SUNFLOWER OIL AS A FUEL FOR COMPRESSION IGNITION ENGINES

by

Abdul Rehman Tahir

A Thesis
presented to the Faculty of Graduate Studies in
partial fulfillment of the requirements for the
degree of
MASTER OF SCIENCE
in
the Department of Agricultural Engineering
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ABSTRACT

Energy is one of the basic requirements of modern society and many energy fuel alternatives are being examined because of escalating fuel prices or because of diminishing conventional sources. Sunflower oil and its methyl ester were investigated as a potential substitute energy fuel for compression ignition engines as described in this report. Sunflower oil is a hydrocarbon fuel containing a small amount of oxygen. The physio-chemical properties of crude-degummed sunflower oil and its methyl ester were examined and compared with No. 2 diesel fuel. All important fuel related properties were determined according to the American Society of Testing and Materials, standard test procedures specified for No. 2 diesel fuel. The fuel performance characteristics of the oil were examined by operating a Buda diesel engine.

The kinematic viscosity of sunflower oil and its methyl ester is respectively about 14 and 2.0% higher than No. 2 diesel fuel at 37.78°C. The cloud, pour, flash and boiling points of sunflower oil and its methyl ester are higher than diesel fuel while the calorific value of sunflower oil and its methyl ester is about 95% of that of diesel fuel. The oil and its methyl ester are heavier than diesel fuel. The cetane rating and volatility of sunflower oil were found to be considerably lower than diesel fuel.

Over one hour interval, sunflower oil maintained almost the same power output and thermal efficiency as No.2 diesel fuel but the specific fuel consumption was 6.0% higher than diesel fuel.

The higher viscosity of sunflower oil is a major disadvantage to its use as a fuel. The low volatility of the oil and the higher pour point of its methyl ester also do not favor their use in unmodified diesel engines operating in cold temperatures.

ACKNOWLEDGEMENTS

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Chapter 1

INTRODUCTION

1.1 Scope of Study

The escalation of OPEC oil prices since 1973, depletion of finite petroleum reserves and threats of shortfalls are exerting a strong leverage on the economy of many developed and developing countries. Many industrial operations in Canada are being powered by petroleum based fuel. Canada is therefore, experiencing a fuel crisis due to high prices. The Canadian agricultural sector is particularly sensitive to this situation because almost all farm operating machines use petroleum fuels.

Energy conservation and fuel extender programs (gasohol) are expedient and important short term measures but are inadequate to satisfy Canada's long range energy needs. It is therefore, of great urgency, that all potential energy fuel alternatives be selected and investigated. Vegetable oils may provide one such alternative and their fuel potential has been examined by a number of researchers in the early decades of this century. In this context, Strayer (1980) and Quick (1980) referred to work done by Gautier in 1928, in which he investigated the potential of various vegetable oils for use as energy fuel.

This master's thesis project was initiated by the Department of Agricultural Engineering to investigate the use of sunflower oil as a fuel for compression ignition engines.

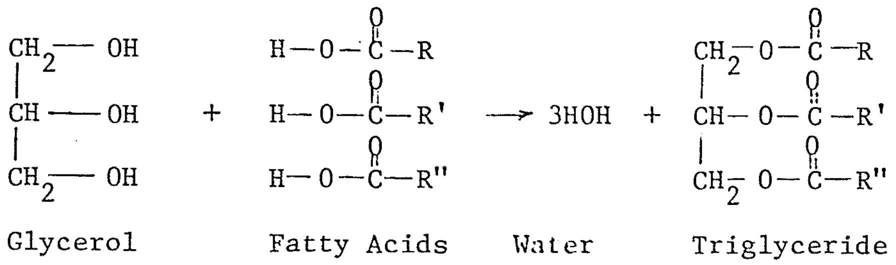
1.2 Agronomic Aspects of Sunflowers

The oilseed sunflower can be grown in many North American agricultural areas with a minimum amount of water. It is estimated that over 2.5 million hectares of oilseed sunflowers were grown in the United States and Canada in 1979. Depending on soil, water, variety and cultural practices, yields ranging from 300 to 1300 kg/ha of seed can be produced within 90 to 120 days of planting (Goodier 1980). Several varieties of sunflowers are being grown in Canada but the majority grown is the oil type, containing from 38 to 50% oil by weight and about 20% protein. The non-oil type also referred to as confectionery, contains 25 to 26% oil and from 22 to 24% protein (Hofman et al. 1980; Cobia and Zimmer 1978).

1.3 Chemical Composition of Sunflower Oil

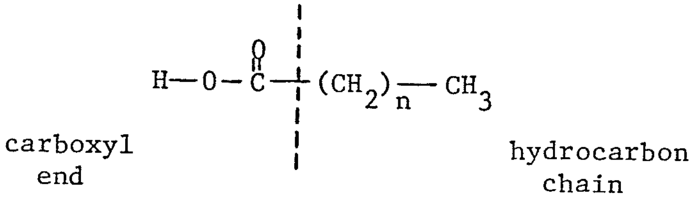
1.3.1 Triglycerides

Sunflower oil is mainly composed (about 95%) of triglycerides, esters of one molecule of glycerol and 3 molecules of fatty acids (Formo et al. 1979). It's chemical structure is shown below.



$$\begin{array}{l} CH_2-OH \\ | \\ CH-OH \\ | \\ CH_2-OH \end{array} + \begin{array}{l} H-O-\overset{O}{\overset{\|}{C}}-R \\ H-O-\overset{O}{\overset{\|}{C}}-R' \\ H-O-\overset{O}{\overset{\|}{C}}-R'' \end{array} \longrightarrow 3HOH + \begin{array}{l} CH_2-O-\overset{O}{\overset{\|}{C}}-R \\ | \\ CH-O-\overset{O}{\overset{\|}{C}}-R' \\ | \\ CH_2-O-\overset{O}{\overset{\|}{C}}-R'' \end{array}$$

Fatty acids are composed of a carboxyl group and a hydrocarbon chain.



$$H-O-\overset{O}{\overset{\|}{C}}-(CH_2)_n-CH_3$$

Fatty acids contribute 94 to 96% of the total mass of a triglyceride molecule. These are the most responsible components for viscosity and calorific value of an oil (Formo et al. 1979; Cobia and Zimmer 1978). Individual fatty acids are distinguished from one another by the length of their respective hydrocarbon chain.

The most common fatty acids found in sunflower oil are: (1) palmitic acid, (2) stearic acid, (3) oleic acid, and (4) linoleic acid. The first two types of fatty acids are saturated whereas the last two are monounsaturated and polyunsaturated respectively. A sample of crude sunflower oil was analysed for fatty acids composition by the Department of Plant Science, University of Manitoba, and the results are shown in Table 1.1.

The composition displayed in the table is sensitive to environmental factors. Especially the percentages of oleic and linoleic interchange due to climate, temperature, genetic factors and the location of seed in the sunflower head. The free fatty acids in sunflower oil are usually 0.5% or more. The amount of free fatty acids predominantly effect the flash point of a

Table 1.1 Fatty acids analysis of sunflower oil by gas chromatography.

Carbon Atoms:No. of double bonds	Fatty Acids	Percentage
16:0	Palmitic	6.0
18:0	Stearic	4.0
18:1	Oleic	18.5
18:2	Linoleic	71.0
18:3	Linolenic	trace*
20:1	Gadoleic	trace*
22:0	Behenic	0.6

*Fatty acids less than 0.5% are classified as a trace.

particular vegetable oil (Formo et al. 1979).

1.3.2 Nontriglycerides

Sunflower oil contains a number of nontriglycerides such as hydrocarbons, waxes, sterols, phospholipids and tocopherols. These are usually less than 5% in crude sunflower oil. Some of these are chemically inert but some of them are very active e.g. tocopherols. Tocopherols have an antioxident property. The proportion of the first three is responsible for the cloud point of sunflower oil (Formo et al. 1979).

1.4 Objectives

The overall objective of this study was to determine the suitability of sunflower oil as an energy fuel for compression ignited engines. Specific objectives include:

(1) To define the important fuel related physical properties of sunflower oil to include; viscosity behaviour with temperature variation, pour point, cloud point, flash point, boiling point, distillation curve, carbon residue, calorific value, cetane number, oxidation stability, density, API gravity and transesterification with methanol.

(2) To determine sunflower oil performance characteristics at various loads placed on a small single cylinder diesel engine.

The properties and performance characteristics of sunflower oil and its methyl ester were compared to No. 2 diesel fuel only throughout this thesis.

Chapter 2

REVIEW OF LITERATURE

The use of vegetable oil as a fuel for internal combustion engines is not a result of modern day research. Several investigations in the use of vegetable oils had been undertaken during the second quarter of the twentieth century. During recent years Australia, New Zealand, The Republic of South Africa, Sweden, Germany, Brazil, Canada and the United States have considered several vegetable oils as potential fuels. Among many vegetable oils examined sunflower oil has emerged to receive widespread attention. Since the province of Manitoba is a major producer of sunflower oil (about 96% of Canada's total) this research project was initiated to investigate the feasibility of using the vegetable oil as an alternate fuel for compression ignition engines.

2.1 Energy ratio and Land Use

An important issue in considering the potential use of a vegetable oil as a fuel is to determine if there is a positive energy balance from its production and use. The energy ratio, which is a ratio of fuel output to the fuel input, was calculated and found to be relatively high (about 10.5 to 1.0) when using sunflower oil as an alternate fuel. Calculations and results are contained in Appendix A, energy ratio. The calculation of a favourable energy ratio suggests that sunflower oil can be investigated as a fuel for diesel engines.

The second important concern is to determine the land area requirements for running a farm on sunflower oil. Calculations contained in Appendix A show that 8 to 10% of the area of Manitoba's average farm (240 ha) would be required for energy fuel selfsufficiency.

2.2 Sunflower Oil Production

Information contained in the Canadian Grain Industry Handbook of 1981 reveals that the average Canadian sunflower seed production over the last six years was about 106.5 thousand tonnes which is equivalent to 46,851 m^3 of oil or 295 thousand barrels of oil. The production trend of sunflower crop is mostly positive. The province of Manitoba is a major contributor in this production which accounts for 96% of the total Canadian Sunflower oil. For calculations see Appendix A, Canadian sunflower oil production.

2.3 Important Physical Properties of Sunflower Oil

2.3.1 Viscosity

The physical properties of sunflower oil exhibits similarities to diesel fuel. One of the most important physical properties of a liquid fuel is its viscosity. At 37.78°C (100°F), the specific temperature of the ASTM test for diesel fuel, sunflower oil (36.33 mm^2/s) is more viscous than diesel (2.4 mm^2/s) by a factor of 16 (Ramdeen et al. 1981). Other research workers such as Peterson et al. (1981) and Quick (1980) have observed almost the same viscosity results (35.3 and 34.7 mm^2/s respectively) for sunflower oil. The results of Yarbrough et al. (1981), Ramdeen et al. (1981) and Bruwer et al. (1980) indicate that the viscosity of sunflower oil changes drastically when cooled below 20°C. At 0°C the viscosity of sunflower oil (187.68 mm^2/s) was higher by a factor of 29 when compared with No. 2 diesel fuel (6.42 mm^2/s).

2.3.2 Cloud, Pour and Flash Points

The cloud point of alkali-refined sunflower oil is -6.6°C, while the cloud point of diesel fuel is -17.0°C (Ramdeen et al. 1981). This considerable difference between the cloud points of two fuels can be related to the higher amount of waxes and gums present in crude sunflower oil and lesser in No. 2 diesel fuel. Cloud point indicates the formation of wax crystals when oil is chilled in a glass jar.

The pour point of alkali-refined sunflower oil (-8.72°C) is higher by a factor of about six when compared with No.2 diesel fuel (-50.0°C)(Ramdeen et al. 1981). Pour point indicates the ceasing of fuel flow. The flash point indicates the thermal stability of a fuel and was recorded as 321°C for sunflower oil and 55 to 77°C for No.2 diesel (Quick 1980). A complete definition of each point will be discussed in chapter 3.

2.3.3 Boiling Point and Distillation Curve

The boiling point of vegetable oils is their initial boiling point observed during the determination of their distillation curve. Ramdeen et al. (1981) reported 321°C as being the initial boiling point of alkali-refined sunflower oil. A strong choking smell at 321°C, from condensates, indicated the chemical decomposition of sunflower oil, which led to an incomplete distillation curve. According to the results of Bruwer et al. (1980) the initial boiling point of sunflower oil was about 260°C. An examination of his curve indicates that the chemical breakdown of sunflower oil might have taken place at 275°C when about 40% of the sample was recovered. The preceeding statement was inferred and is not mentioned by Bruwer. Contrary to the results of Ramdeen et al. and Bruwer et al. in which a distillation curve remained incomplete, Quick (1980) reported 335°C as being the 90% distillation point. There can be two reasons for the difference stated above. First, because of the different oleic/linoleic acids ratio and secondly because the later researcher (Quick) did not strictly observe the ASTM method for distillation of petroleum products.

2.3.4 Calorific Value

Calorific value or the energy content is one of the most important fuel properties to be known when searching for an alternate fuel. The energy value reported by different researchers differ slightly. Ramdeen et al. (1981) determined 45.244, 42.498 MJ/kg and 39.654, 37.204 MJ/kg to be the gross and net calorific values of No. 2 diesel and alkali-refined sunflower oil respectively. Whereas Bruwer et al. (1980) reported 45.5, 42.7 MJ/kg and 39.2, 36.7 MJ/kg as being the gross and net calorific values of No. 2 diesel and crude-degummed sunflower oil respectively.

The gross calorific values (net heat + latent heat of condensation of water vapors resulting from combustion process) of 39.49, 39.38 and 39.63 MJ/kg have been found by Peterson et al. (1981), Hofman et al. (1980) and Quick (1980) respectively.

From the work done by the referenced researchers it is noted that the calorific values of sunflower oil and No. 2 diesel fuel, on a mass basis, do not differ to a great extent.

2.3.5 Cetane Number

Cetane rating, which indicates the volatility of a fuel, was found much lower at 28 to 31 in the case of sunflower oil when compared to No.2 diesel fuel at 47 to 48 (Ramdeen et al. 1981). Bruwer et al. (1980) and Quick (1980) reported 37 as being the cetane rating of sunflower oil. From these cetane ratings it can be noted that the climate in which the sunflowers are grown may effect the cetane rating of the oil produced and the ease of cold starting. Ramdeen et al. (1981) used oil produced in

North Dakota (cold climate area) whereas Burwer et al. (1980) and Quick (1980) used oil produced in South Africa and Australia respectively (warm climate areas).

2.3.6 Carbon Residue

Percent carbon residue in the case of sunflower oil (0.42%) was higher by a factor of 3 than that for No.2 diesel fuel (0.15%) (Quick 1980). Carbon residue indicates the degree of cleanliness in the combustion process.

2.3.7 Oxidation Stability

The rate of oxidation of vegetable oils is determined by the presence of oxygen, degree of unsaturation of fatty acids, light, temperature, antioxidants and prooxidants such as copper (Dorrell 1978).

Dorrell (1978)gave a peroxide value of $\leq$ 10 meq/kg of oil whereas Robertson and Morrison (1977) reported 0.21 and 0.41 meq/kg, as the peroxide value of Alabama and Minnesota sunflower oils respectively.

The degree of unsaturation of sunflower oil is superior to most of the vegetable oils (Cobia and Zimmer 1978).

Tochopherols, which are natural antioxidants in vegetable oils, are somewhat lower than soyabean oil and cotton seed oil. The total concentration of tochopherols is 636 mg/kg of sunflower oil (Dorrell 1978). The amount of copper (prooxidant) in sunflower oil has been reported up to 0.4 mg/kg of oil (Dorrell 1978).

2.3.8 Density and API Gravity

Almost all the vegetable oils are heavier than No. 2 diesel fuel. The density of sunflower oil at 15.56°C is 0.923 kg/L compared to 0.849 kg/L for No.2 diesel fuel. The comparison of the two fuels shows that the crude sunflower oil is 8% heavier than diesel fuel (Ramdeen et al. 1981; Peterson et al. 1981; Hofman et al. 1980; Quick 1980).

API gravity is an index of the fuel density or mass per unit volume. The API gravity of alkali-refined sunflower oil, observed by Ramdeen et al. (1981) at 15.6°C, is 21.77 compared to 35.12 for diesel fuel.

2.4 Engine Performance with Sunflower Oil

According to Georing (1981) and Hofman et al. (1980), over a short run, sunflower oil has shown similar engine performance characteristics as normal diesel fuel.

Quick, as quoted in an interview published in "The Sunflower" April 1980, stated that a South African has run a Mercedes Benz 240D, automatic diesel car, for 10,000 km very successfully using 100% sunflower oil as a fuel, except for starting. He further added that the higher viscosity of sunflower oil, about 10 times the viscosity of diesel fuel, led to starting troubles and injector coking which can lead to lubricating oil dilution.

H. E. Whitted, an enterprising farmer in East Bend, North Carolina, drove his International Harvester 544D tractor and Mercedes Benz 220D for 100 hours on 100% sunflower oil and sunoil-diesel fuel mixtures (Industry news 1980). Contrary to Quick's observations, Whitted found no trouble when he checked the injector pump for gumming, the combustion chamber for corrosion, fuel filters for plugging and injectors for coking. Contradiction of results found by Whitted and Quick, is probably due to the different duration of engine running time or the type of engine used (indirect or direct injection). The observations reported by Quick are considered more reliable, since other researchers have found similar results.

For example, Bruwer et al. (1980) tested 100% sunflower oil (cooking grade) on 9 different models of five different makes of tractors (Fiat, International Harvester, John Deere, Landi and Massey Ferguson). He reported that 7 tractors out of 9 were started quite satisfactory even at 0°C fuel temperature. In these trials of sunflower oil as a fuel, the maximum engine power was down by 3% while the specific fuel consumption (ml or kg/kWh) was up by 10%. Brake thermal efficiency was down by 3%. He further added that the differences noted can probably be attributed largely to the 6.5% lower energy value of sunflower oil and not to lower combustion efficiency.

Similar additional tests, using blends of sunflower oil/

diesel fuel, were conducted for 278, 1004 and 1382 of engine meter hours. At the end of 1006 engine meter hours of trouble-free operation with 20/80 blend (of sunflower oil/diesel), a loss of 8% power was measured at the PTO shaft. Incomplete combustion due to coking of injector nozzles under prolonged part load conditions, led to the contamination of lubricating oil of engines using 100% (filtered and degummed) sunflower oil and blends. The use of high quality lubricating oil and short oil change period was suggested as a means to overcome the contamination of engine crankcase oil.

Over the long run, clogging of fuel filters, fuel lines and sticking of piston rings were also observed but these were reduced to a minimum by filtering sunflower oil with a 6 micrometer particle size filter and by changing the chemical composition to methyl or ethyl esters. The esters of sunflower oil improved the atomization and it also shifted the distillation and viscosity curves close to diesel fuel.

Another important achievement of Bruwer et al. was published in "Grainews" August 1981 issue, in which Bruwer stated the completion of 2,300 tractor engine hours with pure sunflower oil. It represents the longest time any diesel engine in the world has operated on a vegetable oil. The engine used in the test was a Deutz F3L 921W equipped with an indirect type of injection system.

