

A STUDY OF THE COMBUSTIBILITY
OF WEATHERED CRUDE OILS AND
WATER-IN-OIL EMULSIONS

A Study of the Combustibility of
Weathered Crude Oils and Water-in-Oil Emulsions

by

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ABSTRACT

A laboratory study is described in which the combustibility of fresh and weathered crude oils, petroleum products, and water-in-oil emulsions was investigated. A small-scale burning apparatus has been designed and operated to yield data on the ease of ignition, duration and conditions of burning and the fraction burned. Satisfactory correlation exists between these laboratory tests and larger field tests on the same oil reported by Energetex, except that the fraction burned is consistently higher in the laboratory tests, probably as a result of insufficient radiant heating from the smaller flame. Weathering results in loss of volatiles, more difficult ignition, slower burning and, in some cases, surprisingly higher fractions burned. An attempt is described to assemble a simple mathematical model of ignitability as a function of oil fire point and thickness, and the characteristics of the igniting device. The model satisfactorily describes the qualitative ignitability observations and, with further development, may be capable of being used to predict the ignitability of various oils and emulsions under various conditions.

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RESUME

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1. INTRODUCTION

One of the more attractive methods of treating crude oil spills in the Arctic is to burn the oil in situ on water or ice surfaces. It is possible that the lower temperatures which prevail over much of the Arctic year will result in (i) the slower loss of volatiles from the oil, thus maintaining the oil in an ignitable state longer because of the lower fire point and (ii) slower spreading thus leading to thicker oil slicks or pools which will be more readily ignited. The presence of ice may block spreading and may act as a platform for burning oil spilled under first year ice. Because of the problems of lack of a labour force and accommodation and the hazards of operating in ice-infested marine environments a particularly attractive option is the aerial deployment of incendiary devices to ignite the oil or the use of portable flame throwing equipment.

The general issues of Arctic oil spill countermeasures have been reviewed by Logan et al. (1, 2), Ross et al. (3), and Greene and Mackay (4). The feasibility of aerial ignition of oil has been examined by Cormack (5) and actual devices developed and tested by Energetex (6). Experimental oil burns have been reported by Norcor (7) by Coupal (8) and by Day et al. (9), the latter also examining the nature of the emissions. A comprehensive review of oil burning as an oil spill treatment has been compiled by Battelle (10).

In this work the aim has been to examine the effect of oil temperature, evaporation (or weathering) and water content on its ignitability. An experimental laboratory apparatus has been devised which enables the burning of an oil pool to be examined in detail. The ease of ignition (characterised as energy input necessary to cause ignition) is measured, as are temperatures, burn duration and amounts of residue left after burning. A mathematical description of the burning process enables the results to be fitted to a correlation procedure thus permitting interpretation, interpolation and even modest extrapolation. Although there has been considerable work on combustion of hydrocarbon fuels, especially in droplet form, and also from flat surfaces and on the behaviour of fires of plastic materials (see Glassman (11) for review) there has been to our knowledge no study of the in situ combustion of crude oil, taking into account temperature and prior weathering which decreases ignitability because of loss of volatiles.

A related area of interest is the ignitability of water in oil emulsions.

It is believed that the ignitibility and subsequent burning behaviour of a crude oil depend on the following factors:

- (i) Oil composition, particularly volatility
- (ii) Oil slick dimensions, thickness and width
- (iii) Ambient temperature
- (iv) The presence of emulsified water in the oil
- (v) Wind conditions

This work seeks to quantify the effects of the first four variables. It is hoped that by undertaking laboratory and larger-scale "field" tests on the same oils it may be possible to obtain a correlation between the results, thus permitting the cheaper, faster and better controlled laboratory test to be used to predict full scale burning behaviour.

2. EXPERIMENTAL

The apparatus is illustrated in Figure 1. A circular brass dish (6.8cm in dia. and 1.5cm in depth) was used for the combustion of the oil samples. The dish (substrate) temperature and the initial temperature were controlled by silver soldering a second dish on to the bottom of the combustion vessel with inlet and outlet ports for circulation of the cooling fluid which was circulated from a refrigerated bath.

A nickel-chromium wire of known resistance was used to heat the crude oil to permit ignition. A small propane flame (approx. 5mm dia. by 1cm long) was used to ignite the crude oil. The heating wire was submerged just beneath the surface of the oil for each run. Current was supplied by a D.C. power supply and an Acromeg Linear Current integrator was used to measure the total number of coulombs passing through the ignition wire. A 10 Mohm input impedance multi-meter with a full scale accuracy of 3% was used to measure the voltage drop across the ignition wire.

Four electrical 750 watt ring heaters of diameter 13cm placed approximately 5cm above the oil surface, were used to maintain the oil temperature close to the flame temperature during burning. It was observed that their use resulted in considerably higher burning efficiencies as a result of the radiant heating of the oil. It is believed that their use results in a closer simulation of actual oil burning conditions since a large-scale fire experiences more efficient radiation to the evaporating surface.

Chromel - Alumel thermocouples coupled to a Bailey Instruments digital thermometer were used to measure the dish, oil and flame temperature during the burn.

Air was supplied from a pump to the system by 8 separate lines located concentrically about the combustion vessel, four of which were directed to the surface to ensure efficient burning as shown in Figure 1. Each of the lines was connected to a common manifold, and the air velocity was determined by an orifice plate meter.

