Energy, Mines and Resources Canada / Énergie, Mines et Ressources Canada

CANMET

Canada Centre for Mineral and Energy Technology / Centre canadien de la technologie des minéraux et de l'énergie

POTENTIAL OF VEGETABLE OILS AS A DOMESTIC HEATING FUEL

A.C.S.Hayden, C.E.Palmer and E.Bégin
Canadian Combustion Research Laboratory

March 1982

Paper 82-19.1
For presentation to the 75th Annual Meeting,
Air Pollution Control Association
New Orleans, LA, June 1982.

ENERGY RESEARCH PROGRAM
ENERGY RESEARCH LABORATORIES
DIVISIONAL REPORT 82-25(OP)

POTENTIAL OF VEGETABLE OILS AS A DOMESTIC HEATING FUEL

by

A.C.S. Hayden*, C.E. Palmer** and E. Begin***

Abstract

The dependence on imported oil for domestic heating has led to the examination of other potential fuel substitutes. One potential fuel is some form of vegetable oil, which could be a yearly-renewable fuel. In Western Canada, canola has become a major oilseed crop; in Eastern Canada, sunflowers increasingly are becoming a source for a similar oil; for this reason, the Canadian Combustion Research Laboratory (CCRL) has chosen these oils for experimentation.

Trials have been conducted in a conventional warm air oil furnace, fitted with a flame retention head burner. Performance has been measured with pure vegetable oils as well as a series of blends with conventional No.2 oil. The effects of increased fuel pressure and fuel preheating are established. Emissions of carbon monoxide, nitrogen oxides, unburned hydrocarbons and particulates are given for both steady state and cyclic operation.

Canola oil cannot be fired in cyclic operation above 50:50 blends with No.2 oil. At any level above a 10% blend, canola is difficult to burn, even with significant increased pressure and temperature.

Sunflower oil is much easier to burn and can be fired as a pure fuel, but with high emissions of incomplete combustion products. An optimum blend of 50:50 sunflower in No.2 oil yields emissions and performance similar to No.2 oil. This blend offers potential as a means of reducing demand of imported crude oil for domestic heating systems.

---

*Research Scientist, **Research Engineer and ***COOP Student, Canadian Combustion Research Laboratory, ERL, CANMET, Energy, Mines & Resources Canada, Ottawa, Canada K1A 0G1.

Introduction

Recently there has been interest in the replacement of No.2 oil as a domestic heating fuel. In particular, Canada has embarked on a major Off-Oil program, called the Canadian Oil Substitution Program (COSP), designed to dramatically reduce the demand for crude oil in this country over the next decade. In the area of domestic heating, this program concentrates on the replacement of oil with natural gas, propane or wood, along with electricity in those areas of the country where it is not generated by the combustion of oil.

Of long term interest to this program is the potential use of other fuels, such as methanol, as described in Reference 1. Liquid fuels derived from biomass, such as vegetable oils, are another possibility. These offer the allure of renewable energy. As well, being liquids having a high energy density, they can be easily transported and stored. If they can be used in conventional equipment with little or no modifications, a further economic benefit is obvious.

There has been some research carried out with regard to the ease of substitution of vegetable oils in diesel engines, the other main use for middle distillate fuels, as described in References 2, 3 and 4. The authors are unaware of similar activity in stationary source combustion.

The two vegetable oils studied in this paper are canola oil and sunflower oil. In Canada, canola is grown extensively in the Prairie Provinces, with 4 to 8 million acres under cultivation, depending on the market. It is Canada's third most important crop, and yields more than 50% of Canadian vegetable oil utilization. Sunflowers have only one-tenth the acreage of canola in Canada at this time, but it is a rapidly increasing crop, well suited to Canadian climatic conditions.

The Canadian Combustion Research Laboratory (CCRL) has been involved in a major program to reduce oil consumption in home heating in Canada, primarily by improving efficiency with the installation of retrofit equipment such as burner flame retention heads and reduced firing rates, as described in Reference 5.

This paper presents performance data for the combustion of the two pure vegetable oils and of blends with No.2 oil, fired in a conventional oil furnace fitted with a flame retention head burner.

Fuel Properties

A comparison of the properties of canola oil, sunflower oil and No.2 oil are presented in Table I.