Without any modification to the engine, it was made to run at a constant load of 70% maximum power for 24 hours a day, six days per week for nearly five months. It was stopped only periodically to change lubricating oil and to make certain tests. After every successive thousand hours, the engine was dismantled for the inspection of abnormal wear and injector coking. There was no abnormal wear or injector coking noted. Bruwer stated that an indirect type of injection system performs better than a direct type of injection system in a diesel engine.

Almost similar results, to those of Bruwers, were found by Chancellor (1980) when he investigated 10 different vegetable oils in a single cylinder diesel engine, equipped with a precombustion chamber cylinder head. Engine performance, with sunflower oil, in terms of indicated thermal efficiency was a little better when compared with diesel fuel. Atomization, with a conventional diesel injection nozzle, was superior to most of the vegetable oils but inferior to diesel. These results indicate that the precombustion chamber engine design may have been an important factor in obtaining good performance with vegetable oils.

Some evaluation tests using sunflower oil/diesel blends in a 6 cylinder 6571 cm^3 engine were conducted by Hofman et al. (1980) at North Dakota State University, U.S.A. The engine operated on all fuel mixtures and maintained almost full rated (100 kW) PTO power, except for 75% sunflower oil and 25% No.2 diesel fuel mixture, when a slight drop in the power was observed. Hofman stated that the reason for this drop may be the high viscosity of sunflower oil, which slows the flow through filter and fuel lines.

Similar results, as observed by Hofman et al. (1980), were also noted by Paul Nixon at Iowa State University. He tested 100% sunflower oil and sunflower oil-diesel mixtures in a John Deere 4020 tractor for about 10 minutes duration (Industry News 1980; Goodier et al. 1980). According to G. E. Pratt (from North Dakota State University) a farmer in U.S.A. ran his tractor on 100% sunflower oil during planting, then later during the summer he disassembled the engine twice to get it running properly on diesel fuel (Industry news 1980).

Engine tests conducted by Peterson et al. (1981) using 100% sunflower oil and blends in a 4 cylinder diesel engine indicate that the fuel consumption, power output and thermal efficiency over the short run were nearly identical to diesel fuel. The engine running at 50/50 sunflower oil/diesel fuel blend covered more than 90 engine meter hours and no trouble was reported.

Short term tests conducted with crude degummed sunflower oil in an International Harvester 284D (3 cylinder, indirect injection) indicated that the power output, torque and brake thermal efficiency were close to diesel fuel. Fuel consumption was higher by 11% (on volume basis), partly because of the lower heat energy of the oil, lower by 5% for sunflower oil (Quick 1980). The same problems and solutions, as discussed by Bruwer et al., in the use of sunflower oil as a fuel, have also been reported by Quick (1980).

A comprehensive test, regarding the affect of sunflower oil on a diesel fuel system, was made by Schunk and Kucera in 1981 at North Dakota State University, Fargo. Using different percentages of sunflower oil with diesel, at various temperatures they concluded:

(1) The volume of fuel delivered by the injection system decreased as the percentage of sunflower oil in the blends increased or the temperature of blends increased.

(2) Line pressure to the injectors increased as the fuel temperature decreased or the percentage of sunflower oil in the blends increased.

(3) Transfer pump pressures were higher at low fuel temperatures and high sunflower oil percentages.

Several other Universities and private companies in the United States are presently engaged in the investigation of vegetable oils including sunflower oil as a fuel. Their results have not yet been published but most of them have discussed the viscosity related problems.

Chapter 3

EQUIPMENT AND TEST PROCEDURES

Important fuel related physical properties of sunflower oil were determined by using the ASTM (American Society for Testing and Materials) standard methods specified for diesel fuel. These methods were observed in order to compare the properties of alternate fuel (sunflower oil) with standard fuel (No.2 diesel).

3.1 Kinematic Viscosity with Temperature Variation

3.1.1 Definition

The viscosity of a liquid is a measure of the internal friction of the liquid in motion. Viscosity can be dynamic, kinematic, saybolt universal or saybolt furol. For fuels, kinematic and saybolt universal viscosities are most commonly measured. The units of measurement are pascal second, mm^2/s and seconds respectively.

3.1.2 Summary of Method

Since the laboratory was not equipped with an apparatus which can directly measure the kinematic viscosity, a two step viscosity determination method was followed. For temperatures higher than 20°C (70°F), the saybolt viscosity was determined by using a Saybolt Universal Viscometer. The efflux time in seconds for a 60 ml sample to flow through a calibrated orifice was measured under carefully controlled conditions. For temperatures lower than 20°C (70°F) dynamic viscosity was measured using a Brookfield Synchro-Lectric viscometer. The dynamic viscosity and saybolt universal viscosity were converted into kinematic viscosity.

3.1.3. Apparatus

A. For Temperatures Higher Than 20°C

Saybolt viscometer, withdrawal tube, thermometers, thermometer support, filter funnel, receiving flask (60 ml), and a timer reading to tenths of a second.

B. For Temperatures Lower Than 20°C

Brookfield viscometer, stainless steel spindles, v-shaped stand with levelling screws and slider, 1000 ml glass beaker, temperature lowering means, and thermometers.

3.1.4 Test Procedures

3.1.4.1 Procedure A

A Saybolt viscometer was placed in a draft free room. After cleaning the viscometer with gasoline it was dried with pressurized air. A view of the Saybolt viscometer, along with its accessories, is shown in Figure 3.1. A cork stopper, having a cord attached for easy removal, was inserted into the air chamber at the bottom of the viscometer in order to prevent the escape

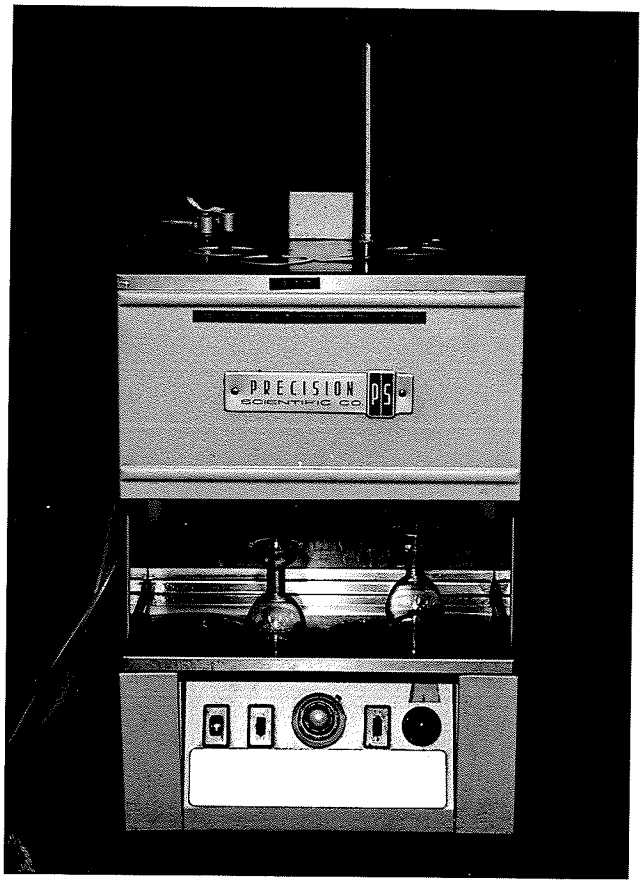


Figure 3.1. Saybolt Universal Viscometer for viscosities above 20°C

of air. Sunflower oil was filtered through a 100-mesh filtering funnel into the viscometer until the level was above the overflow rim. The sample was stirred until its temperature remained constant within 0.25°C (0.5°F) of the test temperature during one minute of continuous stirring. The thermometer was held in the sample for the stirring interval by the thermometer support. The temperature was recorded and the thermometer was then taken out from the sample. Extra oil in the gallery was removed quickly, to maintain the oil level below the overflow rim. This was accomplished by placing the tip of the withdrawal tube at one point in the gallery and applying suction. A 60 ml receiving flask was placed under the air chamber in such a way that the stream of oil impinged on the neck of the flask only. The cork was snapped from the viscometer by means of its attached cord and at the same instant the timer was started. When the bottom of the meniscus reached the 60 ml mark, on the receiving flask, the timer was stopped and the efflux time in seconds was recorded as the saybolt universal viscosity. The oil in the receiving flask was again poured into the viscometer and heated for the next temperature setting. The above procedure was repeated for every new temperature reading. The saybolt universal viscosity at different temperatures was converted into saybolt viscosity at 37.78°C (100°F), by using the following relationship:

$$\mathrm{SUS}(37.78^\circ\mathrm{C}) = \mathrm{SUS}(t^\circ\mathrm{C})/(1 + 0.00006(37.78 - t))$$

where:

SUS(37.78°C) = Saybolt universal viscosity in seconds at reference temperature of 37.78°C

SUS(t°C) = Saybolt universal viscosity in seconds at t°C

The saybolt viscosity value, obtained from the above equation, was used in the table provided by ASTM to obtain equivalent kinematic viscosity at t°C.

3.1.4.2 Procedure B

For temperatures lower than 20°C (70°F) a Brookfield viscometer was used. The Brookfield viscometer with its accessories is shown in Figure 3.2. An 800 ml sample of sunflower oil was placed in a 1000 ml beaker. A practice of selecting larger disc spindles for higher temperatures and smaller disc spindles for lower temperatures was used to select appropriate spindle sizes. The viscometer was mounted on its v-shaped stand and levelled by adjusting the three levelling screws.

The selected spindle and guard were attached to the viscometer, mounted on its stand. An 800 ml sample of sunflower oil was then placed under the spindle and guard. The viscometer with spindle and guard was lowered into the sample by means of the slider adjustment provided on the stand. The slider was arrested when the spindle had reached the immersion

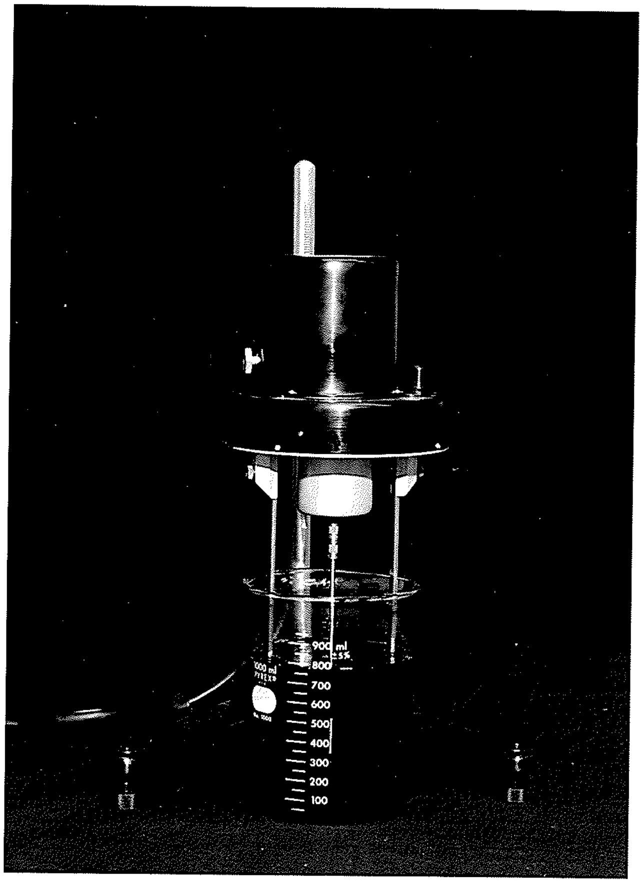


Figure 3.2. Brookfield Synchro-Lectric Viscometer

point. The viscometer motor switch was then turned on, which started the spindle rotating in the sample and caused a deflection of the pointer on the readout dial. A spindle speed of 20 rpm was selected to obtain pointer stabilization within a minimum time. When the pointer position became stable the pointer clutch was disengaged and the motor was stopped. The reading shown by the pointer and the oil temperature, were simultaneously and instantly recorded.

The oil sample was cooled down in a temperature control cabinet available in the Department of Agricultural Engineering to determine viscosities at selected lower temperatures. The pointer readings were recorded for various temperatures following the above procedure. Each reading was then multiplied by a factor, indicated by the spindle number and speed, to obtain the dynamic viscosity. Readings at lower temperatures were taken after 12 hours of continuous cooling and heating for a set temperature to attain accuracy.

Dynamic viscosity was converted into kinematic viscosity by the relationship below:

$$\text{kinematic viscosity} = \frac{\text{dynamic viscosity}}{\text{density of sample}}$$

3.2 Cloud and Pour Points

3.2.1 Definitions

(a) Cloud point: The cloud point of sunflower oil is the temperature at which paraffin wax or other solid substances begin to crystalize out or separate from the oil when chilled under definite prescribed conditions.

(b) Pour point: It is the lowest temperature at which an oil will pour or flow when it is chilled without disturbances under definite prescribed conditions.

3.2.2 Apparatus

Glass jars, thermometers having -40 to 50°C range, cork, cooling bath, jacket, disc and gasket.

3.2.3 Procedure for Cloud Point

Sunflower oil was filtered through a dry lintless filter paper at a room temperature of about 20°C. This filtration was completed to remove any moisture present in the sunflower oil. Clean and clear oil was then poured into the test jar to the level mark and closed by a cork carrying a thermometer. The thermometer and jar were in a coaxial position and the thermometer bulb was set a little above the bottom of the test jar. The jar was then placed in a cooling bath equipped with its accessories and at a temperature -1 to +2°C (30 to 35°F). The test jar in the cooling bath is shown in Figure 3.3. At each temperature

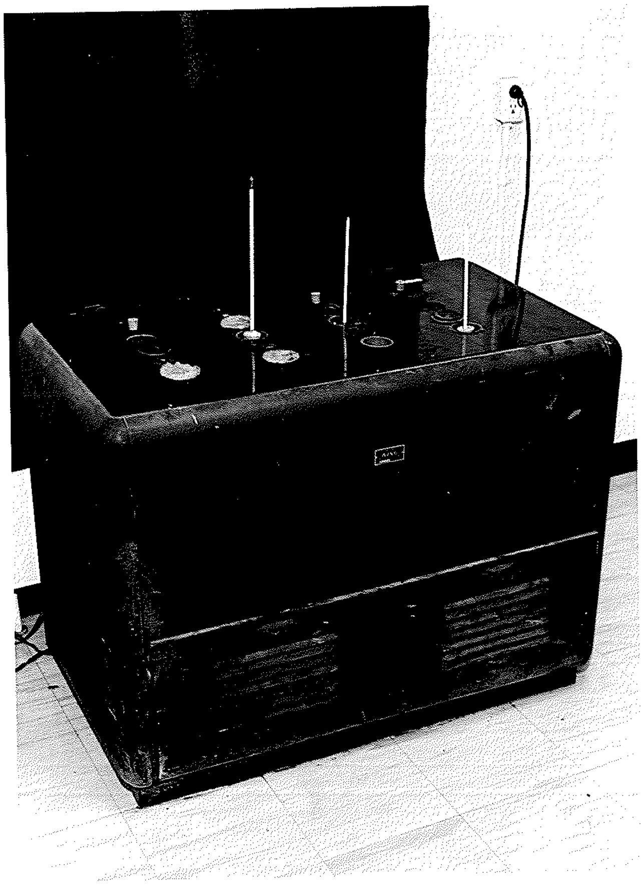


Figure 3.3. Apparatus for Cloud and Pour points.

decrease of 1.0°C (2.0°F), the test jar was removed for about 5 seconds from the bath for haze inspection. After inspection the jar was again placed in the bath. When the oil did not show cloud when it had chilled to 10°C (50°F), the test jar was transferred to the second bath maintained at a temperature of -18 to -15°C (0 to 5°F). Again at every thermometer reading that was a decrease of 1°C, cloud was inspected but no haze or wax was observed up to -7°C (20°F). The test jar was then placed in the third bath maintained at -34 to -32°C (-30 to -25°F). Inspection for the cloud point continued for every predetermined thermometer reading until the sample showed haze at the bottom of the jar. The temperature at which oil first showed wax formation was recorded as the cloud point of sunflower oil.

3.2.4 Procedure for Pour Point

A sample of crude sunflower oil was poured into the test jar to the level mark. The test jar was closed by a cork, carrying a test thermometer in a vertical position in the centre of the jar. The position of the thermometer's mercury bulb was adjusted so that the beginning of the capillary was about 3 mm (0.125 in) below the surface of the oil. A sectional view of the test apparatus is shown in Figure 3.4.

The oil in the test jar was heated without stirring to 46°C (115°F). The oil sample was then cooled to 35°C (90°F) in air. The test jar with thermometer was placed in a cooling bath,

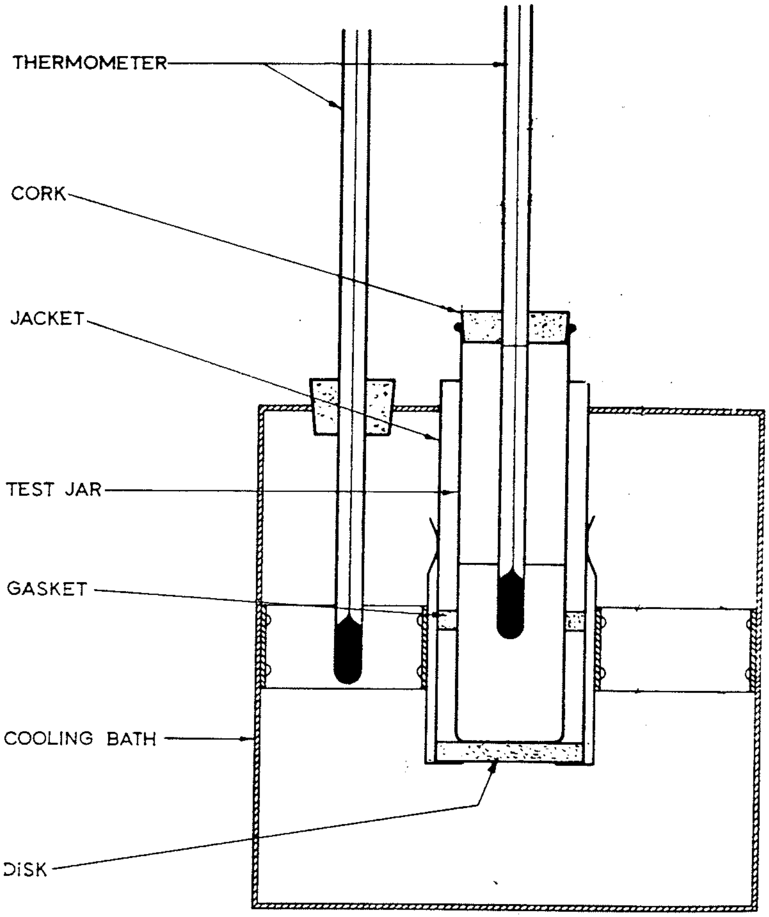


Figure 3.4. A sectional view of the Cloud and Pour points apparatus.

maintained at -1 to +2°C (30 to 35°F). Commencing at a temperature of 11°C (20°F) above the expected pour point and while cooling, the jar was tilted enough to ascertain whether there was a movement of the oil at each thermometer reading that was a multiple of 3°C (5°F). When the oil did not cease to flow, when its temperature was 10°C (50°F), it was transfered to the second bath maintained at -18 to -15°C (0 to +5°F). The oil sample was again inspected at every thermometer reading that was a multiple of 3°C. Again the oil did not cease to flow when it had cooled down to -7°C (20°F). The test jar was then transfered to the third bath maintained at -32 to -34°C (-30 to -25°F). Following the above procedure, the oil was checked for flow until it did not flow when the jar was tilted horizontally for about 5 seconds. At the instant oil ceased to flow the thermometer reading was recorded as the pour point of sunflower oil.