The combustion vessel rested on a brass support plate and was electrically as well as thermally insulated from the plate. An approximately 1cm thick glass column 45.7cm in height and 15.2cm in internal diameter

was placed over the combustion vessel to improve flame stability.

Several types of crude oil and products were used in this work, as tabulated later. The experimental procedure was the same in each case. A volume of oil 1cm thick was placed in the dish, and the cooling fluid circulated. When the oil reached the required temperature, the air pump was turned on at a flow rate of 90 l/min. and the propane flame was lighted. Current was supplied to the ignition wire to ignite the oil. When the oil started to ignite, the electric radiant heater above the oil (which was turned on approx. 30 minutes earlier to make it red hot) was lowered to a height of 5cm above the oil surface. The time to ignite the oil and the duration of the burn were both recorded. If the oil failed to ignite, the current was turned off and the oil was allowed to cool. The voltage was then adjusted to increase the current and the operation was repeated until the oil ignited. The voltage drop at ignition and the total number of joules supplied through the heater and the oil, substrate and flame temperatures were recorded.

At the completion of the burn, the amount of residual oil was recorded. The residual mass was also collected into plastic bottles.

Water in oil emulsions were formed by mixing oil and water in a blender. Water contents were determined by dissolving the emulsion in heptane and distilling out the water, i.e., using the "Dean and Stark" technique. Weathered oil samples were obtained by evaporating the oil in a wind tunnel.

Standard ASTM D86 boiling point vs. fraction distilled curves were prepared for the Alberta crude oil at various degrees of weathering. Gas chromatographic analyses of oil samples were done on a Hewlett Packard 700 instrument with a 10 ft by 1/8 inch SS column packed with 10% SE 30 ultraphase on chromosants P-AW-DMCS-60/80 mesh with a FI detector and 3380A Integrator. Temperatures were programmed from 50°C to 280°C at 10°C per minute.

3. RESULTS

The results of the tests on the various crude oil samples supplied by Energetex are presented in Table 1 and the data from their emulsion samples are given in Table 2.

To provide a more accurate picture of the effect of weathering on combustibility an Alberta crude oil sample was weathered in a wind tunnel and the combustion characteristics measured, the results being given in Table 3. In addition Table 4 gives similar data for one oil at various water contents.

These data are also illustrated in Figures 2 to 14 to aid interpretation.

4. DISCUSSION

It is useful first to discuss the data from the tests on the Alberta crude oil as presented in Table 3. As expected, the ignition time and energy increased considerably as the oil weathered, the reason being that the fire point increases and thus it is necessary to heat the oil more in order to obtain a sufficient rate of vapour evolution to sustain combustion. It may be possible to relate these energies to ignition energy requirements. The burning times increased steadily with weathering, reflecting a slower combustion rate presumably attributable to a lower oil vapour pressure during combustion. The weathered oils gave flames which were noticeably weaker. The oil temperatures were higher for the fresher oils probably as a result of more radiation from the more intense flames. The differences in temperature were not, however, very large. The indicated flame temperatures (which are really the temperatures of the thermocouple rather than the flame) were consistently higher for the fresher oils. The burning efficiencies were rather surprising in that it was expected that weathering would reduce efficiency. On the contrary, the efficiency increased significantly, as shown in Figure 2, until 35% weathering then fell rapidly. This suggests a critical degree of weathering beyond which efficiency falls. It would be useful to know at what time this is reached.

The emulsion data in Table 4 show that as expected more energy is necessary to ignite the oils containing water, presumably due to the need to heat and evaporate some water. The oil burning temperature fell as the water content increased due to the cooling effect of the water. Flame temperatures were also correspondingly lower. The oil burning efficiency (defined as the fraction of the oil which burned) also fell. The higher water content oils showed a greater volume reduction because the water was eliminated; thus the effect of water is to reduce the amount of oil which can be burned but increase the amount of oil plus water (i.e. mousse) which is destroyed. In these experiments the oil-water mixture was always at an initial thickness of 1cm, thus there was less oil when the water content was high. The duration of the burn was thus as expected considerably shorter for the higher water content oils since less oil was burned. The oil burning rates are approximately equal.

The distillation curve data in Figure 3 illustrate the effect of

weathering to be as expected an increase in the initial boiling point and a general movement of the curve to the left and upwards.

Turning to the data from the Energetex samples, in Table 1 the same general pattern emerges. More weathered oils required greater ignition times and energies (Figures 4 and 5), gave lower oil and flame temperatures (Figure 6), burned longer (Figure 7), and usually gave higher burning efficiencies (Figure 8). The marine diesel proved to be most difficult to ignite. Surprisingly the Bunker C was ignited quite easily possibly because its high viscosity permitted intense local heating. In general the final oil thickness was in the range of 1 to 2 mm.

The emulsion data in Table 2 and Figures 9 to 12 are also consistent with the earlier results, high water contents leading to more difficult ignition, shorter burns (but at similar oil burning rates), lower temperatures and lower burning efficiencies.

It had been hoped that the two sets (field and laboratory) of data would give similar results for burning efficiency, enabling the laboratory test to be used to estimate field burning efficiency. Examination of the data shows that the residual oil thicknesses obtained by Energetex were consistently 0.3 to 0.6 mm and mostly about 0.5 mm. There is no systematic trend in the data. The laboratory test gave greater variation and usually higher residues, probably because of less intense radiation during burning.

