (ALA) and gamma linolenic acid (GLA) have three double bonds in the 18 carbon chain (C18:3). Both are essential fatty acids. Linseed (flax) is the richest source of ALA, an Omega-3 fatty acid. Borage and Evening Primrose oils are valued for their GLA content.
Table 1. Melting points of some fatty acids (Gunstone 1958)

<table>
<thead>
<tr>
<th>Fatty acid</th>
<th>Carbon Number</th>
<th>Melting point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lauric</td>
<td>C12</td>
<td>43.5</td>
</tr>
<tr>
<td>Myristic</td>
<td>C14</td>
<td>54.4</td>
</tr>
<tr>
<td>Palmitic</td>
<td>C16</td>
<td>62.9</td>
</tr>
<tr>
<td>Stearic</td>
<td>C18</td>
<td>69.6</td>
</tr>
<tr>
<td>Arachidic (Eicosanoic)</td>
<td>C20</td>
<td>75</td>
</tr>
<tr>
<td>Behenic</td>
<td>C22</td>
<td>80</td>
</tr>
<tr>
<td>Lignoceric</td>
<td>C24</td>
<td>84.2</td>
</tr>
<tr>
<td>Oleic</td>
<td>C18:1</td>
<td>13.5</td>
</tr>
<tr>
<td>Eicosenoic</td>
<td>C20:1</td>
<td>22</td>
</tr>
<tr>
<td>Erucic</td>
<td>C22:1</td>
<td>33</td>
</tr>
<tr>
<td>Linoleic</td>
<td>C18:2</td>
<td>-5</td>
</tr>
<tr>
<td>Linolenic</td>
<td>C18:3</td>
<td>-11</td>
</tr>
</tbody>
</table>

**EDIBLE OILS**

Edible oils can be divided into oils for food or cooking and oils taken as health food supplements. The desirable characteristics of oils for food or cooking include a level of stability that ensures a reasonable shelf life. Food oils ideally should have limited calorific content and have an acceptable flavour and colour. Oils high in oleic acid and linoleic acid are desirable as food oils. In Australia, food oil must contain less than 2% erucic acid.

Table 2. Fatty acid composition of some edible fats and oils (Adapted from Scientific Psychic).

<table>
<thead>
<tr>
<th>Oil or Fat</th>
<th>Saturated</th>
<th>Mono unsaturated</th>
<th>Poly unsaturated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Capric Acid</td>
<td>Lauric Acid</td>
<td>Myristic Acid</td>
</tr>
<tr>
<td>Beef Tallow</td>
<td>-</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Butterfat (cow)</td>
<td>3</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>Canola Oil</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Coconut Oil</td>
<td>6</td>
<td>47</td>
<td>18</td>
</tr>
<tr>
<td>Cottonseed Oil</td>
<td>-</td>
<td>1</td>
<td>22</td>
</tr>
<tr>
<td>Flaxseed Oil</td>
<td>-</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Olive Oil</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Palm Oil</td>
<td>-</td>
<td>1</td>
<td>45</td>
</tr>
<tr>
<td>Palm Kernel Oil</td>
<td>4</td>
<td>48</td>
<td>16</td>
</tr>
<tr>
<td>Soybean Oil</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sunflower Oil</td>
<td>-</td>
<td>-</td>
<td>7</td>
</tr>
</tbody>
</table>

Oil for commercial deep frying needs to be as stable as possible to reduce the number of changes of the oil. Those oils containing a larger percentage of SFAs such as palm oil have been preferred by the hospitality industry due to their stability. However, generally SFAs are considered undesirable in food oils as some have been shown to contribute to increased cholesterol levels, whereas PUFAs such as linoleic acid (C18:2) reduce cholesterol levels. MUFAs (e.g., oleic, C18:1) do not affect cholesterol levels significantly (Hegsted et al. 1965).
The oils taken as health food supplements contain Omega-3 and Omega-6 fatty acids. These are PUFAs that need to be included in the diet because they cannot be made in the body. They are termed essential fatty acids and are important for maintaining the membranes of all cells; for making prostaglandins which regulate many body processes which include inflammation and blood clotting. ALA can be converted in the body to EPA (eicosapentaenoic acid) and DHA (docosahexaenoic acid) found in marine fish oils. The omega-3 fatty acids readily oxidize if exposed to the air but can be stabilized with antioxidants or encapsulated.

OILS FOR FOOD

Animal and vegetable fats and oils have been used for light and heating for thousands of years. The first diesel engine was designed to run on a variety of ‘fuels’ and was first demonstrated running on peanut oil. Diesel engines can run on vegetable oil once the viscosity of the oil is reduced closer to that of mineral diesel either by heat or by chemical conversion to a mono-alkyl ester (Biodiesel). Biodiesel is made by reacting the fat or oil with alcohol; usually either methanol or ethanol in the presence of a catalyst; sodium or potassium hydroxide. During the process the glycerol molecules are split off from the triglycerides to form methyl or ethyl esters, with glycerol as a bye-product. In table 3, the effect of conversion to biodiesel (transesterification) on the melting point of some saturated fatty acids is shown.