3.3 Flash Point

3.3.1 Definition

The flash point is the temperature at which the volatile products are evolved at such a rate that they are capable of being ignited but not of supporting combustion.

3.3.2 Apparatus

Pensky-Martens closed flash tester, heater and thermometer.

3.3.3 Procedure

The flash tester was placed on a steady table in a room free from draft. The flash cup was cleaned thoroughly before filling it with sunflower oil. A sample of oil was then placed in the flash cup. The size of the sample is determined by the level mark on the interior side of the cup. After locking the lid on the cup, it was set in the stove, having special arrangements for the cup. A thermometer for measuring flash point was inserted into the cup in such a way that it should not strike against the stirrer. After lighting the test flame its size was adjusted to about 4 mm (5/32 in) diameter. Sample heating, with the stirrer in operation, was initiated. The rate of heating was controlled to attain 5 to 6°C (9 to 11°F) per minute. After every 1°C (2°F) increase in temperature, the test flame was applied by operating the mechanism as shown in Figure 3.5. The stirrer was stopped while testing for the flash point. This procedure continued until the test flame application caused a distinct flash in the interior of the cup. At the instant a flash was observed the thermometer reading was recorded as the flash point of sunflower oil.

3.4 Distillation and Boiling Point

3.4.1 Definitions

(a) Initial boiling point: The thermometer reading that is observed at the instant the first drop of condensate

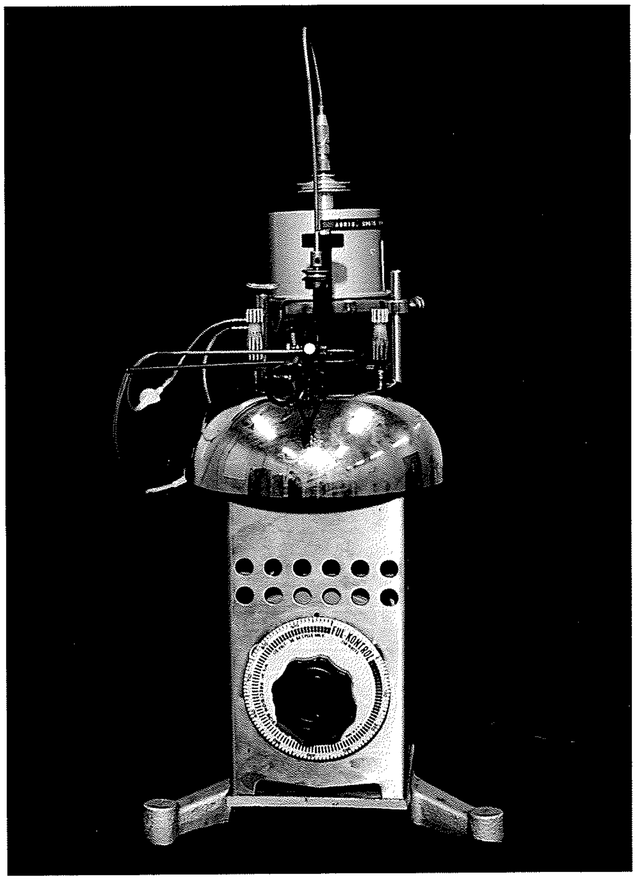


Figure 3.5. Pensky-Martens closed Flash point Tester.

falls from the lower end of the condenser tube.

(b) Decomposition point: The thermometer reading that coincides with the first indication of thermal decomposition of the liquid in the flask. Thermal decomposition is indicated by an evolution of fumes and an erratic thermometer reading.

(c) Final boiling point: This is the maximum thermometer reading obtained during the test. This usually occurs after the evaporation of all liquid from the bottom of the flask. The term maximum temperature is a frequently used synonym.

3.4.2 Apparatus

120 ml flask, condenser, cooling bath, heater, flask support, graduated cylinder of 100 ml capacity, thermometer and crushed ice.

3.4.3 Procedure

The condenser bath was filled with chopped ice and water. The condenser tube was cleaned by swabing with a piece of soft lint-free cloth attached to a copper wire. A 100 ml sample of crude sunflower oil was carefully poured into the distilling flask. This flask was then tightly closed with a cork carrying a 405°C (760°F) thermometer. The position of the cork was adjusted so that the bulb of the thermometer was coaxial with the neck of the flask and the lower end of capillary was levelled with the highest point on the bottom of the inner wall of the vapor tube. The apparatus is shown in Figure 3.6.

The flask with charge was then placed on its support over an electric heater. A tight connection between the flask's vapor tube and the condenser tube was made with the help of a cork and grease. A 100 ml graduated cylinder was placed under the lower end of the condenser tube so that the condenser tube extended about 25 mm (1 in) into the cylinder which was carefully covered with a piece of circular hard board. Heat was applied to the distillation flask and was regulated so that the first drop of condensate fell from the condenser tube within 10 minutes of heating. At the same instant the reading of the thermometer was recorded as the initial boiling point. Heat application was again regulated to obtain condensate at a rate of 4.0 ml/min. At about 316°C (600°F) only 10 ml of darkened distillate was condensed along with heavy dense-white fumes which produced a very irritating odor. This heavy smoking and discoloration of sample was indicative of the thermal cracking and decomposition of fatty acids which resulted in darkening of the distillate. At this point distillation was discontinued which was considered to be at a premature stage according to ASTM regulations. The ASTM method to obtain the distillation curve for sunflower oil during the later stage of its distillation was not observed.

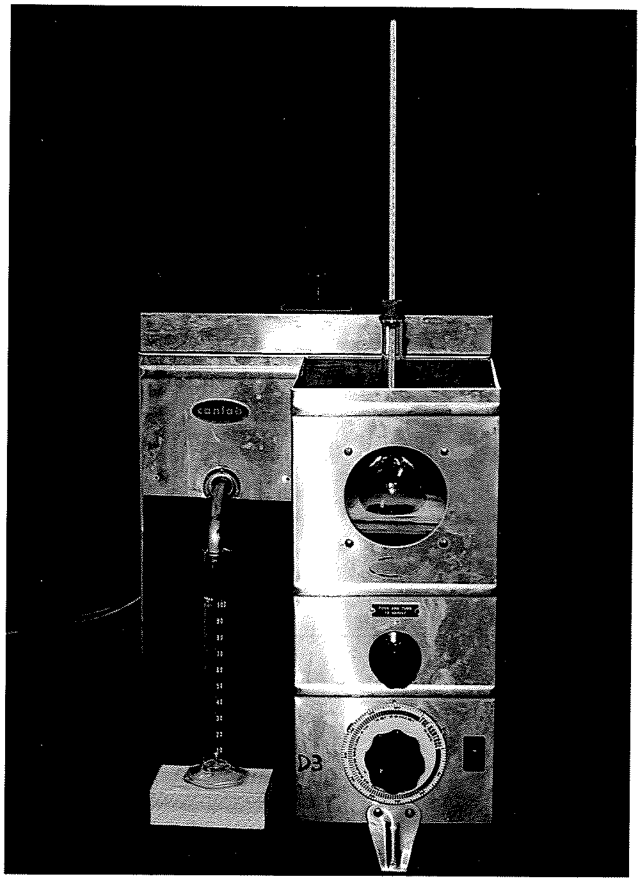


Figure 3.6. An ASTM distillation apparatus for Petroleum fuels.

3.5 Heat of Combustion

3.5.1 Definitions

(a) Gross heat of combustion

This is the heat released by the combustion of a unit mass of fuel in a constant volume bomb with substantially all of the water condensed to the liquid state. It is expressed in kJ/kg or MJ/kg. It is also called the higher heat energy value of the fuel.

(b) Net heat of combustion

This is the heat released by the combustion of a unit mass of fuel at constant pressure of 0.1 MPa (1 atm) with the water remaining in the vapor state and is obtained by calculation.

(c) Energy equivalent

It is the amount of energy required by the calorimeter to raise the temperature of water 1.0 degree, expressed as joules per degree Celsius (J/°C).

3.5.2 Apparatus

Oxygen bomb, calorimeter, jacket, thermometer in the fraction of °C graduation, standard alkali solution of 0.0725 N, benzoic acid, methyl orange indicator, oxygen cylinder and timer in fractions of a second.

3.5.3 Standardization of Colorimeter

The calorimeter with all its parts is shown in Figure 3.7. Two thousand millilitres of distilled water was placed in the oval bucket. A 10 cm long nickel alloy fuse wire was used to connect the two electrodes for ignition purposes. A standard benzoic acid pellet was used for standardization. Initially an empty steel capsule was weighed on the balance and then reweighed with a benzoic acid pellet. This capsule was placed on a support made by the electrodes and the fuse wire was adjusted so that it just touched the sample. One millilitre of distilled water was added to the bomb with a pipette. The bomb was then closed and tightened by hand. Oxygen was added to the bomb until the pressure in the bomb rose to 2,533 kPa (25 atm). After connecting the electric terminals with electrodes the charged bomb was lowered into the bucket with water and the calorimeter was closed by placing its cover in position. The stirrer belt was placed on the driving motor. A thermometer accurate to 2 decimal places was lowered into the bucket water to sense temperature change. A magnifying glass and vibrator were used to read the thermometer accurately. After making all electrical connections the stirrer and timer were turned on simultaneously. Before starting, the water temperature was recorded and then later on it was recorded after one minute intervals. This process continued for about 5 minutes or until temperature rise ceased. At the instant the temperature rise stopped the ignition unit button was pressed to

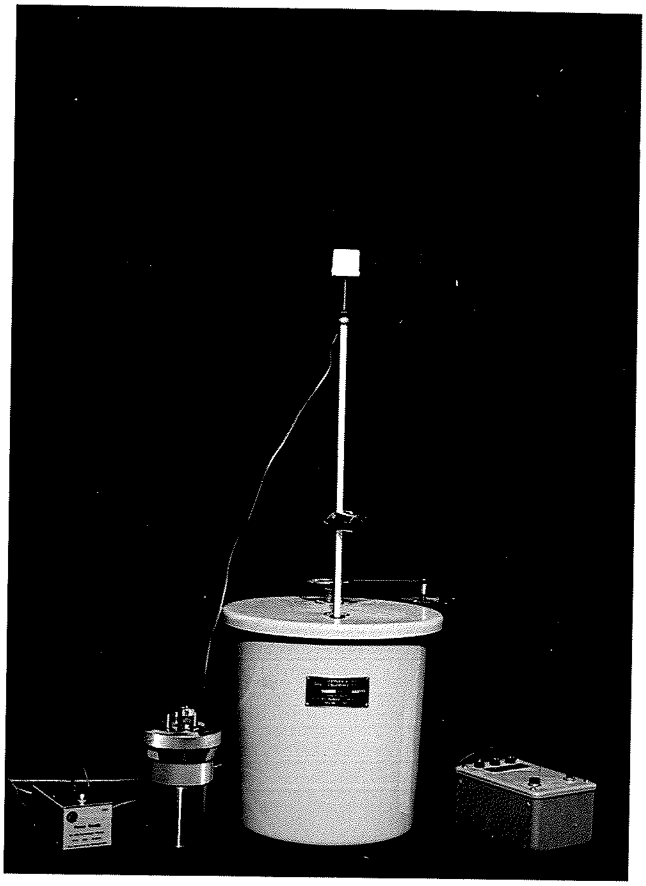


Figure 3.7. Oxygen Bomb Calorimeter to determine Heat of Combustion.

ignite the nickel wire, which ignited the benzoic acid pellet. The heat released was taken up by the bucket water which was indicated by the temperature rise. Due to the rapid increase in temperature during the first 2 minutes, temperature readings were taken after every 15 seconds. Later, temperature readings were taken after one minute intervals. When the temperature stopped rising, temperature reading and time were recorded. Recording of temperature continued for an additional 5 minutes after the temperature rise had stopped. At this stage the stirrer was stopped and the calorimeter cover was removed. The oxygen bomb was taken out and the gases inside were released by opening the safety valve on the bomb head. When all the gases had escaped, the bomb head was unscrewed and the electrodes and the interior of the bomb was washed with a jet of distilled water into a beaker. The length of unburnt wire was carefully measured and noted. About 2 to 3 drops of methyl orange indicator were added to the washings from the bomb. These washings were then titrated against a 0.0725 N sodium carbonate solution, to find the volume of nitric acid formed. A graph of time and temperature, as shown in Appendix C, was drawn to get time at 60% temperature rise. Time and temperature readings were then used to calculate the exact temperature rise by the following equation:

$$t = tc - ta - r_1 (b - a) - r_2 (c - b)$$

where:

t = correct temperature rise (°C)

tc = thermometer reading when temperature stopped rising after ignition

ta = thermometer reading when charge was fired

a = time of firing

b = time at 60% temperature rise

c = time when temperature stopped rising

r_1 = rate of temperature rising during the first 5 minutes

r_2 = rate of temperature change during last 5 minutes

The energy equivalent factor W was then calculated as follows:

$$W = \frac{Hm + e_1 + e_3}{t}$$

where:

W = energy equivalent factor in joule/°C (cal/°C)

H = heat of combustion of standard benzoic acid 26.454 kJ/g (6318 cal/g)

m = mass of standard benzoic acid used (g)

t = corrected temperature rise (°C)

e_1 = correction for heat of formation of nitric acid (J)

e_3 = correction for heat of combustion of the firing wire (J)

3.5.4 Procedure for Heat of Combustion

The procedure for this section is the same as discussed in Section 3.6.3. For this section m, in the above equation, is changed to represent the mass of sunflower oil sample. The following equation was used to calculate the gross calorific value:

$$Hg = (w \times t - e_1 - e_2 - e_3)/m$$

where:

Hg = gross heat of combustion, MJ/kg (cal/g)

w, t, e_1 and e_3 stand for the same as above

e_2 = correction for heat of formation of H_2SO_4

= (14 x percentage of sulfur in sunflower oil x m), J

e_2 was considered equal to zero in the case of sunflower oil because of an undetectable content of sulfur in sunflower oil.

3.6 Density and API Gravity

3.6.1 Definitions

(a) Density

This is the mass of liquid per unit of its volume at 15.56°C. In SI units it is represented by kilograms per litre (kg/L).

(b) API Gravity

The gravity of a liquid fuel is usually expressed in degree API, a scale designed by the American Petroleum Institute. It is measured in degrees and is represented by the following relation:

$$\text{API gravity degree} = \frac{141.5}{\text{sp.gr. } (15.56/15.56\ ^\circ\text{C})} - 131.5$$

No statement of reference temperature is required since 15.56°C is included in the definition.

3.6.2 Apparatus

Glass hydrometers graduated in API units, thermometers and a 1000 ml cylinder.

3.6.3 Procedure

A 1000 ml sample of crude sunflower oil was transferred to a clean, dried hydrometer cylinder. Due to the viscous nature of sunflower oil a lot of air bubbles came over the surface and these were removed by wiping with kleenex tissue. The reference temperature for the cylinder containing the hydrometer and oil sample was obtained by cooling in an incubator until the temperature of 15.56°C was reached. The temperature was read with the help of a thermometer, graduated in fractions of °C. The reference temperature reading was taken after stirring the sample vigorously with a thermometer. The hydrometer was depressed about 2 scale divisions into the oil sample and then released promptly. When the hydrometer was at rest and away from the walls of the cylinder it was read for API gravity. To observe the hydrometer reading accurately, the eye was placed slightly below the level of oil and then raised gradually until the surface, first seen as a distorted ellipse, appeared as a straight line cutting the hydrometer scale. The hydrometer and its cylinder are shown in Figure 3.8. To determine density the reading taken at 15.56°C was substituted in the equation discussed in the definitions. Some hydrometer readings lower and higher than the reference temperature (15.56°C) were also taken. API gravity at 15.56°C was then checked by drawing a graph of lower and higher readings.

3.7 Other Fuel Related Properties

It was not possible to determine all fuel related parameters of sunflower oil in the Department of Agricultural Engineering because of the unavailability of fuel testing equipment. A sample of crude-degummed sunflower oil was sent to the Alberta Research Council to obtain the cetane number, oxidation stability and some additional properties. A summary of the methods used to determine fuel related properties, which could not be completed in the department, are given in Appendix B. Parameters determined by the Alberta Research Council, Edmonton, are discussed in the results and discussion section, Chapter 4.

3.8 Transesterification of Sunflower Oil

The methyl ester of sunflower oil was prepared by transesterification of sunflower oil, in the Department of Chemistry, University of Manitoba, Winnipeg. The procedure and techniques

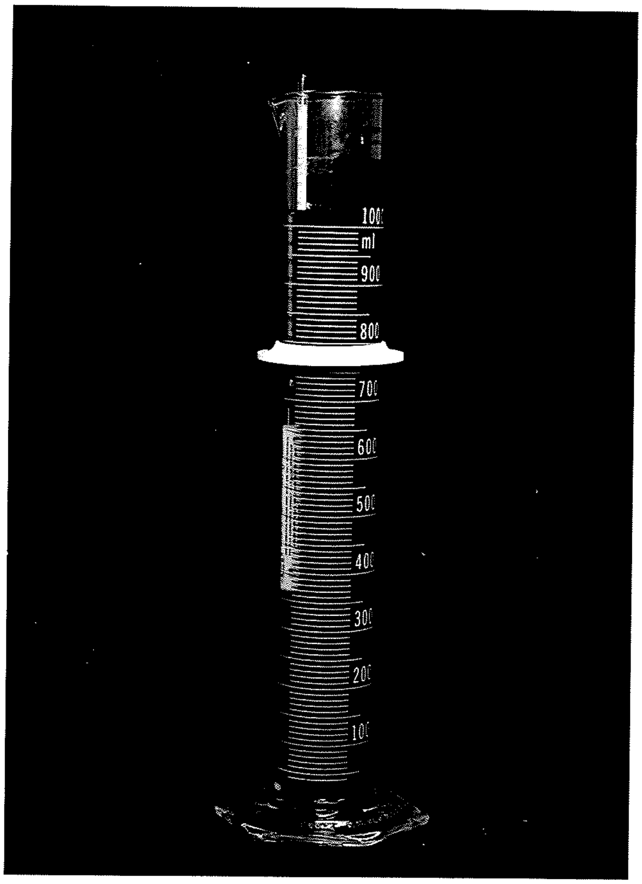


Figure 3.8. Hydrometer to measure API gravity and Density of a fuel.

followed in preparing methyl ester are described in Appendix B. Methyl ester was prepared on a small scale volume of about three hundred millilitres to examine fuel related properties. The same ASTM test procedures as those used for sunflower oil were followed to determine the physical properties of the methyl ester. The properties obtained for the methyl ester of sunflower oil are presented in the results and discussion section, Chapter 4.

3.9 Affects of Sunflower oil on Diesel Fuel Systems

Many problems may develop in the engine fuel system due to the higher viscosity of sunflower oil. The affects of sunflower oil on an engine fuel system were examined by using the following test equipment.

3.9.1 Apparatus

A nozzle tester, injection nozzle (conforming to the Buda engine specifications), fuel filter (glass type), vacuum gage, pressure gage, plastic tubing and fuel buckets.