It is thus concluded that the sets of tests give a broadly consistent picture of the burning characteristics of crude oil and emulsions.

Two issues remain to be examined, the reason for the surprising increase in burning efficiency, and the correlation between "field" and laboratory data.

The increase in burn efficiency is surprising because the fresher oil contains a higher proportion of volatile components which should tend to burn more efficiently. Several explanations can be advanced to explain this anomaly.

- (1) The fresher oils are less viscous and may conduct heat by

convection to the substrate more rapidly. If this were the case the oil temperature would be lower for the fresher oils but in fact the opposite was found, especially for the final oil temperature.

(2) During combustion the hotter, fresher oil undergoes some form of coking reaction resulting in formation of a less combustible residue. GC analyses were done of fresh and weathered crude and marine diesel oils and of the residues. The traces given in Figures 13 and 14 show the usual weathering but show no detectable change in the residues after burning. Cokes, of course, would not show up on the chromatograms. Surprisingly, there is still a considerable quantity of volatile oil present in the residue, even as low as C_{14} or C_{15} . This suggests a third explanation.

(3) During the burning process there is more effective transfer of the volatile components to the surface because of the lower viscosity. Thus although initially present in large quantities, they become more rapidly depleted from the oil at depths. Comparison of the GC traces of the residues of the crude oil does not support this.

(4) In a study of burning of liquids in pools, Roberts and Quince (12) suggested that when m-xylene was burned it formed a low emissivity diffusion flame but as the burning rate increased the flame emissivity increased rapidly leading to cooling and extinction. A less intense, slow burning flame may thus be more effective in radiating heat back to the oil per unit mass of oil burned. A more intense flame may be less stable. Certainly the fresh oil flames were initially much brighter and intense. It remains difficult to explain why the fresh oil flame does not revert to a less intense lower emissivity flame at a late stage in the burning.

(5) In the Energetex report it is suggested that "micro-explosions" or sputtering of the oil (presumably caused by local overheating of oil or water) propelled non-volatile oil into the flame resulting in better combustion. This appears to occur more for weathered oils, possibly because of higher viscosities. The validity of this suggestion cannot be tested.

It was noted that the weathered oil burned more slowly than the fresh oil, thus it is possible that more time was available to heat the substrate and fractionate out the more volatile material.

This issue is probably of greater scientific interest than it is relevance since the effect is quite small, corresponding to about an 8% difference in burning efficiency.

An objective of this study was to determine if a correlation could be established between the laboratory data and those obtained in full-scale tests by Energetex (1979). Further, it is interesting to analyse the Energetex data in an attempt to predict combustibility from oil properties.

The oil properties most likely to be useful in predicting ignitibility are fire point, flash point and initial boiling point (IBP).

Examination of the data showed that the fire point was an average of 9°C higher than the flash point; however the data are quite variable as indicated in Figure 15 (Table 6). Since fire point is the more significant quantity, it was used in further correlations.

Figure 16 is a log-log plot of IBP versus fire point and gives a regression equation.

$$\begin{aligned} \text{IBP} &= 11.0 (\text{Fire Point})^{0.6} && (\text{temperatures in } ^\circ\text{C}) \\ \text{or } \text{Fire Point} &= 0.018 (\text{IBP})^{1.67} \end{aligned}$$

Relationships between flash point and IBP can be obtained by substituting (flash point + 9) for fire point in the above equations.

An alternative relationship between IBP and fire point is suggested by postulating that the oil vapour pressure must be raised to some critical value in order to support combustion. The IBP usually exceeds the fire point by 30 to 100°C, thus the fire point corresponds to a vapour pressure below 1 atmosphere. The Clapeyron-Clausius equation can be used to calculate the vapour pressure P at the fire point F(K) by assuming that the vapour pressure is 1 atm at the IBP (K) as follows:

$$\ln(P/1.0) = \Delta H \{1/(IBP) - 1/(F)\} / R$$

Here ΔH is the enthalpy of vaporization (approximately 7000 cal/gmol) R is the gas constant (2.0 cal/gmol K) and the temperatures are in absolute units (K). A plot of the reciprocals of IBP and fire point is given in Figure 17. The mean difference in reciprocal temperatures is 0.00045 K^{-1} corresponding to a vapour pressure at the fire point of 0.2 atm.

It is also interesting to compare the fire point with the oil temperature at ignition as measured in the laboratory apparatus as plotted in Figure 18. It appears that volatile oils of low fire point had to be heated above the fire point by 20 to 40°C to achieve ignition. This is presumably a function of air flow over the oil surface. For less volatile oils agreement is better. It is apparent that these two quantities are essentially measurements of the same quantity.

In this study the best characterisation of ignitibility is ignition energy which is plotted in Figure 19 against fire point and in Figure 20 against the laboratory oil ignition temperature. It is apparent that the relationship is highly non linear, i.e., high fire point oils require disproportionately large amounts of ignition energy. The reason for this is that to heat an oil to say 150°C from 0°C takes longer and is thus less efficient than heating an oil to say 100°C as a result of heat loss during the heating period.