While the two vegetable oils have similar properties, they are quite different from No.2 oil. Their specific gravities are about 10% greater than for No.2, yet because of their relatively high oxygen contents, their heating values are about 10% less. The major difference is in the viscosities, which is nearly 15 times higher than for No.2 oil.

In examining the two vegetable oils, their conventional fuel properties seem very similar. The only major difference is in their fatty acid composition. Canola oil has three times as much oleic acid than linolenic, while the reverse is true for sunflower oil. This relative relationship of fatty acids indicates that sunflower oil has a significantly higher instability, which is dependent on the degree of unsaturation (Reference 6).

Unlike some other potential alternate liquid fuels, vegetable oils are miscible with No.2 oil at any temperature and at any ratio, with the properties of the resultant blend lying between those of each pure substance, although not necessarily in a linear ratio.

Experimental Procedure

Results presented in this paper are based on laboratory trials conducted at CCRL. The trials were carried out in a conventional warm air oil furnace with concentric tube heat exchanger, using a high pressure gun-type burner and firing into a ceramic fibre combustion chamber. Initially, a nozzle with a semi-solid spray was used, but a hollow core nozzle was found to give consistently superior results. Similarly, initial experiments were attempted using a cast iron combustion head, but this gave unsatisfactory performance due to poor air fuel mixing. For all subsequent experiments, only flame retenton heads were used. Tests reported herein all used a flame retention head and a hollow core nozzle. As the amount of vegetable oil in the blend increased, a larger flame retention head (i.e. one with greater secondary air opening) was required to give satisfacory performance.

All flue gas properties were measured with continuous analyzers, as follows: carbon dioxide and carbon monoxide with non-dispersive infrared; oxygen with paramagnetic; nitrogen oxides with chemiluminescence; hydrocarbons with a flame ionization detector and smoke with a continuous opacity meter calibrated for particulate loading. A Bacharach smoke tester was also used to give steady state smoke numbers. Flue gas temperatures were measured with CrAl thermocouples. Fuel flow was determined using a balance and a stopwatch.

Measurements were made for both steady state and for the transient start-up, shut-down condition, using a data logging system and magnetic tape.

To overcome the high viscosity of the vegetable oils, the fuel was preheated using heating tape on the line and an in-line preheater located immediately before the nozzle. Fuel temperature was varied to determine optimum performance for each blend. The effects of varying fuel pressure on performance were also examined.

Trials were carried out firing both vegetable oils as "neat" fuels and as a series of blends with conventional No.2 oil. Specific blends run were 75/25, 50/50, 25/75 and 10/90 vegetable oil/No.2 oil, respectively, for both the canola and sunflower oils.

Experimental Results

Canola Oil

With canola oil, it was impossible to obtain cold start ignition of the fuel at blends greater than 50:50. However, if ignition could be achieved artificially, continuous running was possible at 75:25 blends with No.2 oil. Under normal operational settings, with pump pressure at 100 psig and no fuel preheating, performance was poor with high emissions.

Figure 1 shows the effect of increasing pump pressure on the opacity, a measure which was calibrated to particulate loading, for a blend of 75% canola oil, 25% No.2 oil. Increasing pump pressure gave a linear decrease in the opacity reading. As a point of reference, 20% opacity at 10% CO_2 and a stack temperature of 275^{o}C corresponds to a particulate loading of 7.3 mg/kg of fuel burned.

Table II shows the effect of varying fuel pressure upon steady state performance for a 50:50 blend. In this set of experiments, the fuel temperature was held constant at 22^{o}C and the pressure varied from 80 psig to 150 psig, in 10 psig intervals. There is a definite optimum at 120 psig, at Test CP5. At this point, the excess air, flue gas temperature and particulate loadings are lowest, with the efficiency at a maximum. A similar characteristic was observed for all blends with both vegetable oils.

Changing fuel temperature has a significant effect on viscosity, an important factor because of the high viscosity of the vegetable oils. In general, increased viscosity yields an increased flow for high pressure burners. This effect is shown in Figure 2. With oil temperature varied from 22 C to 94 C, heat input to the burner decreased linearly from 148 kBtu/hr to 114 kBtu/hr.