3.9.2 System layout

A nozzle testing apparatus, donated by Powell Equipment in Winnipeg, was cleaned and modified for testing sunflower oil. The modifications effected were basically to achieve a closed circuit cycle. A metalic pipe was replaced by plastic tubing between fuel tank and fuel pump. A glass type fuel filter was introduced into the fuel line immediately after a check valve, in the line leading from the fuel tank. A vacuum gage was placed between the fuel filter and fuel pump to indicate vacuum which may develop due to filter blockage. A dampening valve and pressure gage were installed in the line on the pressure delivery side of the pump to indicate the line pressure or the nozzle valve opening pressure. An injector nozzle conforming to the Buda engine specifications was connected to the outflow pipe from the pump. The opening pressure of the nozzle was set at 1,000 kPa (1450 Psi) and no later resetting adjustment was made. A plastic tube was connected to the nozzle to confine and facilitate the collection of fuel, discharged from the nozzle. The modified apparatus is shown in Figure 3.9.

3.9.3 Test procedure

The fuel tank was filled with No. 2 diesel fuel to obtain control data on the operation of the fuel system. The motor was then turned on to circulate the fuel through the system. Air was removed from the system by opening the air bleed valve on the side of the pump. When all of the air was purged from the system and steady operation achieved, the apparatus was ready for testing. The fuel collecting bucket was placed under the discharge line and at this instant time was recorded. After six hours the first bucket was replaced by a second and the mass of the fuel discharged

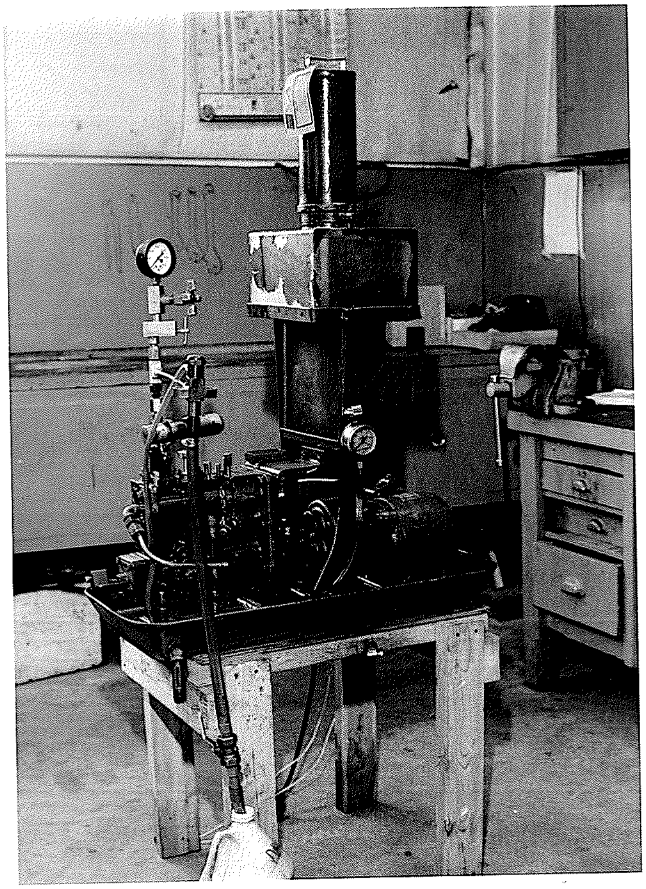


Figure 3.9. A Test Bench to examine the affects of sunflower oil on diesel fuel systems.

in the first was determined by an electronic balance accurate to one gram. During the six hour interval, both vacuum and pressure gages were read from time to time. The system was operated for about 34 hours using diesel fuel and then it was switched to sunflower oil. Diesel fuel was completely removed from the system. After refuelling the system with sunflower oil the above procedure was repeated for 210 hours.

3.10 Testing Sunflower Oil as an Alternate Fuel in a Diesel Engine

3.10.1 Definitions

(a) Torque

Torque is the product of the length of a pivot arm and a force acting perpendicularly at the free end of that arm. In SI units its dimension is expressed in Newton-meters (N.m).

(b) Power

Power is defined as the rate of doing work. In SI units it is measured in watts (W) or kilowatts (kW).

(c) Specific fuel consumption

Specific fuel consumption is expressed as the amount of fuel consumed by an engine per hour to develop one kilowatt of power. Its units of measurement are kilograms per kilowatt-hour (kg/kW.h).

(d) Thermal efficiency

Thermal efficiency or the engine fuel efficiency is defined as a ratio of the engine power output to the fuel-energy consumption per hour.

3.10.2 Test equipment

Limited engine tests were conducted to evaluate the performance characteristics of sunflower oil as a fuel. Equipment and material used to perform these tests are listed below.

Buda diesel engine, generator used as a dynamometer, electrical resistances and heater, tachometer, timer, temperature, gage, spring balance, thermocouples and multivoltmeter.

Engine and generator specifications are given in Table 3.1.

3.10.3 Equipment layout

A used single cylinder "Buda" diesel engine was restored for testing purposes. The engine was equipped with a precombustion chamber and a centrifugal type governor. A 4 kW generator available in the department of Agricultural Engineering was modified to act as an electric dynamometer. This was done by placing the generator in a cradle, which was then mounted on ball bearings, resting on a frame. A torque arm of about 0.4 m was attached in the centre of the cradle, which was free to rotate.

The cradle was balanced along the central axis, under no-load conditions, by putting some counter mass units on the opposite side of the torque arm. A container was used to hold the simple mass units to balance the cradle under loaded conditions. A pointer opposite to the torque arm was used to indicate the exact amount of mass needed to counteract the torque caused

Table 3.1

Specifications of engine, generator and electrical resistances.

1. Engine

Make	Buda
Engine type	4 cycle, vertical diesel
No. of cylinders	one
Bore X Stroke cm (in)	8.73 x 8.73 (3 7/16 x 3 7/16)
Maximum Power	7.5 kW (10 hp)
Combustion System	precombustion chamber
Lubrication System	splash
Cooling System	water cooled

2. Generator (used as a dynamometer)

Maximum voltage output	230 V (at 3600 rpm)
Maximum current	34 A " "
Frequency	60 Hz " "
Power	4 kW

3. Electrical resistances

Rated load of 5 resistances	330 x 3 and 660 x 2
Calrod heater	one (2000 W)

by electrical loads. A view of the system is shown in Figure 3.10. The generator was coupled to the engine with two "A" type v-belts. The speed ratio of engine to generator was about 2.68. The engine was loaded by switching on selected electrical resistances in the generator circuit. The electrical resistances were connected parallel to each other in-order to avoid malfunctions of the system because of voltage changes.

3.10.4 Procedure to determine performance characteristics of sunflower oil

Power output and specific fuel consumption of crude-degummed sunflower oil and No.2 diesel fuel were determined by operating a Buda diesel engine. Since the engine was very old and a complete complement of equipment was not available in the department to test a small engine, a procedure was developed to make a comparison of certain fuel and engine related parameters using diesel and crude-degummed sunflower oil. At the initiation of the fuel performance tests, two fuel containers were filled with diesel fuel and sunflower oil respectively. The engine was operated on diesel fuel first to obtain control data on fuel performance characteristics. The engine was allowed to warm up until the engine temperatures had stabilized before any fuel test was performed. The engine clutch was then engaged to operate the generator and three electrical resistances were switched into the circuit. The engine governor was adjusted by a manually operated

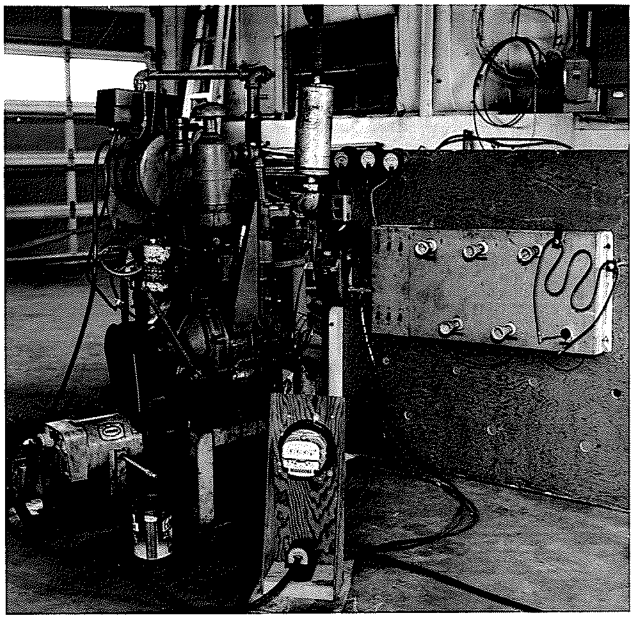


Figure 3.10. Buda diesel engine with a generator and loading system for fuel performance test.

governor control lever to allow the engine to run at approximately 1000 rpm. Due to torque from the load on the generator its frame tended to rotate around its armature in the direction of the engine's crankshaft rotation. This rotation was restrained by hanging a container with known mass on the torque arm. The mass was adjusted by adding or removing increments of mass from the container to attain the reference position of the torque arm. The engine speed was determined by using a counter-type tachometer and a timer. The speed and mass were then used to calculate torque and power. For the second setting, five electrical resistances were switched on and again the governor was adjusted to obtain a selected speed. Due to the increased load on the generator an increased mass was required to balance the torque arm. After the second governor setting no electrical resistance was added. Further load and speed changes were achieved by adjusting the governor setting until the engine attained the highest-underload speed. At this stage, the test was discontinued because the engine could not be speeded up. Every test, at all governor settings, was continued for one hour, during this time the engine speed was checked intermittently. At the end of every one hour interval fuel consumption was measured in grams by means of a spring balance. The same procedure was followed for sunflower oil and no modification was made to the equipment except that a fuel transfer pump was added in the fuel system to facilitate the flow of sunflower oil through the filters.

After testing both fuels (No. 2 diesel and sunflower oil) a test for maximum power was conducted by using diesel fuel. The engine throttle was set at the wide-open position to attain the highest-no-load speed possible. After locking the throttle-position the engine was allowed to warm up under no-load conditions until the engine temperatures stabilized. Enough load was then applied to cause the engine speed to reduce. The load was gradually increased until the engine began smoking and tended to stall. The engine speed and mass required to balance the torque arm for each load setting were noted. After calculating the power, a curve between engine speed and power output was drawn to determine the maximum power developed by the Buda engine.

Chapter 4

RESULTS AND DISCUSSION

4.1 Physical Properties of Sunflower Oil and its Methyl Ester

4.1.1 Kinematic viscosity

The kinematic viscosity of crude-degummed sunflower oil was determined over a temperature range of -15.5 to 100°C (4 to 212°F) while the kinematic viscosity of the methyl ester of sunflower oil was determined over a temperature range of 1.0 to 70°C (34 to 158°F). The kinematic viscosity of the methyl ester, below 21.0°C was determined by the Industrial Technology Centre, Winnipeg. A summary of the viscosity results at selected temperatures is given in Tables 4.1a and 4.1b, and they are plotted in Figure 4.1. The raw data is presented in Appendix C under the kinematic viscosity of sunflower oil and its methyl ester.

The viscosity of a fuel plays an important role in the performance of an engine fuel system operating through a wide temperature range. It was desired to compare the viscosity of crude-degummed sunflower oil and its methyl ester with the viscosity of No.2 diesel fuel. At 37.78°C (100°F), the specified temperature for an ASTM viscosity test for diesel fuel, sunflower oil (33.45 mm^2/s) was found to be 14 times more viscous that No. 2 diesel fuel (2.40 mm^2/s). The viscosity (5.2 mm^2/s) of the methyl ester of sunflower oil was found to be about twice that of diesel fuel. At

Table 4.1(a)

Kinematic viscosity of crude-degummed sunflower oil at selected temperatures.

Temperature		Kinematic viscosity
°C	°F	mm^2/s
-5.56	22	271
-4.44	24	207
-0.56	31	159
10.00	50	100
21.11	70	63.8
32.20	90	40.9
42.20	108	29.77
54.44	130	20.57
65.56	150	15.50
76.70	170	12.20
87.80	190	9.76
98.90	210	7.95

Table 4.1(b)

Kinematic viscosity of methyl ester of sunflower oil at selected temperatures.

Temperature		Kinematic viscosity
°C	°F	mm^2/s
1.3	34.3	19.66
7.2	45.0	17.56
13.7	56.7	14.70
20.3	68.5	13.74
*25.7	78.0	8.90
35.7	96.0	7.0
40.0	104.0	5.20
70.0	158.0	2.80

*The kinematic viscosity values of temperatures below 25.7°C were determined by the Industrial Technology Centre, Winnipeg, with an "RVF" Brookfield viscometer.

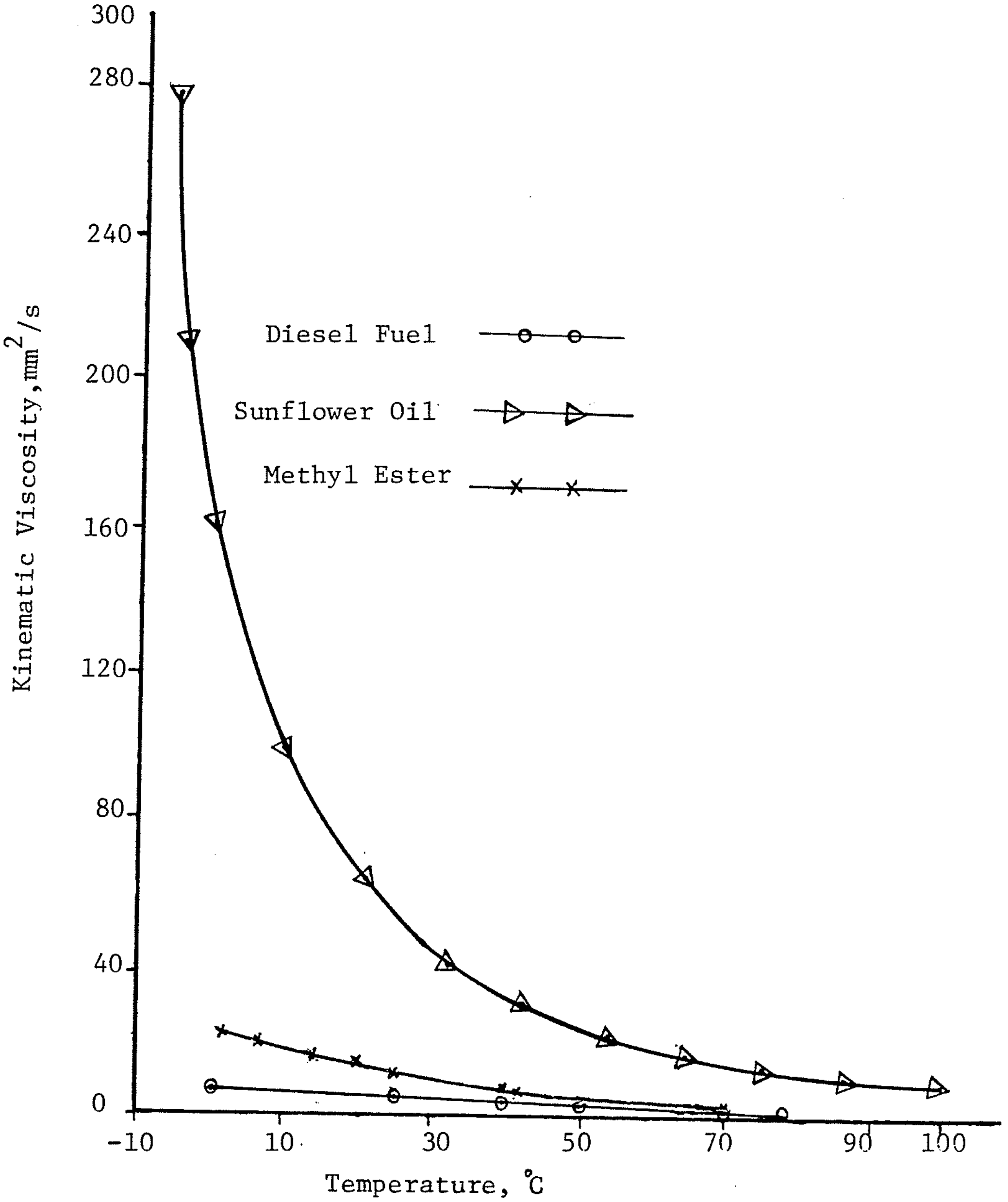


Figure 4.1. Kinematic viscosity of No.2 diesel fuel, crude degummed sunflower oil and its methyl ester

0°C diesel fuel has a viscosity of 6.42 mm^2/s compared to 157.28 mm^2/s for sunflower oil, different by a factor of 24. These results indicate that in cold temperatures, the higher viscosity will be a serious problem affecting satisfactory engine fuel system operation.

The kinematic viscosity value determined by the author agrees well with the results of Ramdeen et al. (1981), Quick (1980) and Bruwer et al. (1980). They found 34.33, 34.7 and about 38 mm^2/s at 37.78°C (100°F) as being the kinematic viscosity of alkali-refined, filtered-degummed and crude sunflower oil respectively.

4.1.2 Cloud and Pour points

The cloud and pour points of a fuel are of great importance to engines operating in cold climates. The cloud point indicates the start of fuel line and filter clogging because of the wax formation while the pour point indicates the ceasing of fuel flow. The temperatures at which cloud and pour points occurred are given in Table 4.2

The cloud and pour points (-7.77 and -15.0°C) observed for crude-degummed sunflower oil are a little higher than No. 2 diesel fuel (-9 and -18.5°C). However, the cloud and pour points (-2.8 and -4.0°C) of methyl ester vary to a greater degree when compared with diesel fuel. The cloud point determined for sunflower oil is quite close to the results of Ramdeen et al. (1981), Yarbrough et al. (1981), and Quick (1980). They reported -6.5, -7.0 and

Table 4.2

Cloud and Pour points of diesel fuel, sunflower oil and its methyl ester.

Fuel Type	Cloud Point		Pour Point	
	°C	°F	°C	°F
No. 2 diesel	-9.0	15.8	-18.5	-1.3
Crude-degummed sunflower oil	-7.77	18.0	-15.0	5.0
Methyl ester	-2.8	27.0	-4.0	24.8

-6.6 as being the cloud point of alkali-refined, degummed dewaxed and crude sunflower oil respectively.

The pour point (-15.0°C) found for sunflower oil differs with the results of Ramdeen et al. (1981), who state -8.72°C as being the pour point of alkali-refined sunflower oil. The difference in the results may be due to difference in the degree of refined oil used. The difference between cloud and pour point is about 8°C which agrees with Ramdeen et al. (1981) who states with the reference to Deere (1970) that the difference of up to 11°C is not uncommon.

4.1.3 Flash point

The flash point is not directly related to engine performance. It is, however, of importance in connection with legal requirements and safety precautions involved in fuel handling and storage. The method used for its determination is Pensky-Martens closed tester (Barger et al. 1963).

The observed flash points for sunflower oil and No. 2 diesel fuel were 214°C (418°F) and 68°C (154°F) respectively. This great difference between the flash points of two fuels can be attributed to the length of the carbon chain in the molecules and the degree of unsaturation (number of double bonds).

Since the diesel fuel is highly saturated (no double bond) and has a shorter carbon chain (C16), it is volatile. On the other hand sunflower oil is highly unsaturated (3 to 6 double bonds), has a longer carbon chain (C57), and it is highly viscous.