An elementary analysis can be used to suggest a relationship between heating time, energy and fire point.

If we consider a mass of oil M g of heat capacity C_p (J/gK) at an initial temperature T_0 (K) heated at a constant rate H J/s but losing heat at a rate $h(T-T_0)$ J/s when at a temperature T (K) then a differential heating equation can be written in time t (s)

$$H - h(T-T_0) = d(MC_p T)/dt$$

The h term is a combined heat transfer area and heat transfer coefficient. Integrating from zero time gives

$$T = T_0 + (H/h) (1 - \exp(-ht/MC_p))$$

Since the heating rate is H J/s, the total energy used to reach T is Ht (J). Interestingly when t is large T tends to a maximum temperature $(T_0 + H/h)$ at which the input heating rate H equals the loss rate $h(T-T_0)$. The relationship between fire point (T) and ignition energy (I) should thus be of the form above which can be rearranged to give

$$\ln(1 - (h/H)(T-T_0)) = -hI/HMC_p = -ht/MC_p$$

This suggests plotting $(1 - (h/H)(T-T_0))$ against I or t on semi log paper from which the slope can be used to give a value for (h/MC_p) . This plot requires

prior knowledge of (h/H) but this can be estimated as the asymptotic value of T when the ignition energy tends towards infinity. For the laboratory results this is approximately 170°C , thus (h/H) is 0.006. Such a plot is given in Figure 21.

In the Energetex study the best indications of ignitibility are pre-heat time, ignition time or their sum which are plotted in Figure 22 (Table 5) against fire point for several oils. The graph clearly shows that prolonged ignition times are necessary when the fire point becomes large. These data suggest that there is some maximum attainable value of oil temperature (i.e., H/h) for a given igniting system. If this exceeds the fire point ignition is achievable, if not ignition is not achievable. The data in Table 14 of the Energetex report suggest that this maximum temperature (H/h) is dependent on oil thickness, being lower for thin oil slicks which are more readily cooled. It can be postulated that if two slicks of different thickness are heated at the same rate H then the temperature of the thin slick will increase faster because of its lower thermal mass MC_p but it may lose a higher proportion of volatile material and achieve a lower final temperature because of faster heat transfer to the substrate.

If a body of oil of unit area is heated from above at a rate H J/s and reaches steady state with transfer to the substrate then H will equal $K\Delta T/Z$ where ΔT is the temperature gradient across the oil, K is the thermal conductivity and Z is the oil thickness. Assuming a constant substrate temperature T_o , the upper oil surface temperature T_s will thus be

$$T_s = T_o + \Delta T = T_o + HZ/K$$

For a given H and K there is thus a maximum T_s which can be achieved dependent on Z . Thick oil pools can achieve hotter upper surfaces than thin oil pools. The term h as used earlier can be regarded as essentially K/Z , thus a useful indicator of oil ignitibility is the group H/h or HZ/K which has units of temperature and represents a maximum achievable upper oil surface temperature and which may or may not exceed the fire point depending on Z , K and the heating rate H .

For a 1 cm (0.01 m) oil pool this temperature may be 200°C , and above the fire point, implying a value of 20000 for H/K , thus for a 5 mm pool HZ/K .

is 100°C and possibly below the fire point. It is thus suggested that for a given igniting device (i.e., given H) the criterion of ignitibility is that HZ/K exceeds the fire point.

An additional complication is that if the pre-ignition period is too long there will be a loss of volatiles, thus an increase in IBP and fire point, thus the oil temperature may be rising towards an ever increasing target ignition or fire point temperature. For thin slicks it is possible that the increasing fire point "outstrips" the oil heating and no ignition is achieved, only some volatile material is lost. An important implication (if this conjecture is valid) is that the best igniting devices will release heat very rapidly and thus reduce pre-ignition times.

A final version of the heating equation which contains the oil thickness but not the volatilisation effects is thus

$$\ln(1 - \{K/ZH\}(T - T_0)) = -Kt/ZMc_p$$

but since M is ρZ for unit area, where ρ is density, the right hand side becomes

$$-Kt/Z^2 \rho c_p$$

Assuming that most oils have similar values for K, ρ and c_p this can be simplified to

$$- Ct/Z^2$$

where C is a constant.

Figure 23 is an illustrative plot of this equation for the stated values of C , K/H and Z . The K/H value of 0.00006 was deduced from the H/h or HZ/K value of 170° and Z of 0.01 m, the C value was deduced from the observation that a typical long but successful pre-ignition time is 200s thus assuming that this corresponded to a 70% approach to the asymptotic temperature, the group Z^2/C must be approximately 200s, which for a 1 cm slick gives C equal to 5×10^{-7} .

This figure shows that thin slicks heat up faster but reach a lower steady state temperature than thick slicks. By comparing the oil fire point with these temperature curves it is possible to determine the minimum thickness which can be ignited by a given device. For example, if the oil

fire point is 80°C slicks thinner than 5 mm cannot be ignited unless the heating rate H is increased. For a slick of thickness 1 cm and fire point 80°C, the ignition time must be at least 120s, and preferably longer. This set of curves thus provides a rational method of estimating ignitibility as a function of oil fire point, thickness and the heating rate of the device.