Table III presents steady state and cyclic data for blends of canola from 50% to as low as 10% relative to No.2 oil, all at a number one Bacharach smoke number at steady state. To obtain stable performance at the 50:50 blend, pump pressure was increased to 180 psig and the oil heated to 85°C. Holding the fuel supply parameters constant and decreasing the amount of canola in the blend to 25% showed a 72% reduction in carbon monoxide emissions at steady state, while the cyclic emissions of CO and hydrocarbons were halved. Keeping the same fuel blend, but removing the effect of fuel preheat gave a major increase in the cyclic emissions of unburned hydrocarbons and particulates, while making the fuel somewhat difficult to ignite. At 10% canola, ignition was achieved with no pressure increase nor fuel preheat; all emissions, with the exception of particulates due to cycling, were at the same level as for No.2 oil.

Sunflower Oil

With sunflower oil, performance was markedly better than for canola. Satisfactory ignition and a number one smoke was achieved even with the pure vegetable oil.

Table IV presents steady state and cyclic data for sunflower:No.2 oil blends, ranging from pure sunflower oil to pure No.2 oil. For the blends, fuel pressure and temperature set to achieve best performance. Blends from 75:25 and below show no significant difference in performance, either related to efficiency or emissions. At 25% sunflower oil, good performance results with fuel pressure only slightly above normal, at 120 psig, but with an oil temperature of 83°C. Only at 10% sunflower oil can the normal fuel operating parameters of 100 psig and ambient temperature be used.

In particular, the 50:50 blend of sunflower in No.2 oil gave very good performance, at an oil pressure of 170 psig and a fuel temperature of 69°C. Emissions of carbon monoxide were below those of No.2 oil, while hydrocarbons, steady state particulates and NOX levels were similar. Only the transient cyclic particulate emissions were increased with this sunflower blend.

In all cases, sunflower oil blends required less fuel preheat or pressure augmentation while ignition quality was always superior, when compared to canola oil.

On-Going Research

Experiments are continuing with other vegetable oils to confirm if the fatty acid make-up of the oil is the dominant, or at least the prime indicative factor, of its suitability for combustion in domestic oil burners.

Long term cycling tests with 50:50 blends of sunflower oil are underway to determine if potential failure due to nozzle coking could be a problem in the field.

Conclusions

1. Only high pressure gun-type burners equipped with flame retention heads having increased secondary air openings and fitted with hollow core nozzles are suitable for firing vegetable oil blends.

2. Ten percent blends of canola oil or sunflower oil can be burned in domestic oil furnaces, with no change to the fuel handling system from conventional practice.

3. Sunflower oil and its blends with No.2 oil are much more suitable alternate fuels for domestic heating systems than canola oil. For blends above 25% sunflower oil, fuel in-line preheaters should be installed and fuel pressure increased.

4. Pure canola oil cannot be fired in conventional domestic oil heating equipment at this time, due to poor ignition characteristics. Blends of 50:50 or less of canola in No.2 oil can be considered with significant fuel line preheat and increased nozzle pressure.

5. There is an optimum fuel operating pressure for each blend. This optimum increases with increased vegetable oil content and is higher for canola than for sunflower oil.

6. Long term cycling trials should be carried out to determine if nozzle coking with sunflower oil might be a problem in field operation.

7. Work should continue on vegetable oil characteristics and performance to provide an index of potential combustion suitability.

8. Vegetable oils such as sunflower may have a place as a renewable liquid heating fuel in the future, particularly as a 50:50 blend with No.2 oil, as conventional fuel costs increase and availability decreases, provided it is not at the expense of food supply.

References

1. A.C.S. Hayden, R.W. Braaten and C.E. Palmer, "Methanol as a domestic heating fuel", APCA Paper 81-8.6, 74th Annual Meeting of Air Pollution Control Association, Philadelphia, June 1981.

2. R.C. Strayer and W.K. Craig, "Canola oil as a fuel for diesel engines", CI/CS Paper 81-7, Annual Meeting of Combustion Institute, Canadian Section, May 1981.

3. M. Ziewjewski and K.R. Kaufman, "Endurance test of a sunflower oil/diesel fuel blend", North Dakota State University, SAE Paper 820257, February 1982.

4. R.A. Baranescu and J.L. Lusco, "Sunflower oil as a fuel extender in direct ignition turbocharged diesel engines", International Harvester, SAE Paper 820260, February 1982.