The flash point (214°C) determined for crude-degummed sunflower oil differs with the observation of Yarbrough et al. (1981) and Quick (1980).

They gave this value as 257°C and 321°C for degummed sunflower oil and crude sunflower oil respectively. The difference in the results can be due to:

(a) The amount of free fatty acids present in the sample tested and

(b) The ASTM method used to determine the flash point.

The amount of free fatty acids has a predominant effect on the flash point of vegetable oils (Formo et al. 1979). A difference of up to 100°C, in the flash points, has been observed due to different methods of determination.

4.1.4 Boiling point and distillation curve

The boiling point of sunflower oil is its initial boiling point determined during the distillation test. The distillation curve is an important property in determining the operating characteristics of a fuel. Practically, it is an indirect measure of the temperature that will be required to give vaporization of the fuel in the manifold and cylinders of the engine. The 10% point (temperature) of the curve is associated with engine starting, the 50% point indicates the engine warm-up and the 90% point is related to engine acceleration, crankcase dilution, and fuel economy (Barger et al. 1963).

Crude-degummed sunflower oil and its methyl ester were distilled by the National Testing Laboratories Ltd., Winnipeg, according to the ASTM test procedure. A sample of the methyl ester was also distilled by the Industrial Technology Centre, Winnipeg. The results found by both the laboratories are reported in Appendix C.

When the sunflower oil was heated, the formation of blackish-white-dense clouds started to take place in the flask at about 80°C (176°F). The initial boiling point took place at 216°C (420°F), up to which point the oil maintained its original color. Just after the initial boiling point a discoloration of the oil began to be noted and at about 316°C (600°F) only 10 ml of darkened distillate came over along with heavy dense white fumes and a very strong odor. This heavy smoking was indicative of thermal cracking and decomposition of fats, resulting in a darkening of the distillate. The dark residue formation is similar to heating glycerol to form an acrolein product or acrylic aldehyde, having a very irritating odor. The distillation was then discontinued because of the chemical decomposition of sunflower oil. The distillation of methyl ester of sunflower oil was more satisfactory than sunflower oil. Decomposition of methyl ester took place at about 348°C when 85% of the sample was distilled over. Distillation curves of No. 2 diesel fuel, methyl ester and the first two points for the curve of sunflower oil are shown in Figure 4.2.

Figure 4.2 shows that the initial boiling point of sunflower oil and No. 2 diesel fuel are quite close while the initial boiling

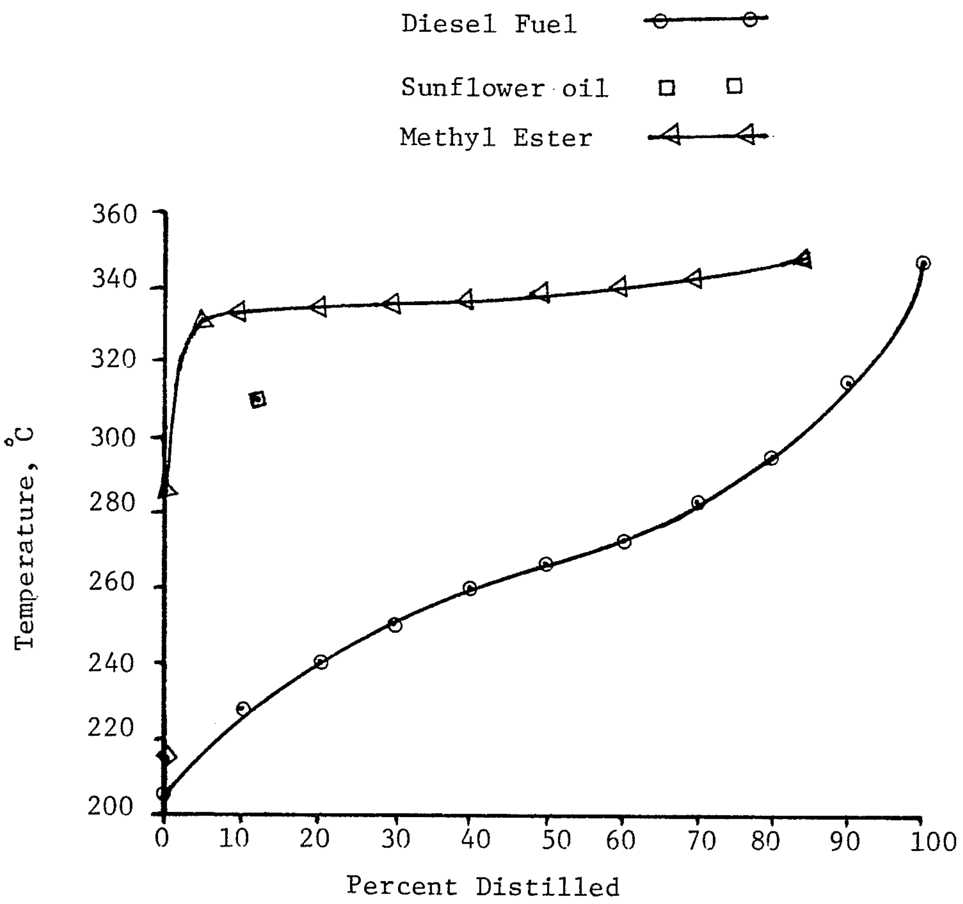


Figure 4.2. Distillation curves of No.2 diesel fuel, crude-degummed sunflower oil and its methyl ester.

point of methyl ester is a bit higher. The 10% point, which is required to start an engine, is higher in the case of both sunflower oil and its methyl ester than No. 2 diesel fuel. This characteristic indicates that the cold starting will be a serious problem while using sunflower oil or methyl ester as an alternate fuel, particularly in cold temperatures. The distillation curves of both sunflower oil and its methyl ester do not coincide with the curves of other researchers. There may be many reasons for this but the most predominant is the chemical composition of the oil, which to a great extent is dependent on the climate of the region where the sunflower crop is produced.

4.1.5 Heat of combustion (Calorific value)

The heat of combustion or calorific value of a fuel is an important measure, since it is the heat produced by the fuel within the engine cylinder that enables the engine to do work. The calorific value may be reported as gross or net (low or high), depending upon the method and conditions of the test. These terms are defined in Chapter 3.

The heat of combustion of No. 2 diesel fuel, sunflower oil and its methyl ester were determined by using an Oxygen Bomb Calorimeter. The average results found and calculated are presented in Table 4.3. The raw values and method of calculation are given in Appendix C in the heat of combustion section.

From Table 4.3, it is clear that the gross calorific values

Table 4.3

Gross calorific value of diesel fuel, sunflower oil and its methyl ester.

Fuel Type	MJ/kg	MJ/L
No. 2 diesel	45.676	38.779
Crude-degummed sunflower oil	39.646	36.633
Methyl ester	40.0	35.17

of sunflower oil (36.63 MJ/L) and diesel fuel (38.78 MJ/L) do not differ to a great extent on a volume basis (about 5.5% lower for sunflower oil). However, calorific values (39.646 MJ/kg for sunflower oil and 45.676 MJ/kg for diesel) do differ by 13.2% being lower for sunflower oil on a mass basis.

The methyl ester of sunflower oil, with calorific values of 40 MJ/kg on a mass and 35.17 MJ/L on volume basis, has 12.4% and 9.3% respectively less heat content than No. 2 diesel fuel. The calorific values mentioned are gross heat values.

The lower heat content in the case of sunflower oil would result in higher specific fuel consumption in an engine. The difference in specific fuel consumption, however, is not totally dependent on the difference in heat values but also on the efficiency of the engine which is converting fuel energy into work. The results of gross calorific value agree very closely with other researchers. Ramdeen et al. (1981), Yarbrough et al. (1981), Bruwer et al. (1980), and Quick (1980) have reported 39.654, 39.6, 39.6, and 39.38 MJ/kg respectively as being the gross heat value of sunflower oil.

4.1.6 API gravity and Density

The gravity of a fuel is usually expressed in degrees API, a scale devised by the Americal Petroleum Institute. The boiling temperature, the volatility, and the heat value are somewhat related to the API gravity so it is used as a means of estimating these values (Barger et al. 1963).

The API gravity of No. 2 diesel fuel and sunflower oil was determined by the hydrometer method. The API gravity was then converted into density (kg/L) by the relationship defined in Chapter 3.

The density of methyl ester was determined by a gravimetric method which was converted into API gravity by using the same relationship referred above. Both, the API gravity and the density are based on a temperature of 15.56°C (60°F). Since the laboratory was not equipped with a constant temperature bath, a graphical procedure was adopted to determine the API gravity and density of the fuels at the reference temperature. A best fit line drawn, using a least square regression analysis with correlation factor of 0.999, is presented in Figure 4.3. The results obtained for the API gravity and density are given in Table 4.4. The hydrometer readings observed at various temperatures are given in Appendix C.

From the results shown in Table 4.4, crude-degummed sunflower oil with an API gravity of 21.65 degrees is heavier than No. 2 diesel fuel (API 35.13 degrees). With respect to density, sunflower oil (0.924 kg/L) and methyl ester (0.873 kg/L) are heavier by 8.8% and 3.6% than No. 2 diesel fuel.

The higher density of sunflower oil will mean increased costs for handling and transportation. But this may be partially offset by the less hazardous nature of the oil (e.g. higher flash

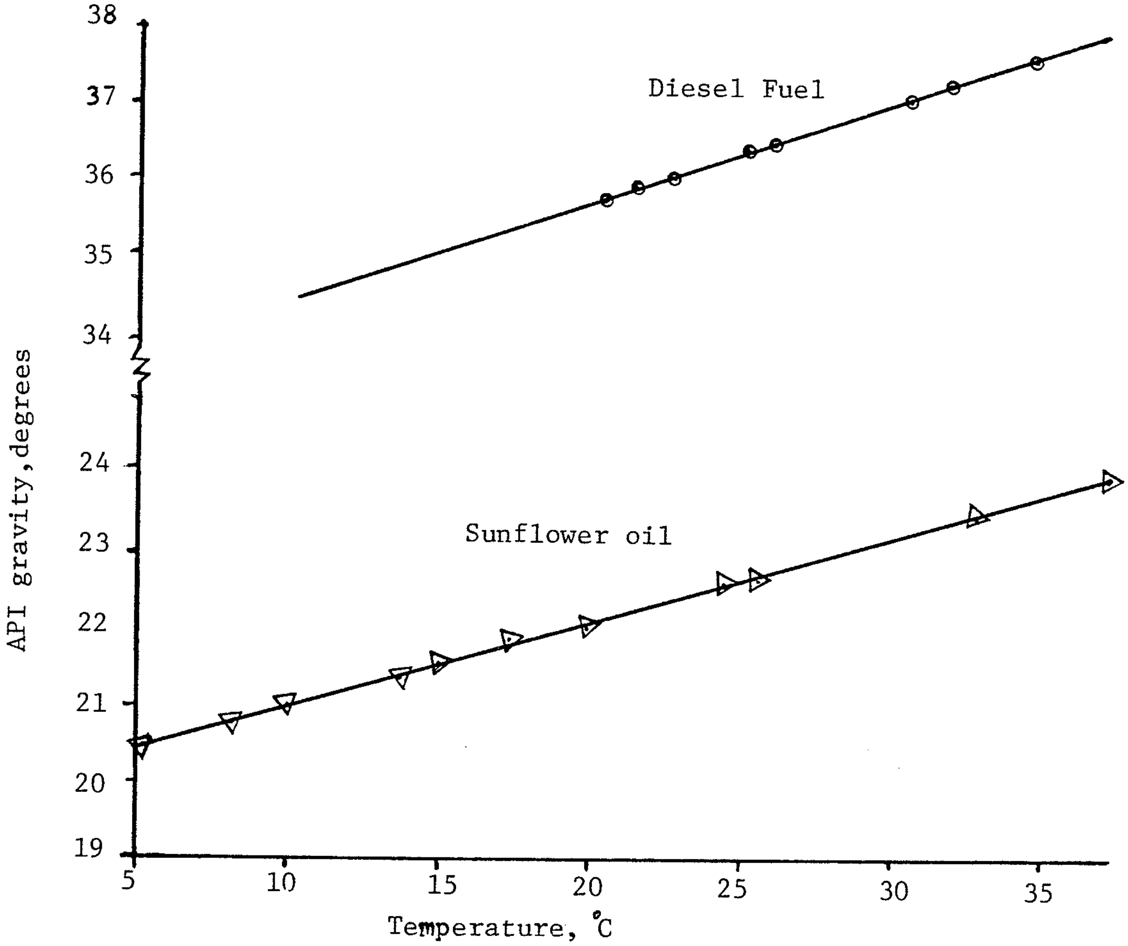


Figure 4.3. API gravity of No.2 diesel fuel and crude-degummed sunflower oil by hydrometer method.

Table 4.4

API gravity and density of diesel fuel, sunflower oil and its methyl ester.

Fuel Type	API gravity (degrees)	Density	
		kg/L	lb/US gal
No. 2 diesel	35.13	0.849	7.08
Crude-degummed sunflower oil	21.65	0.924	7.71
Methyl ester	30.58	0.873	7.28

point, very low sulfur content, and less skin diseases).

The values found for density or API gravity are almost the same as determined by Ramdeen et al. (1981), Peterson et al. (1981), and Quick (1980). Ramdeen et al. and Peterson et al. reported 0.923 kg/L while Quick reported 0.925 kg/L, as the density of sunflower oil. Almost all vegetable oils have densities close to these values.

4.1.7 Other fuel related properties

The properties of sunflower oil which could not be determined in the Department of Agricultural Engineering due to the lack of equipment are discussed in this section. A sample of crude-degummed sunflower oil was sent to the Alberta Research Council, Edmonton, Alberta, for the determination of cetane number and oxidation stability. In addition to these properties the sample was also tested for carbon residue, ash content, corrosion, acidity, sulfur content and the other properties discussed in the previous sections. The results obtained by the Alberta Research Council (ARC) are presented in Table 4.5. The values determined by the author are also duplicated in the table for comparison.

4.1.7.1 Cetane number

The cetane number represents the volatility (ignition quality) of a fuel. A more volatile fuel has a higher cetane number than that of a less volatile fuel.

Table 4.5

Crude-degummed sunflower oil properties determined by the Alberta Research Council (ARC) and the Author.

Fuel Property	Sunflower oil		No. 2 Diesel		ASTM No. ARC/AUTHOR	Probable Source of variation in Sunflower oil results
	ARC	Author	Determined	Published[a]		
K. Viscosity, mm^2/s (40/40.56°C)	30.6	31.17	-	2.0*-4.3**	D524/D2983	Different methods used
Cloud Point, °C	-6.0	-7.77	-9.0	-	D2500/ D2500	Precision of temp. measuring device
Pour Point, °C	-12	-15.0	-18.5	-	ISO3016***/ D97	Oxidation of oil and different methods
Flash Point, °C	318	214.44	67.5	-	D92/D93	Different methods used
Calorific value, MJ/kg	-	39.646	45.676	-	-/D240	
API gravity, degrees (15.56°C)	21.3	21.65	35.13	-	D287/D287	Oxidation of oil and precision in taking readings

...cont'd...

Table 4.5 cont'd....

Fuel Property	Sunflower Oil		No. 2 Diesel		ASTM No. ARC/AUTHOR	Probable Source of variation in Sunflower oil results
	ARC	Author	Determined	Published		
Density, kg/L (15.56°C)	0.926	0.924	0.849	-	D287	Negligible difference
Cetane No.	34	-	-	40*-48**	D613	
Oxidation Stability mg/100 ml	78.3	-	-	-	D2274	
Carbon Residue, %	0.39	-	-	0.35**	D526	
Ash Content, %	0.04	-	-	0.01**	D482	
Acidity, mgKOH/g	1.1	-	-	-	D976	
Sulfur, %	0.02	undetectable	-	0.50**	D1552/ D129	Different methods used
Corrosion	1a	-	-	No. 3	D130	

*Minimum

**Maximum

***not an ASTM method and also unknown to the author

[a] From Tractors and Their Power Units by Liljedahl et al. (1979)

The cetane number for crude-degummed sunflower oil sample as determined by ARC is 34, compared with 48 for No. 2 diesel fuel. The notable difference in the cetane numbers of two fuels may be due to their chemical composition and the degree of refining. The long chain fatty acids with double and triple bonds, in the case of sunflower oil, have more binding force than diesel fuel, which has a shorter carbon chain and single bonds. Therefore, high temperatures are required to vaporize sunflower oil by reducing the attraction between two atoms of a molecule. On the other hand, crude sunflower oil has more waxes and gums than the more refined sunflower oil, so it is not as volatile as diesel.

4.1.7.2 Oxidation stability

Oxidation stability is an important parameter to be known for vegetable oils. Oxidation increases the viscosity and deteriorates the flavor of vegetable oils with the passage of time. Many of the vegetable oils are poorer in oxidation stability than sunflower oil (Cobia and Zimmer 1978). Sunflower oil, even with this superiority, has been observed being oxidized within two to three days when a small sample of about 10 ml of crude oil has been exposed to light and air at room temperature.

The value of oxidation stability, determined by ARC with the accelerated ASTM method, is 78.3 mg/100 ml, which is lower than rape seed oil (86.8 mg/100 ml) but higher than canola oil (43.6 mg/100 ml).

4.1.7.3 Carbon residue

Since sunflower oil is mostly composed of carbon and hydrogen it has a tendency to form carbon deposits when burned in an engine. If the carbon residue of a fuel is known then it is very effective in predicting the carbon deposition from the fuel. This tendency is usually estimated by using the Ramsbottom Coking Method.

The carbon residue determined by ARC is 0.39% for sunflower oil, compared to 0.35% (Published value) for No. 2 diesel. From the results it may be concluded that sunflower oil will leave more carbon deposits than diesel fuel after burning in the engine.

4.2 The Affects of Sunflower Oil on Diesel Fuel Systems

The affects of sunflower oil on a typical diesel fuel system were examined by operating a closed circuit system (Test Bench). A line diagram of the system is shown in Figure 4.4. The average mass of fuel discharged and line pressure measured at six hour intervals, over a 210 hours period were recorded. These values were converted to fuel discharged per hour and are presented in Table 4.6.

Values in Table 4.6 show clearly that the mass of sunflower oil discharged during one hour is considerably higher than that of diesel fuel. On the basis of the fuel mass discharged it can be concluded that the fuel consumption, in the case of sunflower oil, will be higher than diesel fuel, to maintain the same power output providing that the engine uses all the energy available in the fuel.