In any assessment of the feasibility of burning oil which has migrated through first year ice it is thus initially important to know what spectrum of thickness the oil will have and the corresponding degrees of weathering. The processes of migration, slick thickening and natural evaporation result in formations of oil pools which may or may not be ignitable. It appears that this entire process may be capable of mathematical description. The weakest link is information about pool depths. It is thus essential to gather information on the rate of oil migration to the surface.

The overall process of oil migration, natural evaporation, attempted ignition and burning is illustrated conceptually in Figure 24 for successful and unsuccessful burning attempts. The aim of future research efforts should be to quantify these processes in order that the feasibility of burning can be accurately assessed.

5. CONCLUSIONS

A small scale oil burning apparatus has been designed, operated, and modified which is capable of yielding data on the ignitability of crude oils, petroleum products and water-in-oil emulsions.

Ignitability and burning data from the apparatus and from full-scale tests by Energetex show satisfactory agreement. Less satisfactory agreement is obtained for the fraction of the oil left unburned. This fraction is higher in the laboratory apparatus. It thus appears that the laboratory test can give useful information about the feasibility of oil combustion.

A simple mathematical model is presented of the ignition process which could possibly be developed into a predictive method for assessing the feasibility of igniting and burning oils of various types, degrees of weathering, water contents and slick thicknesses.