Table 3. The melting points (°C) of some fatty acids and their methyl esters

<table>
<thead>
<tr>
<th>Fatty acid</th>
<th>Carbon Number</th>
<th>MP of Fatty Acid</th>
<th>MP of Methyl Ester</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lauric</td>
<td>C12</td>
<td>43.5</td>
<td>5</td>
</tr>
<tr>
<td>Myristic</td>
<td>C14</td>
<td>54.4</td>
<td>19</td>
</tr>
<tr>
<td>Palmitic</td>
<td>C16</td>
<td>62.9</td>
<td>30</td>
</tr>
<tr>
<td>Stearic</td>
<td>C18</td>
<td>69.6</td>
<td>39</td>
</tr>
<tr>
<td>Arachidic (Eicosanoic)</td>
<td>C20</td>
<td>75</td>
<td>47</td>
</tr>
</tbody>
</table>

Reducing the melting point of the fatty acids by transesterification, effectively reduces the melting points of the various fats and oils that could be used to fuel a diesel engine closer to that of mineral diesel. This also reduces the cloud point (CP) and cold filter plugging point (CFPP) of the fuel facilitating the use of the esters (biodiesel) at lower temperatures.

Biodiesel should have high energy content and the Australian Standard for biodiesel dictates a minimum cetane number of 51. Oils with high content of saturated fatty acids contain the most energy and provide for a high cetane number. The SFA content of coconut oil (83%) accounts for its cetane number of 70. Whereas, the cetane number of soybean oil, in which the SFA content is around 15%, is much lower at 53 (Tables 2 and 4). The iodine number (Table 4) is related to the content of unsaturated fatty acids in the oil or biodiesel and affects their oxidative stability. The higher the iodine number, the more unstable the oil and the more susceptible it is to be oxidized. The Australian Standards sets a minimum oxidation stability of 6 hours at 110°C.

Any animal and vegetable fat or oil may be used to make biodiesel, however the feedstock must be comparatively cheap, the supply sustainable and there must be a use for any by-products. Oils that are mostly composed of PUFAs will need to be blended with other fats and oils to increase the stability of the oil. In cooler environments, oils with a large content of SFAs will need to be blended with oils with minimal SFAs to reduce the melting point of the fuel.

Table 4. Some oils, their melting points (°C), iodine values and cetane number. (Calais P and Clark AR, 2007)
<table>
<thead>
<tr>
<th>Oil or Fat</th>
<th>Melting Point</th>
<th>Iodine Number</th>
<th>Cetane Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coconut</td>
<td>25</td>
<td>10</td>
<td>70</td>
</tr>
<tr>
<td>Palm Kernel</td>
<td>24</td>
<td>37</td>
<td>70</td>
</tr>
<tr>
<td>Mutton Tallow</td>
<td>42</td>
<td>40</td>
<td>75</td>
</tr>
<tr>
<td>Palm</td>
<td>35</td>
<td>54</td>
<td>65</td>
</tr>
<tr>
<td>Olive</td>
<td>-6</td>
<td>81</td>
<td>60</td>
</tr>
<tr>
<td>Castor</td>
<td>-18</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>Peanut</td>
<td>3</td>
<td>93</td>
<td></td>
</tr>
<tr>
<td>Rapeseed</td>
<td>-10</td>
<td>98</td>
<td>55</td>
</tr>
<tr>
<td>Cottonseed</td>
<td>-1</td>
<td>105</td>
<td>55</td>
</tr>
<tr>
<td>Soybean</td>
<td>-16</td>
<td>130</td>
<td>53</td>
</tr>
<tr>
<td>Tung</td>
<td>-2.5</td>
<td>168</td>
<td></td>
</tr>
<tr>
<td>Linseed (Flax)</td>
<td>-24</td>
<td></td>
<td>178</td>
</tr>
</tbody>
</table>

Some plant oils will not generally be used to make biodiesel as they have a value greater than that of fuel: Oils containing a high percentage of erucic acid are valued as engine lubricants and as a source of erucamides, slip agents used in the plastics industry and in heat sensitive dyes. Oils, such as linseed oil that consist mostly of omega-3 fatty acid have a high value as health food supplements. They also are used as drying oils in paints, varnishes and polishes.

**FOOD OR FUEL**

Is an alternative fuel needed? Australia, along with most of the world, is seriously dependent on mineral oil. We are dependent on a resource that is non renewable and the supplies are depleting. This dependence is not limited to the use of mineral oil for fuel or energy. Biodiesel, a renewable fuel, can be used instead of mineral diesel or blended with it, extending the resource. Any fat or vegetable oil can be used as fuel. Oils, composed mostly of MUFAs make biodiesel that meets the standards without the need to blend. Other oils will need to be blended depending on their fatty acid composition. Economics and availability of supply will be the major factors in determining which feed stocks will be used for fuel. Ideally, oils, undesirable for human consumption and with no better industrial use, will be used for fuel.

**ACKNOWLEDGEMENTS**

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[http://journeytoforever.org/biofuel.html](http://journeytoforever.org/biofuel.html)