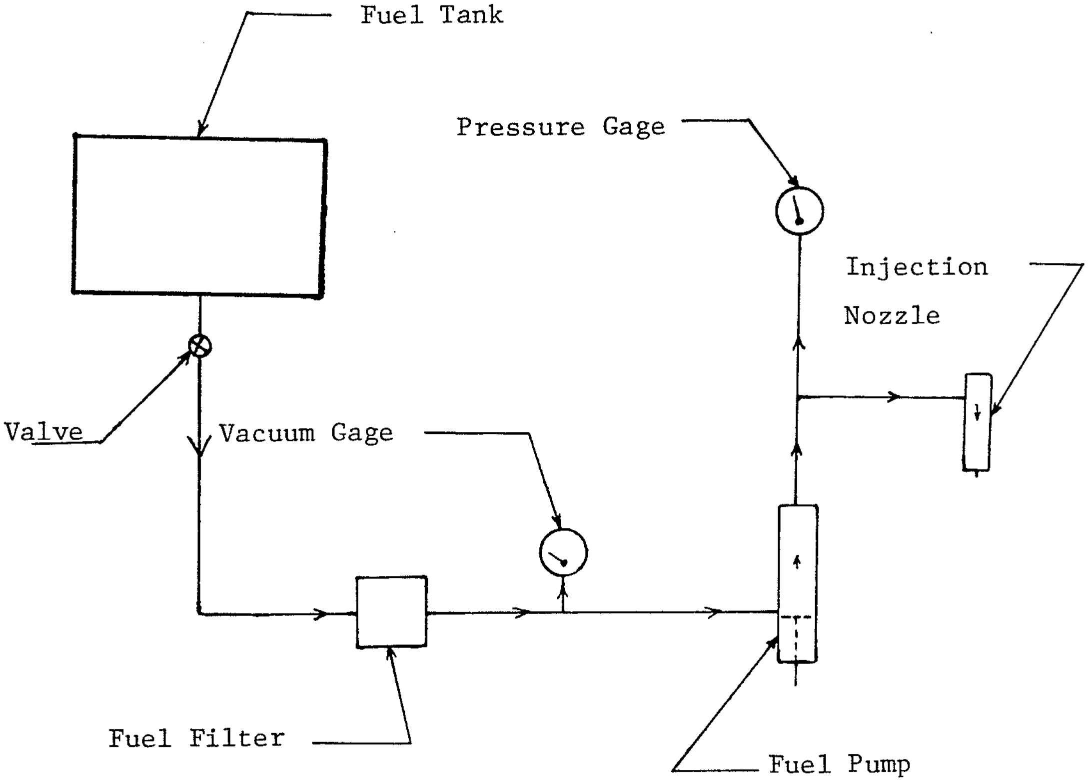


Figure 4.4. Schematic diagram of the Test Bench.

Table 4.6

Average discharge and injection pressure data obtained from bench test over 34 and 210 hours of duration for diesel fuel and sunflower oil respectively.

Stat. Analysis	Sunflower Oil		No. 2 Diesel	
	Discharge kg/h	Pressure kPa	Discharge kg/h	Pressure kPa
Average	0.4885	10,233	0.410	10,025
Standard deviation	0.002	62	0.0013	34

Diesel fuel and sunflower oil were circulated for 34 and 210 hours respectively, in the closed circuit system. In the case of diesel fuel almost no pressure and vacuum build up were indicated by the gages through 34 hours of operation. In the case of sunflower oil, however, a vacuum gage indicated a small unreadable vacuum scale deflection, in the line between the pump and fuel filter, after 190 hours of operation. After 210 hours the vacuum gage indicated an observable deflection but it could not be recorded because of the large graduations of the gage scale. The indication of vacuum was probably due to fuel filter plugging. A pressure build up of about 200 kPa (28 Psi), in the line between injector and pump, remained almost constant throughout the entire testing period of 210 hours. This pressure build up can be attributed to the viscous characteristics of sunflower oil.

4.3 Performance Characteristics of Sunflower Oil

Some engine and fuel related performance characteristics of crude-degummed sunflower oil and No. 2 diesel fuel were determined by operating a Buda diesel engine. The parameters obtained from the performance evaluation tests are power output, specific fuel consumption, and thermal efficiency. The data of engine power output obtained at various speeds by different governor setting is given in Appendix C. Graphically it is presented in Figure 4.5(a). The data for maximum power output obtained at wide open throttle position is shown in Figure 4.5(b). The specific fuel

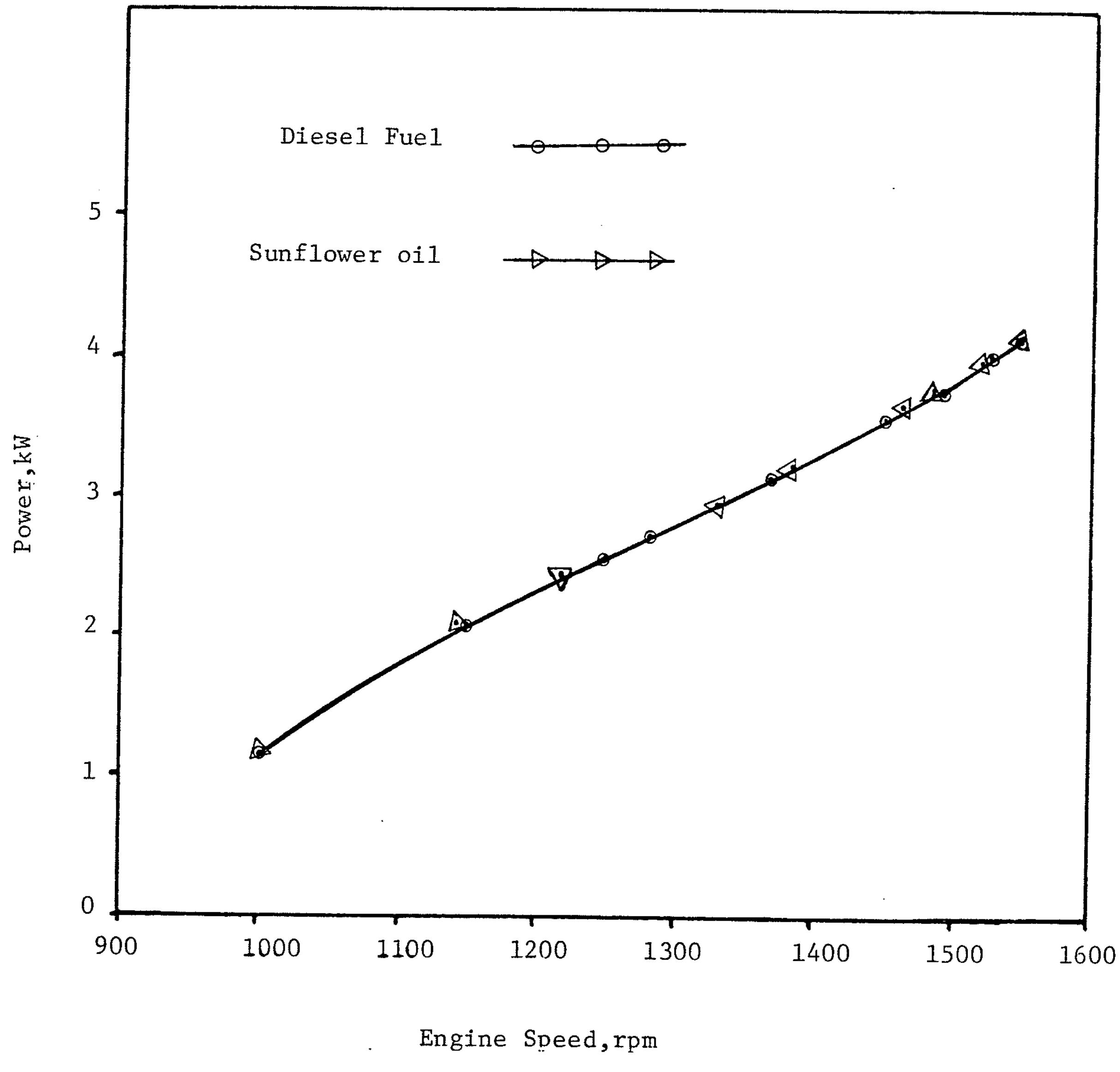


Figure 4.5(a). Power performance curve of No.2 diesel fuel and crude-degummed sunflower oil.

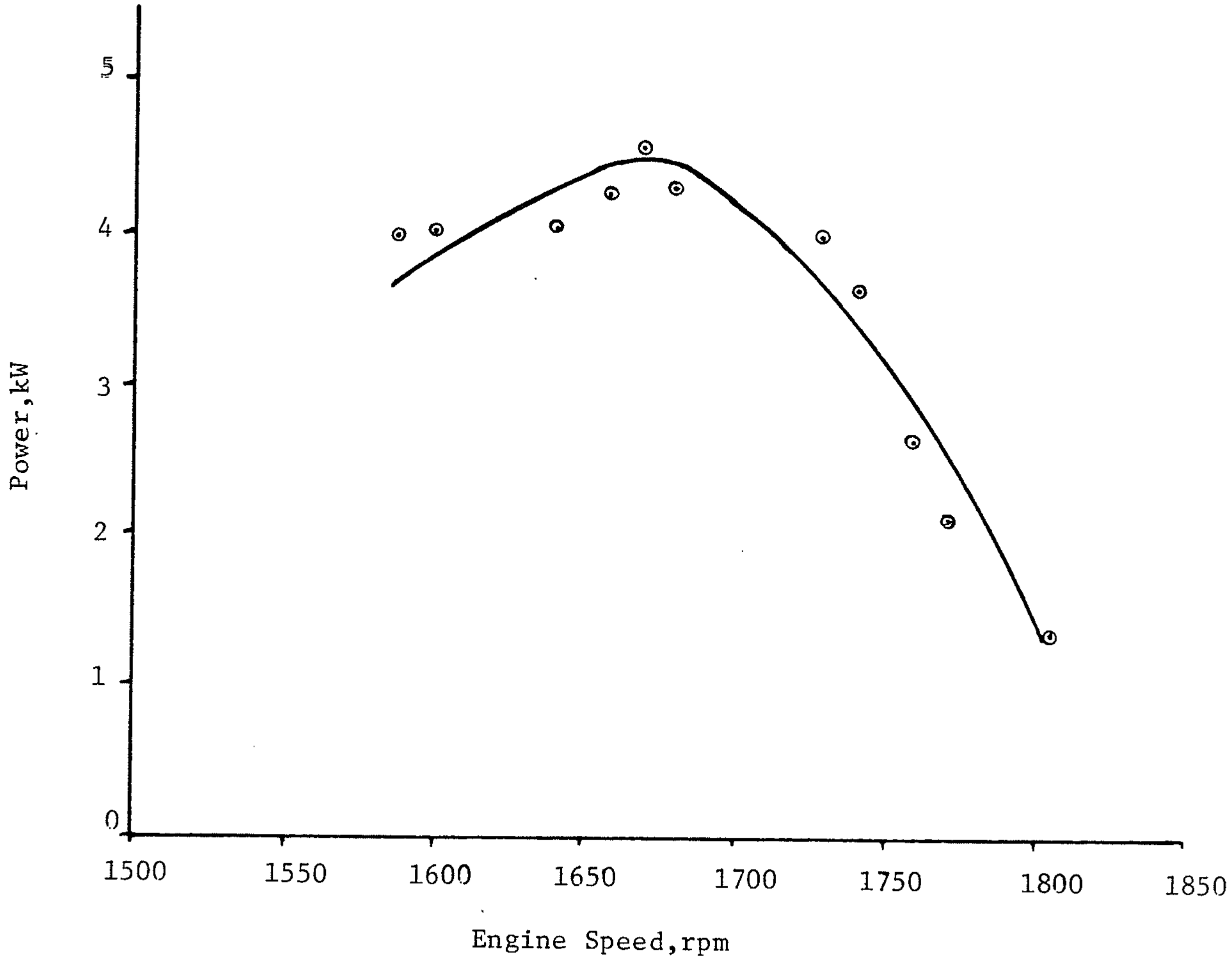


Figure 4.5(b). Maximum power curve for Buda diesel engine with wide open throttle position.

consumption and thermal efficiency at different percentages of maximum power are shown in Figure 4.6. It is clear from Figure 4.5(a) that the points on the power curves of sunflower oil and No. 2 diesel fuel tend to coincide with each other over the entire speed range of the engine. The difference in the power output with diesel fuel and sunflower oil, over one hour interval, at various engine speeds is negligible.

Figure 4.6 indicates that the specific fuel consumption and thermal efficiency with sunflower oil are 6% and about 2% respectively higher than No. 2 diesel fuel. The difference in specific fuel consumption is because of lower energy value of sunflower oil. At smaller percentages of maximum power, specific fuel consumption of sunflower oil tends to deviate slightly from the diesel fuel curve. At higher percentages, however, both fuel consumption curves tend to coincide with each other. The difference in thermal efficiency of the two fuels may be due to the high rate of heat transfer by exhaust gases in the case of diesel fuel or different rates of fuel leakage from the fuel pump.

It was observed during the fuel performance tests that the sunflower oil was not able to flow through the secondary filter even at room temperature without the addition of a fuel transfer pump in the fuel system. Engine starting problems and heavy knocking were also encountered.

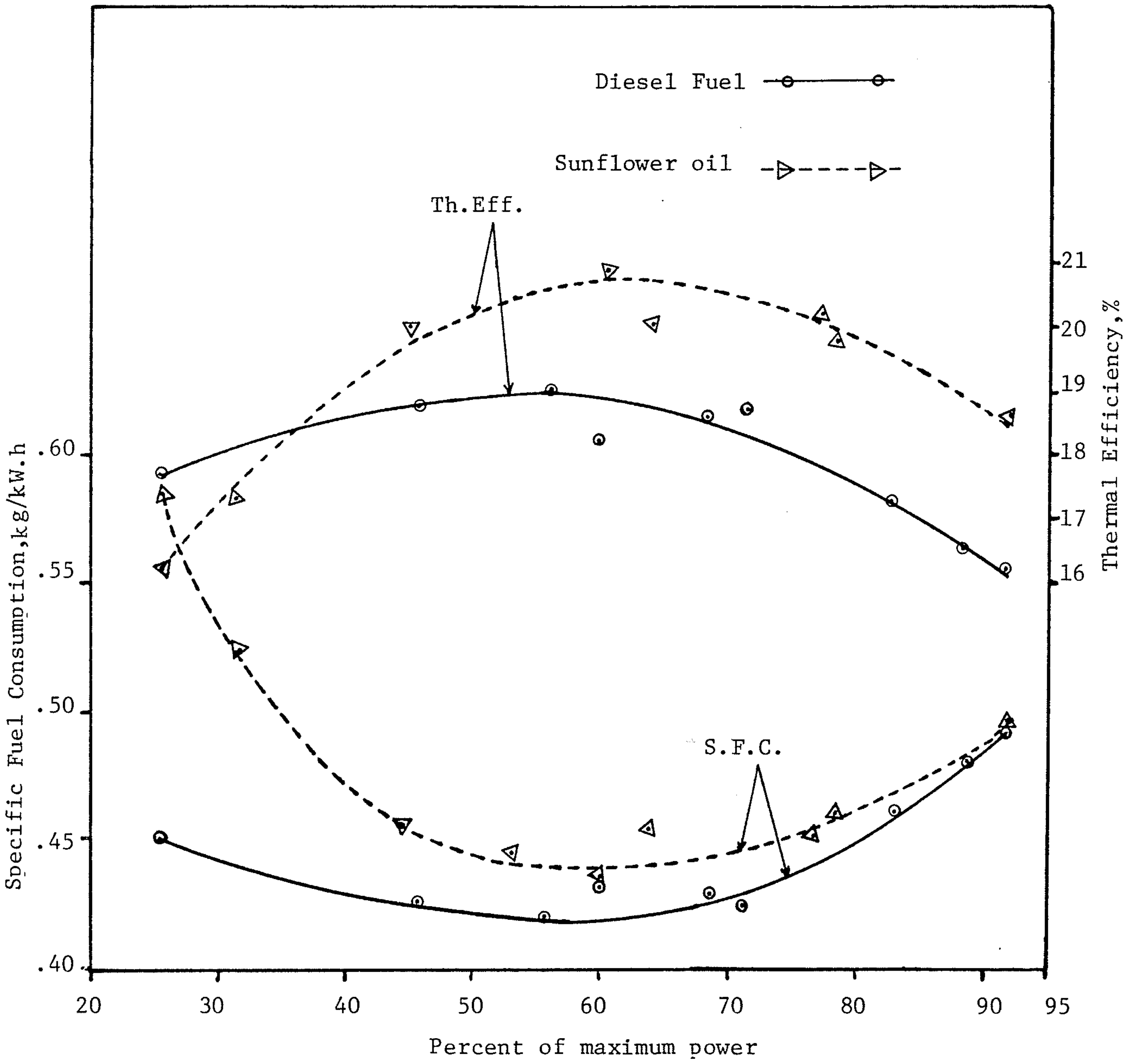


Figure 4.6. Specific fuel consumption and thermal efficiency of No.2 diesel fuel and crude-degummed sunflower oil.

Chapter 5

CONCLUSIONS

Conclusions drawn from the results obtained and discussed in Chapter 4 are noted following:

1. The most detrimental parameter in the use of sunflower oil is its higher viscostiy; about 14 times higher than diesel at the reference temperature. The higher viscosity of sunflower oil does not favor its use in unmodified diesel engines. The problems to be encountered with higher viscosity are filter and fuel line obstructions, higher injection line pressure and poor atomization.
2. The problem of higher viscosity can be solved by transesterification of sunflower oil to methyl ester. Although the viscosity curve of methyl ester, up to 0°C is quite close to No.2 diesel fuel yet it can not be used as a fuel below -5.0°C because it ceases to flow below this temperature. It is satisfactory in tropical climates provided its economy of utilization can be justified.
3. The fuel properties that determine a good compresssion ignition fuel are primarily cetane rating and volatility. These are related to the knock characteristics and ease of cold starting. Sunflower oil has a relatively low cetane rating and high boiling point. The 10% point, which is required to start an engine, on the distillation curve of sunflower oil is quite high and the oil will not start a cold engine as readily as No. 2 diesel fuel.
4. The difference in the heat of combustion (MJ/kg) of No. 2 diesel

diesel fuel, sunflower oil and its methyl ester is about 13%. Theoretically, an engine should consume 13% more sunflower oil and methyl ester to complete the same amount of work as the No. 2 diesel fuel. Since the fuel consumption is not totally dependent on the difference of heat values, only 6% more sunflower oil consumption was recorded.

5. The thermal efficiency of sunflower oil is quite satisfactory in an engine employing an indirect combustion system. It means that the contamination of the lubricating oil may be delayed.

6. Sulfur content, carbon residue and ash content of crude-degummed sunflower oil are quite comparable to diesel fuel. Due to its lower sulfur and ash content it is expected that less corrosion and abrasion will occur on engine parts.

7. Oxidation of vegetable oils is also a limiting factor in their storage and utilization as fuel. Higher oxidation rates will leave heavy gum and wax deposits in engine fuel tanks and on stationery engine parts when exposed to high temperatures and free oxygen.

Chapter 6

RECOMMENDATIONS

A further study is required to adequately determine the suitability of sunflower oil as an alternate fuel for compression ignition engines. Recommendations for a future study are as follows:

1. A comprehensive examination of the physical properties of sunflower oil and its methyl ester would be required with some fuel additives. Heating of the fuel tank and lines will depress the pour point of the methyl ester of sunflower oil and could allow the tractor to operate in the lower ambient temperatures.
2. Engine endurance tests with sunflower oil and its methyl ester should be investigated in direct and indirect combustion engines to assess the long term affects of these substitute fuels on engine parts and lubricating oil.
3. The major obstacle in the use of vegetable oils as fuel is cost. A comprehensive study regarding the economics of on-farm oil-extraction and storage practices should be undertaken.

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APPENDIX A

- Area, yield and production of sunflower seed by selected years
- Calculations for energy ratio, land requirements and Canadian sunflower oil production

Table A-1*

Area of sunflower seed in Manitoba and Canada by selected years.