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Cut-Away Side View

Top View of Burning Cup

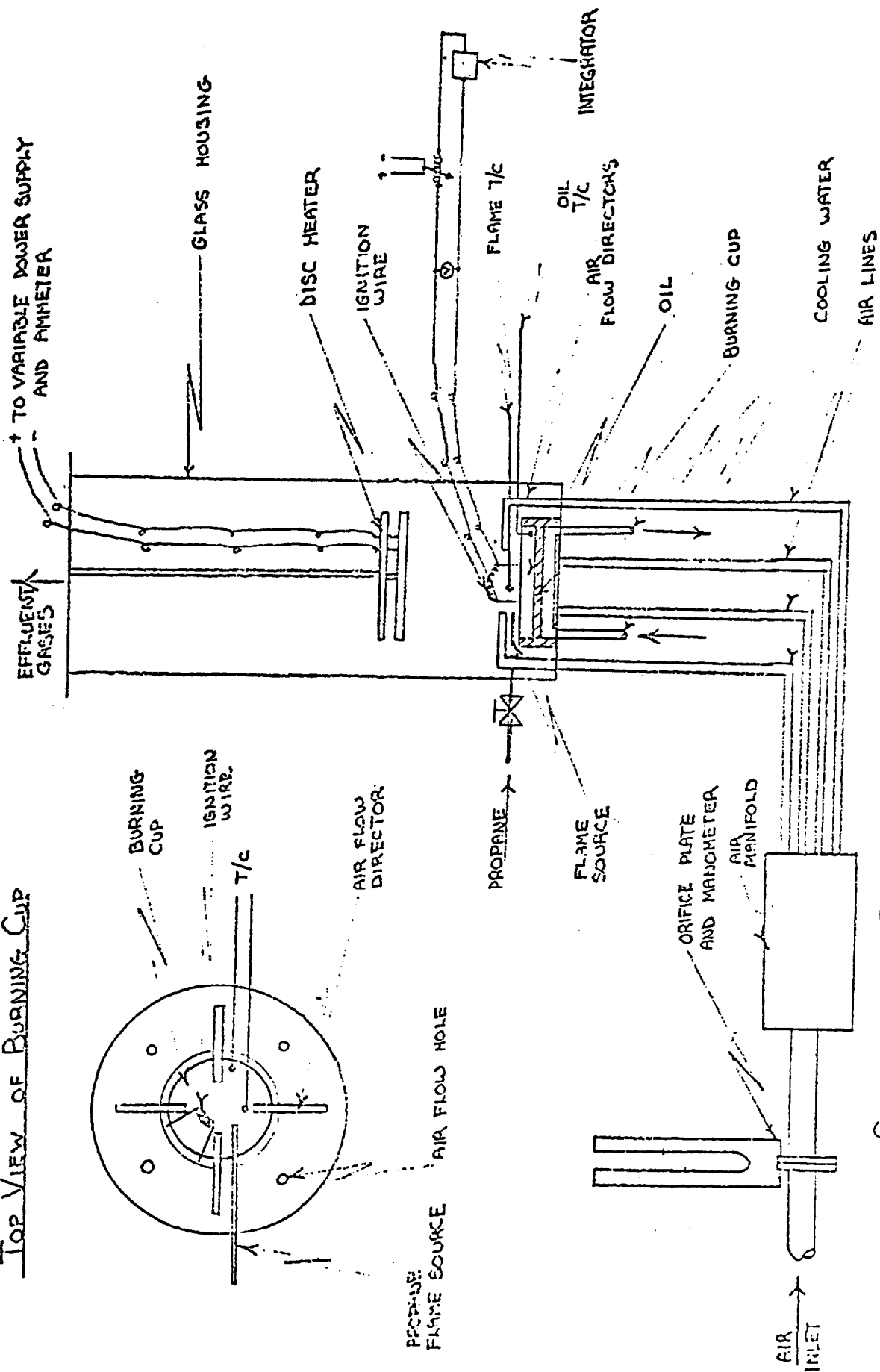


Figure 1. SCHEMATIC DIAGRAM OF OIL BURNING APPARATUS