5. Hayden and Braaten, "Domestic oil heating systems retrofit to save energy", Proceedings, IEA First International Conference on Energy Conservation Technology, Berlin, April/81.

6. M. Vaisey-Gender and N.A. Michael Eskin, "Canola oil, properties and food quality", University of Manitoba, Publication No.55, Rapeseed Association of Canada, Winnipeg, August 1979.

Table I. Fuel Properties.

	Canola	Sunflower	No.2
Ultimate Analysis, kg/kg			
Carbon	.778	.776	.875
Hydrogen	.119	.109	.121
Oxygen	.103	.115	–
Sulphur	–	–	.003
Higher Heating Value, Btu/lb	17424	16782	19276
Specific Gravity	0.917	0.924	0.861
Flash Point, °C	213	227	50
Viscosity at 40°C, cSt	35.0	33.7	2
Fatty Acid Composition			
16:0 Palmitic	4	6	
18:0 Stearic	2	5	
18:1 Oleic	60	18	
18:2 Linoleic	20	64	
18:3 Linolinic	10	1	

Table II. Effect of oil pressure on steady state performance of 50:50 blend of canola in No.2 oil.

Test No.	CP1	CP2	CP3	CP4	CP5	CP6	CP7	CP8
Heat Input, kBtu/hr	127	137	143	146	149	159	161	141
Flue Gas Comp., % by v.								
CO_2	6.6	7.0	6.9	7.2	8.0	6.6	6.5	5.6
O_2	12.5	12.3	12.3	12.0	10.5	12.5	12.7	14.2
Excess Air	130	117	120	112	91	130	134	170
Flue Gas Temp., °C	342	353	353	355	340	353	361	330
Emissions, g/kg fuel								
CO	2.19	1.72	2.09	2.34	2.11	1.82	1.85	3.44
HC	.17	.13	.10	.06	.04	–	–	–
Particulates	1.00	.50	.36	.15	.13	.16	.16	.36
NOX	1.28	1.41	1.61	1.61	1.75	1.94	2.16	2.65
Steady State (ss) Effic., %	69	70	70	71	74	68	68	67
Oil Temperature, °C	22	22	22	22	22	22	22	22
Oil Pressure, psig	80	90	100	110	120	130	140	150

Table III. Performance of optimized canola blends for steady state and cycling operation.

Test No.	C1	C2	C3	C4	C5
Heat Input, kBtu/hr	82	76	88	62	64
Ratio Canola:No.2	50/50	25/75	25/75	10/90	0/100
Flue Gas Comp., % by v.					
CO_2	10.5	11.4	12.8	8.9	11.9
O_2	9.6	8.4	7.4	10.7	7.8
Excess Air	47	33	33	41	26
Flue Gas Temp., °C	289	251	268	213	216
Emissions					
CO ss, g/kg	.749	.208	.052	.091	.215
cyclic, g/cycle	1.38	.749	.729	.579	.777
HC ss, g/kg	-	-	.057	-	.125
cyclic, g/cycle	.336	.182	.896	.082	.156
Particulates ss, g/kg	.083	.079	.073	.067	.072
cyclic, g/cycle	.52	5.6	81.8	39.4	4.6
NOX ss, g/kg	1.18	.92	1.44	2.20	1.41
Steady State (ss) Effic., %	81.0	83.0	84.0	84.0	85.0
Oil Pressure, psig	180	180	180	100	100
Oil Temperature, °C	85	88	22	22	22

Table IV. Performance of optimized sunflower blends for steady state and cycling operation.

Test No.	SF1	SF2	SF3	SF4	SF5	SF6
Ratio Sunflower:No.2	100/0	75/25	50/50	25/75	10/90	0/100
Heat Input, kBtu/hr	114	131	99	76	77	76
Flue Gas Comp., % by v.						
CO_2	10.2	12.5	14.1	10.8	11.5	11.1
O_2	10.0	7.3	5.5	9.1	8.4	8.8
Excess Air	56	28	11	41	32	35
Flue Gas Temp., °C	341	321	288	255	271	255
Emissions						
CO ss, g/kg	.227	.052	.015	.346	.093	.230
cyclic, g/cycle	2.022	.278	.081	.997	.543	.457
HC ss, g/kg	.028	.079	.051	–	.021	–
cyclic, g/cycle	.154	.151	.132	.379	.221	.041
Particulates ss, g/kg	.096	.078	.067	.083	.083	.084
cyclic, g/cycle	6.65	4.02	6.86	6.01	3.20	1.77
NOX ss, g/kg	1.17	1.18	1.33	1.62	1.41	1.43
Steady State (ss) Effic., %	77.0	81.0	84.0	83.0	82.0	83.0
Oil Pressure, psig	190	190	170	120	100	100
Oil Temperature, °C	83	75	69	83	22	22