Year	Manitoba x 10^3ha	Canada x 10^3ha
1975	25.1	25.1
1976	20.0	20.0
1977	67.0	68.2
1978	87.0	91.5
1979	154.0	161.3
1980	129.0	136.3
Average	80.35	83.73

*Table A-1 after Canadian Grains Industry Statistical Handbook 1981.

It is noted from table A-1 that the province of Manitoba has 96% of the total area of the sunflower seed grown in Canada.

Table A-2*

Sunflower seed yields in Manitoba and Canada by selected years.

Year	Manitoba kg/ha	Canada kg/ha
1975	1191	1191
1976	1200	1200
1977	1185	1188
1978	1324	1314
1979	1355	1350
1980	1231	1219
Average = $\frac{\text{Total production}}{\text{Total area}}$	1278	1272

*Table A-2 after Canadian Grains Industry statistical Hand Book 1981.

Table A-3*

Sunflower seed production in Manitoba and Canada by selected years.

Year	Manitoba x 10^3t	Canada 10^3xt
1975	29.9	29.9
1976	24.0	24.0
1977	79.4	81.0
1978	115.2	120.2
1979	208.7	217.8
1980	158.8	166.1
Average	102.7	106.5

*Table A-3 after Canadian Grains industry statistical Hand Book 1981.

A.1 CALCULATIONS FOR ENERGY RATIO AND LAND REQUIREMENTS

A.1.1 Energy Ratio

(a) Energy output

1. Average yield of Manitoba's sunflower seed = 1278 kg/ha
2. Average oil content of sunflower seed = 45%
3. Total oil yield = 0.45 x 1278 = 575 kg/ha

   Considering 95% extraction rate of sunflower oil (Personal communication with CSP Foods Ltd., Altona)
4. Net yield = 575 x 0.95 = 546 kg/ha

   Gross calorific value of sunflower oil = 39.63 MJ/kg

   (Assuming energy from meal and oil left in meal is used for transporting and extracting sunflower oil)
5. Total energy output = 39.63 x 546 = 21.64 GJ/ha

(b) Energy input

Assumptions:

1. Average farm size in Manitoba 240 ha
2. Total no. of farms = 32,104 (1980 yearbook, Manitoba Agriculture)
3. Fuel consumption on farms in Manitoba (consumption of petroleum products, 1977) Diesel = 134,295 m^3

   Gasoline = 310,024 m^3

4. Heat value (Quick, 1980) Diesel = 38.4 MJ/L = 38.4 GJ/m^3

   Gasoline = 34.8 MJ/L = 34.8 GJ/m^3

5. Total energy used on farms in Manitoba

   = 134,295 x 38.4 + 34.8 x 310,024 = 15,945,763 GJ

6. Energy input = No.5/No.1 x No.2 = 2.0695 GJ/ha

<u>Energy Ratio</u> = Energy output/Energy input

$$= \frac{21.64}{2.0695} \approx 10.5$$

A.1.2 Land Requirements

Average farm size = 240 ha

Average farm energy requirement = 2.07 x 240

= 496.8 ≈ 500 GJ

Energy content of sunflower oil = 39.63 MJ/kg

Oil Extraction efficiency = 95%

$$\text{Sunflower oil needs} = \frac{500 \times 10^9}{39.63 \times 10^6} = 12616 \text{ kg}$$

$$\text{Sunflower seed needs with 45\% oil content} = \frac{12616}{0.45} = 28037 \text{ kg}$$

Land Needs

(a) with 1150 kg/ha yield $= \frac{28037}{1150} \simeq 24.4$ ha

(b) with 1350 kg/ha yield $= \frac{28037}{1350} \simeq 20.8$ ha

Percent of Manitoba Average Farm

(a) $= \frac{24.4}{240} \times 100 = 10$

(b) $= \frac{20.8}{240} \times 100 = 8.66$

A.2 CANADIAN SUNFLOWER OIL PRODUCTION

Average production of sunflower seed = 106.5×10^3 t

Confectionery sunflower seed = 5% of average production

(1980 Yearbook, Manitoba Agriculture)

Net production of oiltype sunflower seed = 101.17×10^3t

Average oil content of sunflower seed = 45%

Gross sunflower oil production = $0.45 \times 101.17 \times 10^3$

= 45.52×10^3t

Oil extraction rate = 95% of oil content

Net sunflower oil production = $45.52 \times 10^3 \times 0.95$

= 43.244×10^3t

Density of sunflower oil = 0.923 kg/L = 923 kg/m^3

Volumetric sunflower oil production = 46,851 m^3

APPENDIX B

1. Summarized ASTM test procedures for; Cetane number, Oxidation stability, Carbon residue, Ash content and Corrosion. (These determinations were made by the Alberta Research Council, Edmonton).
2. Procedure to prepare methyl ester of sunflower oil. (Methyl ester of sunflower oil was prepared by M. Z. Khan., a Ph.D. student in the Department of Chemistry, University of Manitoba, Winnipeg).

B.1 Cetane Number

This is the whole number which is nearest the percentage on a volume basis of normal cetane in a blend with alphamethylnephthalene that matches the ignition quality of the sample fuel when compared by this method. It represents the tendency of a fuel to resist detonation during combustion in an engine. Ignition quality, in the case of diesel engines, is the ease of burning of a fuel due to compressed air in an engine cylinder.

Cetane is a hydrocarbon with a very high ignition quality, and is chosen to represent the top of the scale with a cetane number of 100. The hydrocarbon alphamethylnephthalene has exceedingly low ignition quality, and is chosen to represent the bottom of the scale with a cetane number of zero.

The cetane number of a fuel is determined by comparing its ignition quality with that of blends of reference fuels of known cetane numbers under standard operating conditions. This is done by varying the compression ratio for the sample fuel and each reference fuel to obtain a fixed "delay period", that is the time interval between injection and ignition. When the compression ratio for the sample fuel is bracketed between those for two reference fuel blends differing by not more than five cetane numbers, the rating of the sample fuel is calculated by interpolations.

B.2 Carbon Residue

This procedure determines the amount of carbon residue left after evaporation and pyrolysis of the oil, and has the objective to provide an indication of its relative coke forming characteristics.

A sample of fuel, after being weighed in a special glass bulb having a capillary opening, is placed in a metal furnace maintained at approximately 550°C (1020°F). The sample is thus quickly heated to the point at which all volatile matter is evaporated out of the bulb while the heavier residue remaining in the bulb undergoes cracking and coke forming reactions. In the latter portion of the heating period, the coke or carbon residue is subjected to further slow decomposition or slight oxidation due to the breathing of air into the bulb. After a specified heating period, the bulb is removed from the bath, cooled in a desicator, and again weighed. The remaining residue is calculated as a percentage of the original sample and reported as the Ramsbottom carbon residue.

B.3 Oxidation Stability

Stability is the capacity of an oil to maintain its flavor (not go rancid) and to resist changes in viscosity after prolonged period of exposion to air and high temperatures.

This procedure determines the stability of sunflower oil under accelerated oxidizing conditions. A measured volume of filtered oil is aged for about 16 hours at a high temperature of 95°C (203°F) while oxygen is bubbled continuously through the sample. After aging and cooling, the total amount of insoluble matter is determined.

B.4 Ash Content

Diesel engine injectors are precision made units of extremely close fits and tolerances, and therefore are sensitive to any abrasive material in the fuel. Since the ash content is directly related to wear of the injection system it should be kept low.

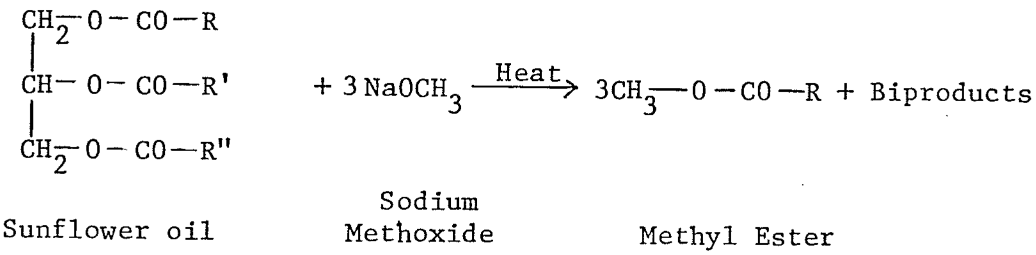
A sample of fuel is placed in a suitable dish or crucible, ignited and allowed to burn until only carbonanceous material remains. The residue is ignited to constant mass by heating with a flame or in a muffle furnace. After cooling, mass of the dish is again determined and the difference between the first and second mass determinations is the ash content of the sample fuel.

B.5 Corrosion

Some sulfur compounds may be corrosive to various metals, particularly copper. A polished copper strip is immersed in a measured quantity of the sample and heated at a temperature of 100°C (212°F) for about three hours or depending upon the materials being tested. At the end of this period, the copper strip is removed, washed, and compared with ASTM copper strip corrosion standards.

B.6 Procedure to Prepare Methyl Ester of Sunflower Oil

Sodium methoxide (1.2 mole) solution was prepared by dissolving sodium metal (33g and slightly in excess of 1.363 moles) in methanol (1100 ml, excess) (reagent grade, Fisher Scientific Co.) at room temperature. Sunflower oil (400 g, 0.456 mole) was then added and the resulting solution was stirred and heated under reflux over a steam bath for 45 minutes. The reaction equation can be written as:



$$\begin{array}{l} CH_2-O-CO-R \\ \quad| \\ CH-O-CO-R' \\ \quad| \\ CH_2-O-CO-R'' \end{array} + 3\,NaOCH_3 \xrightarrow{Heat} 3CH_3-O-CO-R + \text{Biproducts}$$

The reaction was monitored by a nuclear magnetic resonance spectra of hydrogen proton ('H-nmr) of a small sample removed from the reaction mixture. After completion of the reaction, excess methanol (~900 ml) was removed on a vacuum rotary evaporator. The concentrated reaction mixture was poured into 100 ml of water, stirred and extracted with ether (3 x 150 ml). The ethereal solution was concentrated by evaporation and the residue dissolved in benzene (about 150 ml). After drying over sodium sulphate overnight, the organic solvents were removed under vacuum to yield a moderately viscous yellowish liquid (325.6 g; 85% yield). The vacuum distillation of the crude esters yielded a clear liquid (94% recovery from the crude esters) with a boiling point of 138°C under 1.3 mm mercury pressure.

Nuclear magnetic resonance spectra of hydrogen proton ('H-nmr) for crude-degummed sunflower oil, crude methyl esters, and distilled methyl esters, were obtained with a "VARIAN" Ananspect EM-360 NMR Spectrometer. The chemical shifts are given in delta (δ) units relative to tetramethylsilane (TMS) as an internal standard. Deutoro chloroform ($CDCl_3$) was the solvent used.

'H-nmr of sunflower oil and methyl esters are shown in Figures B.1, B.2, and B.3. 'H-nmr δ: peak at 3.68 (S) for methyl esters ($CH_3\text{-}O\text{-}CO\text{-}R$); no peak at 4.30 - 4.16 (m) for sunflower oil ($-CH_2\text{-}O\text{-}CO\text{-}R$ and $-\underset{|}{C}H\text{-}O\text{-}CO\text{-}R$).

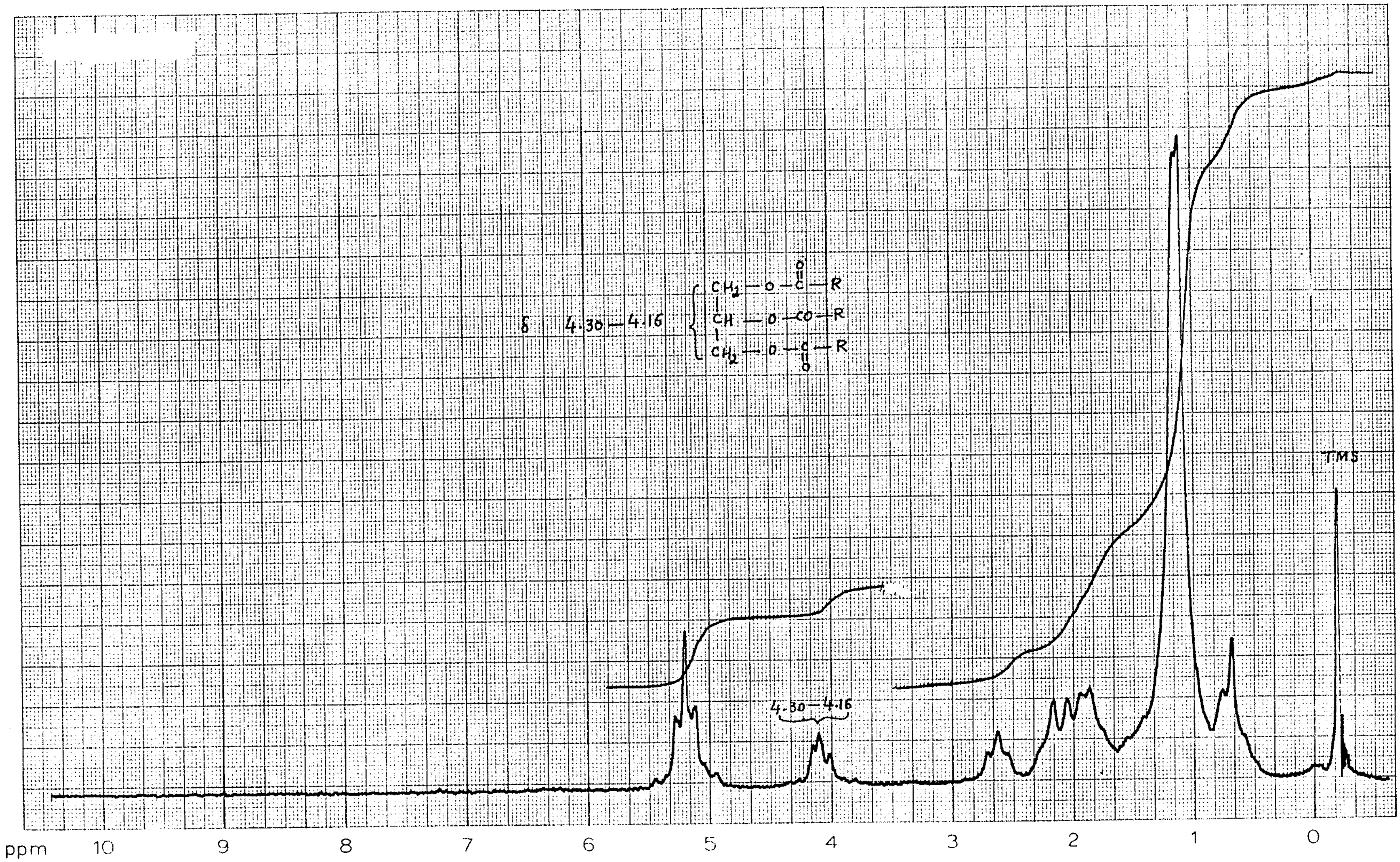


Figure B.1. 'H-nmr of Crude-degummed Sunflower oil.

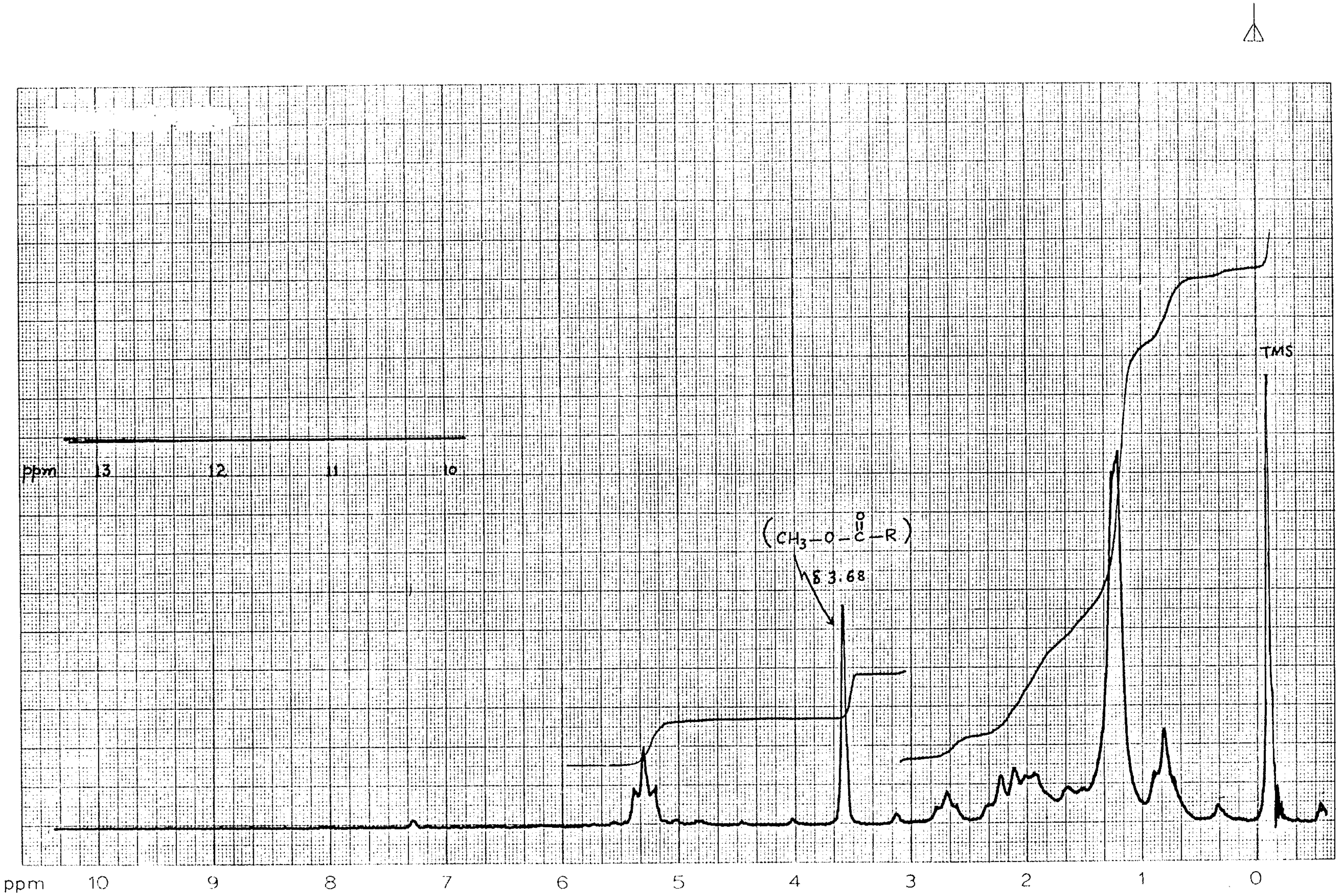


Figure B.2. 'H-nmr of Crude Methyl Ester of Sunflower oil.