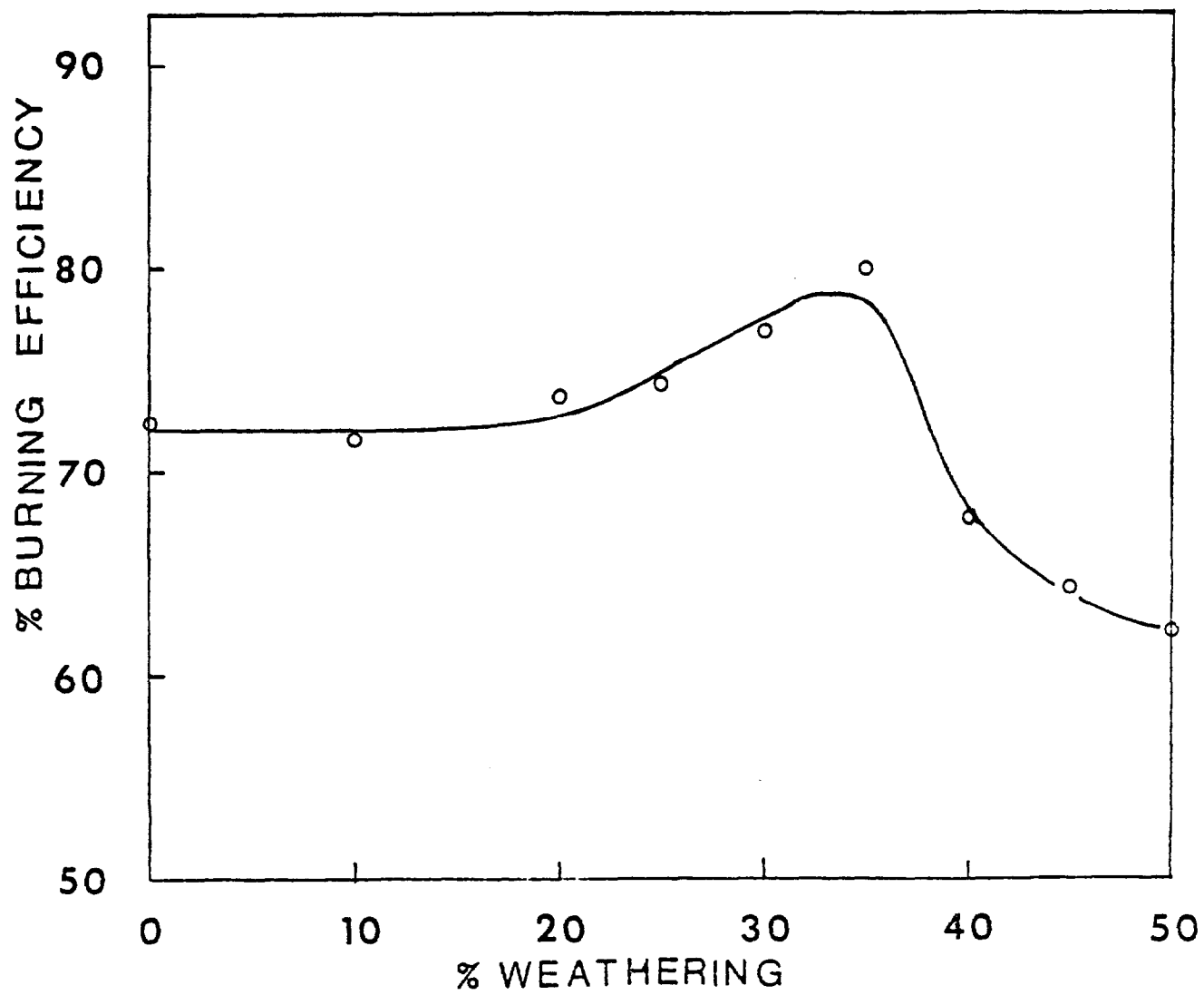


Figure 2. Effect of weathering on burn efficiency

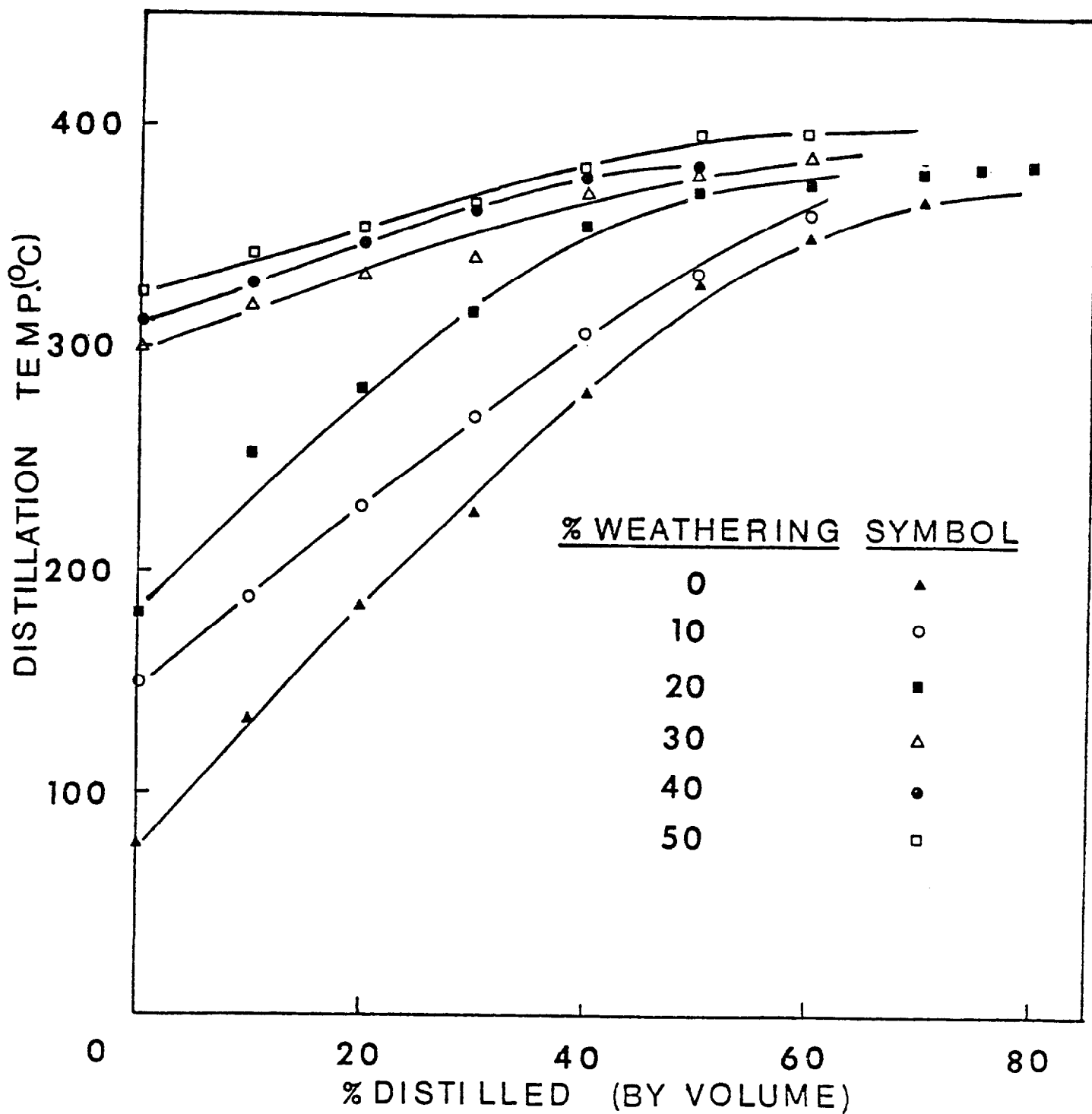


Figure 3. Distillation curves for Alberta crude oil