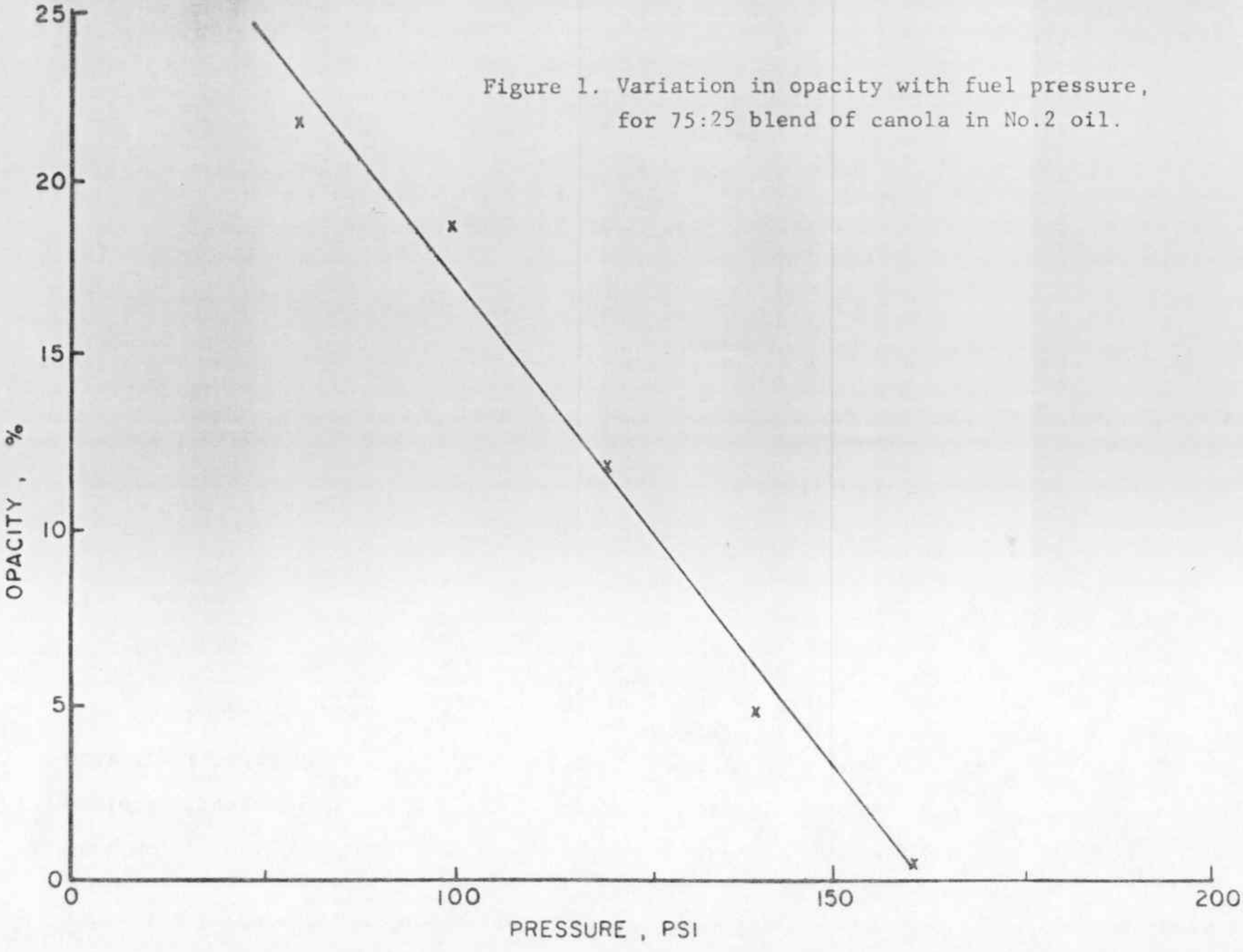

Figure 1. Variation in opacity with fuel pressure, for 75:25 blend of canola in No.2 oil.