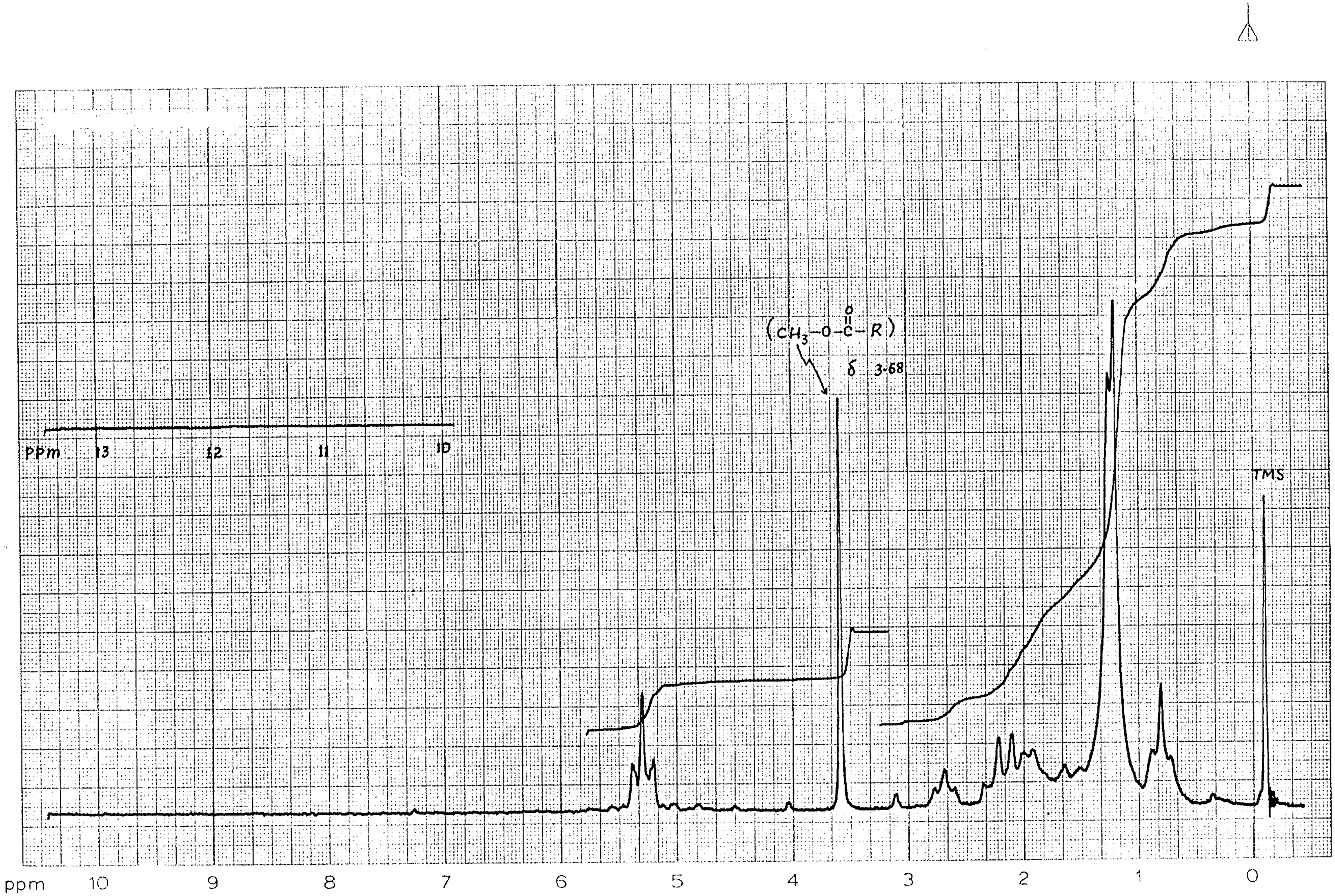


Figure B.3. 'H-nmr of distilled Methyl Ester of Sunflower oil.

APPENDIX C

Raw Data and Sample Calculations of Results

C.1 Kinematic Viscosity of Sunflower Oil and its Methyl Ester

Table C.1 Saybolt universal viscosity and equivalent kinematic viscosity of crude-degummed sunflower oil by Saybolt Universal viscometer.

Temperature		Saybolt universal Seconds (SUS)	Equivalent Kinematic viscosity, mm^2/s
°F	°C		
70	21.11	296	63.80
75	23.89	258	48.80
80	26.67	227	43.95
85	29.44	205	44.10
90	32.22	190.7	40.90
95	35.00	173.8	37.15
100	37.78	157.0	33.45
105	40.56	146.8	31.17
108	42.22	140.5	29.77
115	46.11	123.7	25.97
120	48.89	115.2	24.02
125	51.67	107.4	22.22
130	54.44	100.5	20.57
140	60.00	88.0	17.58
150	65.56	79.6	15.50
160	71.11	72.5	13.66
170	76.67	67.0	12.18
180	82.22	62.8	11.04
190	87.78	58.3	9.76
200	93.33	54.6	8.69
210	98.89	52.3	7.95

C.1.1 Conversion of Saybolt Universal Viscosity into Kinematic Viscosity

Saybolt universial viscosity was measured in seconds over a temperature range, from 21°C (70°F) to 100°C (212°F) for sunflower oil and 20 °C (68°F) to 70°C (104°F) for methyl ester, using a Saybolt Universal viscometer. Each reading was then converted to represent Saybolt viscosity at 37.78°C (100°F) by the following relationship:

$$\mathrm{SUS}(37.78^\circ\mathrm{C}) = \mathrm{SUS}(t^\circ\mathrm{C})/(1 + 0.00006\ (t - 37.78))$$

The values obtained by the above equation were read from the conversion table, provided by ASTM D2161, which gives the kinematic viscosity directly at any temperature measurement in Celsius degrees.

Table C.2 Dynamic viscosity and equivalent kinematic viscosity by Brookfield Synchro-Lectric viscometer (raw data).

Temperature		Spindle No.	Speed	Factor	Visco-meter Reading	Dynamic viscosity mPa.s	Equivalent Kinematic viscosity mm^2/s
°F	°C		rpm				
4.2	-15.44	2	20	20	57	1140	999
6.0	-14.44	2	20	20	53.0	1060	935
10.5	-11.96	2	20	20	41.9	838	751
15	-9.44	2	20	20	32.7	654	595
16.5	-8.61	2	20	20	29.3	586	536
18	-7.78	2	20	20	26.5	530	488
22	-5.55	1	20	5	58.1	290	270
24.5	-4.17	2	20	20	11.1	222	209
28.5	-1.96	2	20	20	9.5	190	182
32	0	1	20	5	32.5	162	157
36	1.11	1	20	5	29.5	147.50	145
40	2.22	1	20	5	26.95	136.75	134.5
43.7	6.5	1	20	5	22.53	112.65	106.37
50	10.0	1	20	5	19.25	96.25	100.00
58.5	14.72	1	20	5	15.25	76.25	82.00
60	15.56	1	20	5	14.6	73.00	79.00
65	18.33	1	20	5	14.2	71.00	78.37

C.1.2 Method to Convert Dynamic Viscosity into Kinematic Viscosity

A Brookfield Synchro-Lectric viscometer was used to measure the dynamic viscosity over a temperature range of 18°C (65°F) to -15.5°C (4.5°F). Viscometer readings were multiplied by a factor, indicated against speed and spindle no., to obtain dynamic viscosity in mPa.s (centipoise).

The dynamic viscosity was converted into kinematic viscosity at any temperature by using the following equation:

$$\text{Kinematic viscosity, t°C} = \frac{\text{Dynamic viscosity, t°C}}{\text{Density, t°C}}$$

The density of sunflower oil at different temperatures was obtained following Formo et al. (1979) using the formula which follows:

$$\text{Density, t°C} = \text{Density, 15.56°C} + (15.56 - t) \times 7 \times 10^{-3}$$

(7×10^{-3} g/ml/°C is a coefficient of expansion for triglycerides of vegetable oils).

C.2 Distillation Results of Methyl Ester of Sunflower Oil

Table C.3 ASTM distillation data for methyl ester of sunflower oil at barometeric pressure.

Percent Recovered	Temperature, °C		
	ITC*		NTL**
Initial Boiling Point	260	310	284.4
5	329	330	336.7
10	333	332	338.9
20	334	334	340.0
30	335	335	341.1
40	336	336	343.3
50	337	337	344.4
60	338	338	344.4
70	340	341	346.1
80	344	344	346.1[b]
90	350	349	thermal
95	352[a]	349[a]	cracking

[*] Industrial Technology Centre, Winnipeg

[**] National Testing Laboratories, Winnipeg

[a,b] Maximum temperatures noted by ITC and NTL respectively.

C.3 Heat of Combustion by Oxygen Bomb Calorimeter

Table C.4 Heat of combustion of diesel fuel, sunflower oil and its methyl ester.

Fuel Type	Gross Heat of Combustion (MJ/kg)					Average Heat Value (MJ/kg)
	1	2	3	4	5	
No. 2 diesel	46.003	45.805	45.3	-	-	45.676
Crude-degummed sunflower oil	40.116	39.394	39.75	39.91	39.062	39.646
Methyl ester	40.267	39.863	39.87	-	-	40.00

C.3.1. Sample Calculation of Gross Calorific Value

mass of capsule = 12.58 g
mass of capsule + sample = 13.54 g
mass of sample (m) = 0.96 g

After igniting the mass m of sample in the oxygen bomb the following time and temperature readings were observed:

Time, min	Temperature, °C
0	22.42
1	22.59
2	22.616
3	22.618
4	22.618
5	22.618
5.75	23.68
6.00	24.40
6.25	24.98
6.50	25.32
7	25.76
8	26.17
9	26.31
10	26.365
11	26.385
12	26.385
13	26.385
14	26.385
15	26.380

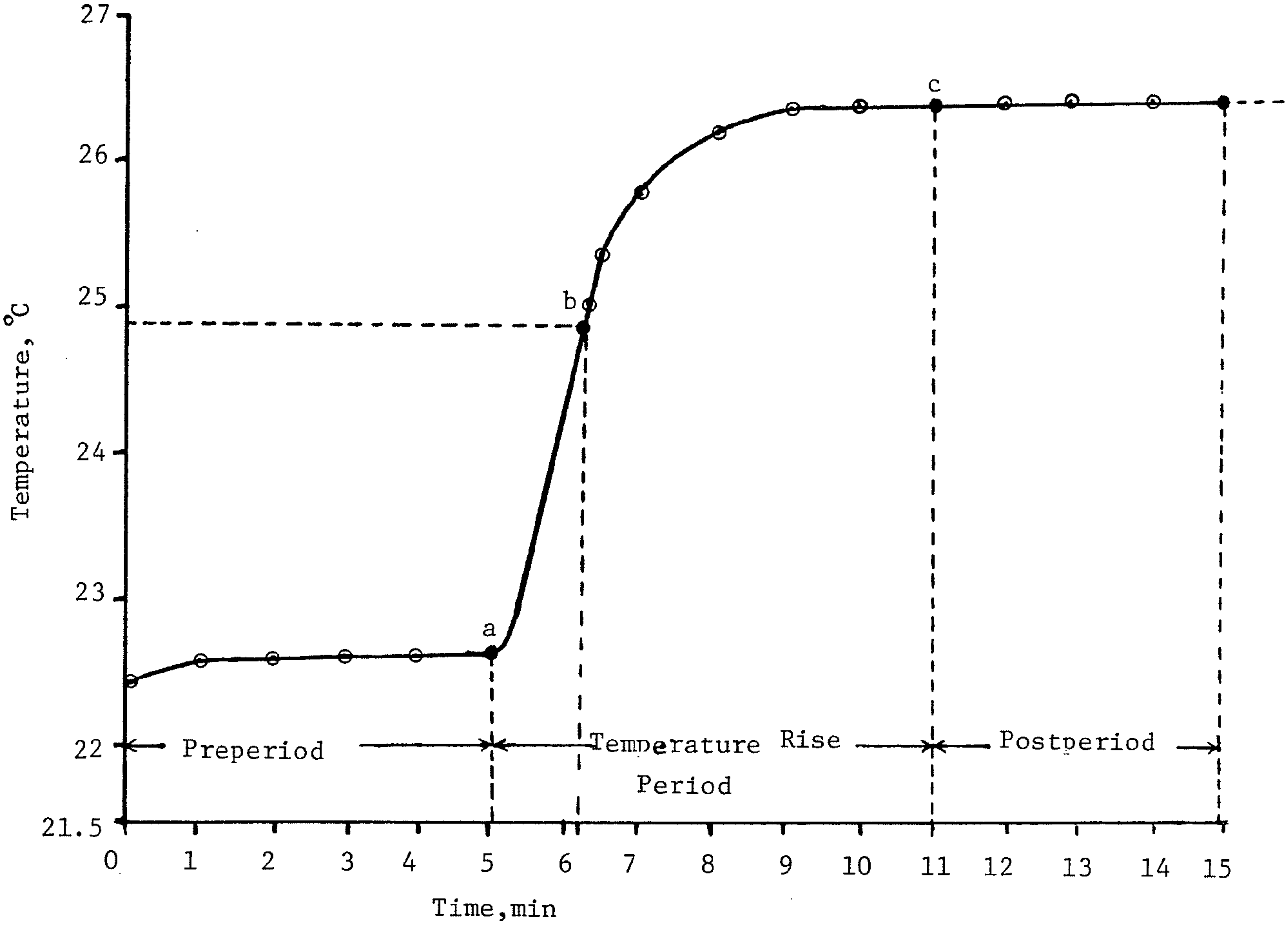


Figure C.1. Temperature rise curve for Oxygen Bomb Calorimeter with Sunflower oil.

C.3.1.1 Titration with Sodium Carbonate (0.0725 N)

Initial Reading (ml)	Final Reading (ml)	Na_2CO_3 used/25 ml washing
28.6	29.7	1.1
29.7	30.9	1.2
30.9	32.1	1.2

Total Na_2CO_3 used for 200 ml washings $= \frac{1.2}{25} \times 200 = 9.6$ ml

C.3.1.2 Calculations for Net Temperature Rise

$$t = tc - ta - r_1 (b - a) - r_2 (c - b)$$

where:

a = time of firing = 5

b = time at 60% temperature rise from graph = 6.2

c = time when the temperature rise become stable after ignition = 11

ta = temperature at time a = 22.618

tc = temperature at time c = 26.385

r_1 = rate of temperature change before a = 0.0396

r_2 = rate of temperature change after C = -0.001

t = corrected temperature rise, °C

$$t = 26.385 - 22.618 - 0.0396 (6.2 - 5.0) + 0.001 (11 - 6.2)$$

$$= 3.77°C$$

C.3.1.3 Gross Calorific Value (Hg)

$$Hg = (t \times W - e_1 - e_2 - e_3)/m$$

where:

Hg = gross heat of combustion

t = corrected temperature rise = 3.77°C

W = energy equivalent of calorimeter = 2424 cal/°C

e_1 = correction for heat of formation of nitric acid

= Na_2CO_3 used = 9.6 cal

e_2 = correction for heat of formation of sulfur

= 14 x % of sulfur in sample x m = 0

e_3 = correction for heat of fuse wire

= 2.3 x 4.7 = 10.81 cal

$$Hg = (3.77 \times 2424 - 9.6 - 0 - 10.81)/0.96$$

$$= 9497.9896 \text{ cal/g}$$

$$= 9497.9896 \times \frac{4186.8}{10^6} = 39.766 \text{ MJ/kg}$$

C.4 Hydrometer Readings for API Gravity and Density

Table C.5 Hydrometer readings at different temperatures for API gravity and density of sunflower oil.

Temperature °F	°C	Hydrometer Readings, degrees
32.0	0	19.9
41.0	5.0	20.4
46.6	8.0	20.8
50.0	10.0	21.0
55.4	13.0	21.4
59.0	15.0	21.6
60.0	15.56	21.65
63.0	17.22	21.85
68.54	20.3	22.05
69.62	20.9	22.15
71.6	22.0	22.30
76.1	24.5	22.57
78.0	25.56	22.65
91.4	33.0	23.50
97.7	36.5	23.90
106.7	41.5	24.40
112.0	44.44	24.70

Table C.6 Hydrometer readings at different temperatures for API gravity and density of No. 2 diesel fuel.

Temperature °C	Hydrometer Readings, (degrees)
20.3	35.70
21.3	35.85
22.3	35.95
25.2	36.3
26.6	36.38
30.5	36.96
32.0	37.2
34.8	37.5

C.5 Average Performance of No.2 Diesel Fuel and Crude-Degummed Sunflower oil by Operating Buda Diesel Engine

Torque arm = 0.345 m

Engine pulley to generator pulley speed ratio = 2.68

Torque, N.m = Mass 9.8 x 0.345 x 2.68 = Mass x 9.061

Power, kW = 2π x Engine speed x Torque/60 x 1000

= Mass x Engine Speed x 9.4887 x 10^{-4}

Specific fuel consumption (S.F.C.), kg/kW.h = $\frac{\text{Fuel consumed/hr}}{\text{Power}}$

Thermal efficiency (Th.Eff.), % = 360/(S.F.C. x gross heat value)

Gross heat value of sunflower oil = 39.646 MJ/kg

Gross heat value of No. 2 diesel fuel = 45.68 MJ/kg

Table C.7 Data of maximum power with No. 2 diesel fuel.

Engine Speed rpm	Mass kg	Torque N.m	Power kW
1804	0.772	7.0	1.321
1770	1.234	11.3	2.087
1760	1.532	13.9	2.558
1740	2.183	19.8	3.604
1728	2.421	21.9	3.969
1723	1.810	16.4	2.957
1678	2.700	24.5	4.299
1668	2.864	26.0	4.533
1658	2.700	24.5	4.247
1654	2.748	24.9	4.313
1640	2.580	23.37	4.013
1600	2.654	24.05	4.029
1587	2.654	24.05	4.000

Table C.8 Average performance data for diesel fuel.

Engine Speed rpm	Mass kg	Torque N.m	Power kW	Percent of Max Power	Fuel used kg/h	S.F.C. kg/kWh	Th. Eff. %
1000	1.211	11.0	1.150	25.4	0.517	0.450	17.7
1138	1.923	17.4	2.076	45.8	0.882	0.425	18.7
1248	2.148	19.5	2.544	56.1	1.064	0.418	19.0
1284	2.228	20.2	2.715	59.9	1.188	0.437	18.2
1366	2.396	21.7	3.101	68.4	1.326	0.427	18.6
1381	2.470	22.4	3.237	71.4	1.377	0.425	18.7
1464	2.622	23.8	3.642	-	-	-	-
1485	2.663	24.1	3.753	82.8	1.725	0.459	17.3
1527	2.762	25.0	4.000	88.3	1.926	0.481	16.5
1550	2.823	25.6	4.152	91.6	2.034	0.490	16.2

Table C.9 Average performance data for sunflower oil.

Engine Speed, rpm	Mass, kg	Torque N.m	Power, kW	Percent of Max. Power	Fuel used per hour, kg/h	S.F.C. kg/kWh	Th.Eff. %
1000	1.221	11.1	1.158	25.5	0.647	0.558	16.3
1105	1.363	12.4	1.429	31.5	0.780	0.525	17.3
1130	1.906	17.3	2.044	45.0	0.930	0.455	20.0
1210	2.104	19.1	2.416	53.3	1.075	0.454	20.4
1285	2.239	20.28	2.730	60.2	1.190	0.435	20.87
1320	2.314	21.0	2.898	63.9	1.317	0.454	20.0
1370	2.419	21.9	3.145	-	-	-	-
1410	2.595	23.5	3.510	77.4	1.583	0.451	20.13
1445	2.624	23.8	3.560	78.5	1.630	0.458	19.83
1516	2.762	25.0	3.973	-	-	-	-
1551	2.835	25.7	4.172	92.0	2.040	0.489	18.57