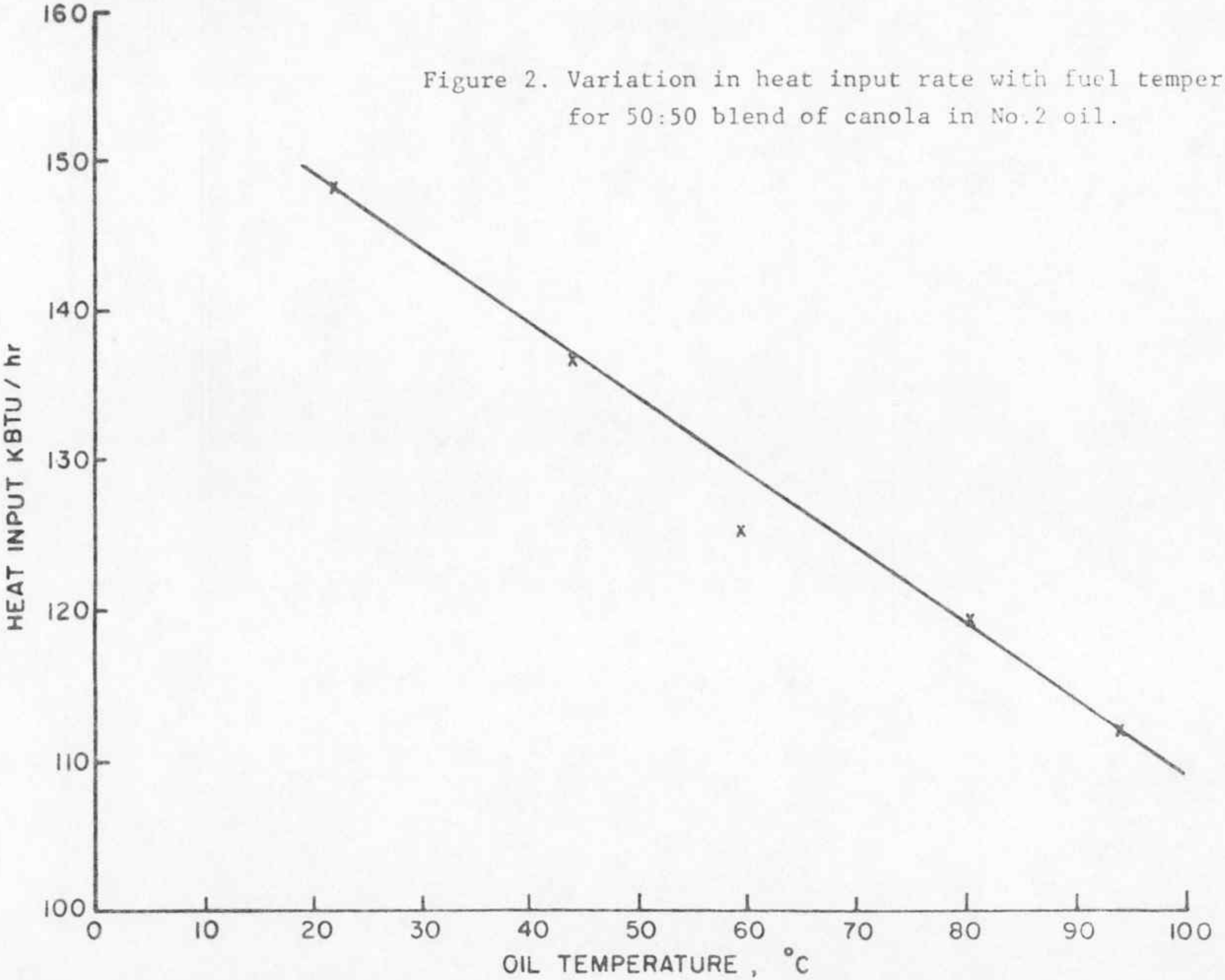

Figure 2. Variation in heat input rate with fuel temperature, for 50:50 blend of canola in No.2 oil.