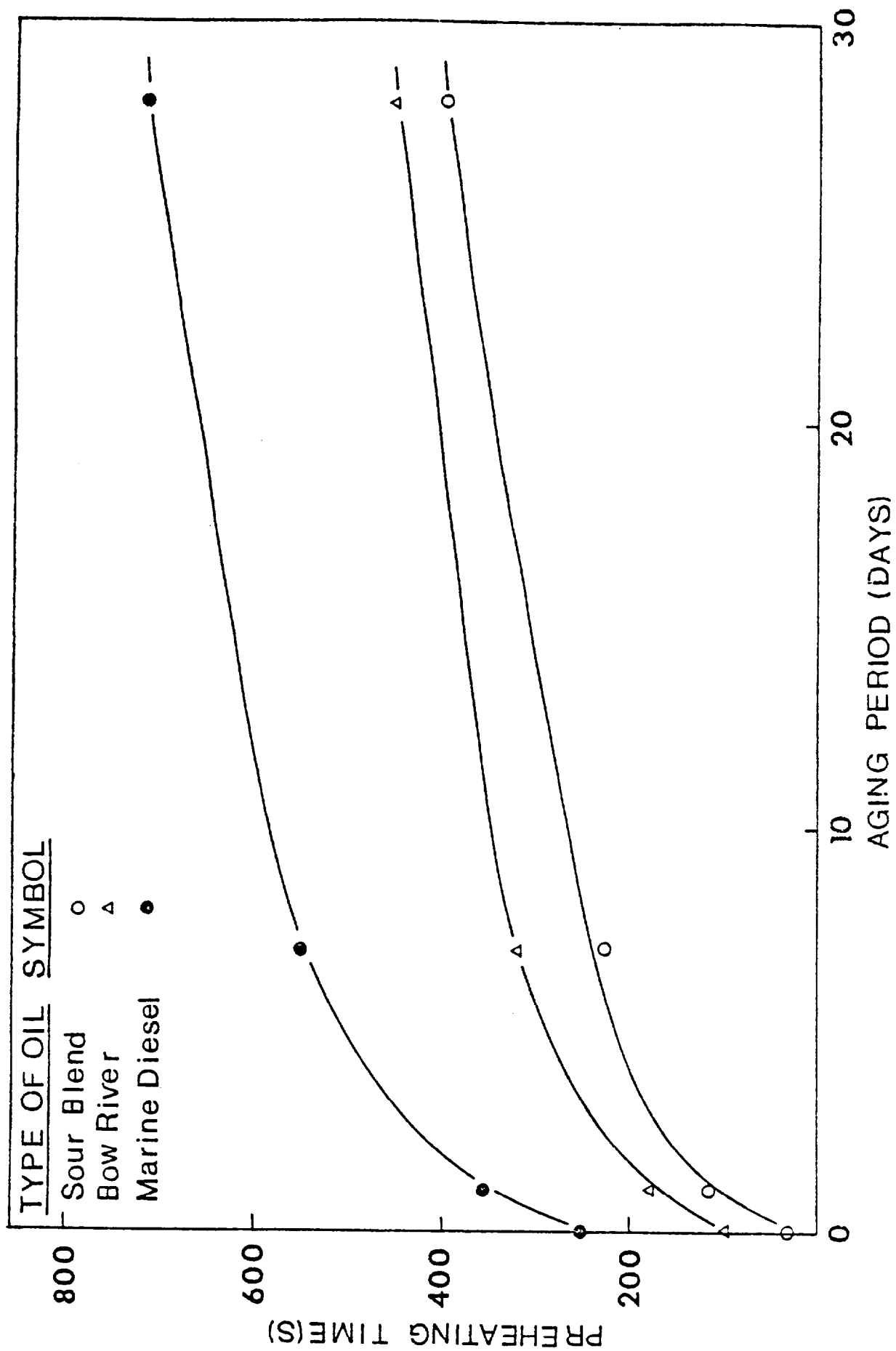


Figure 4. Preheating time vs aging period

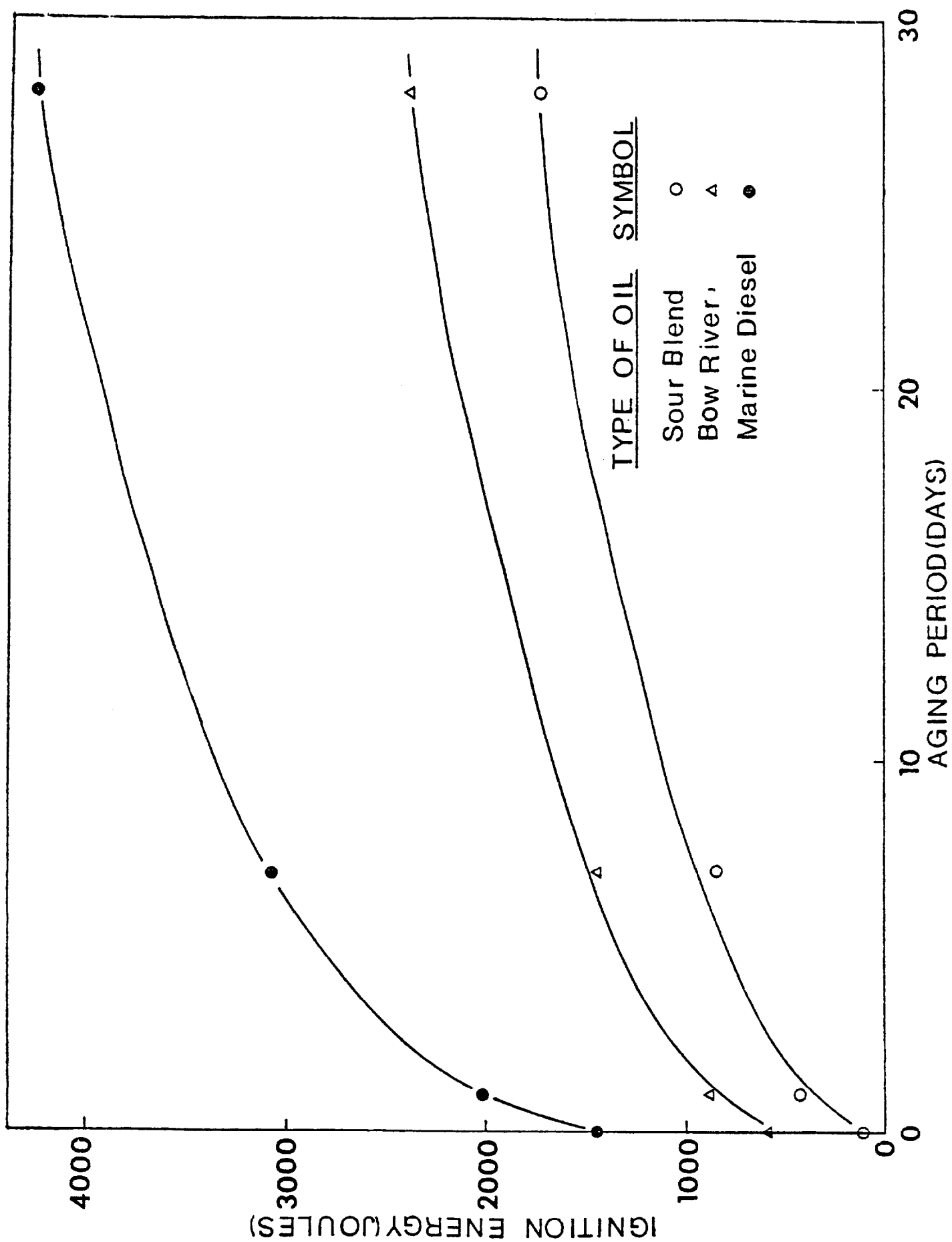


Figure 5. Ignition energy vs aging period

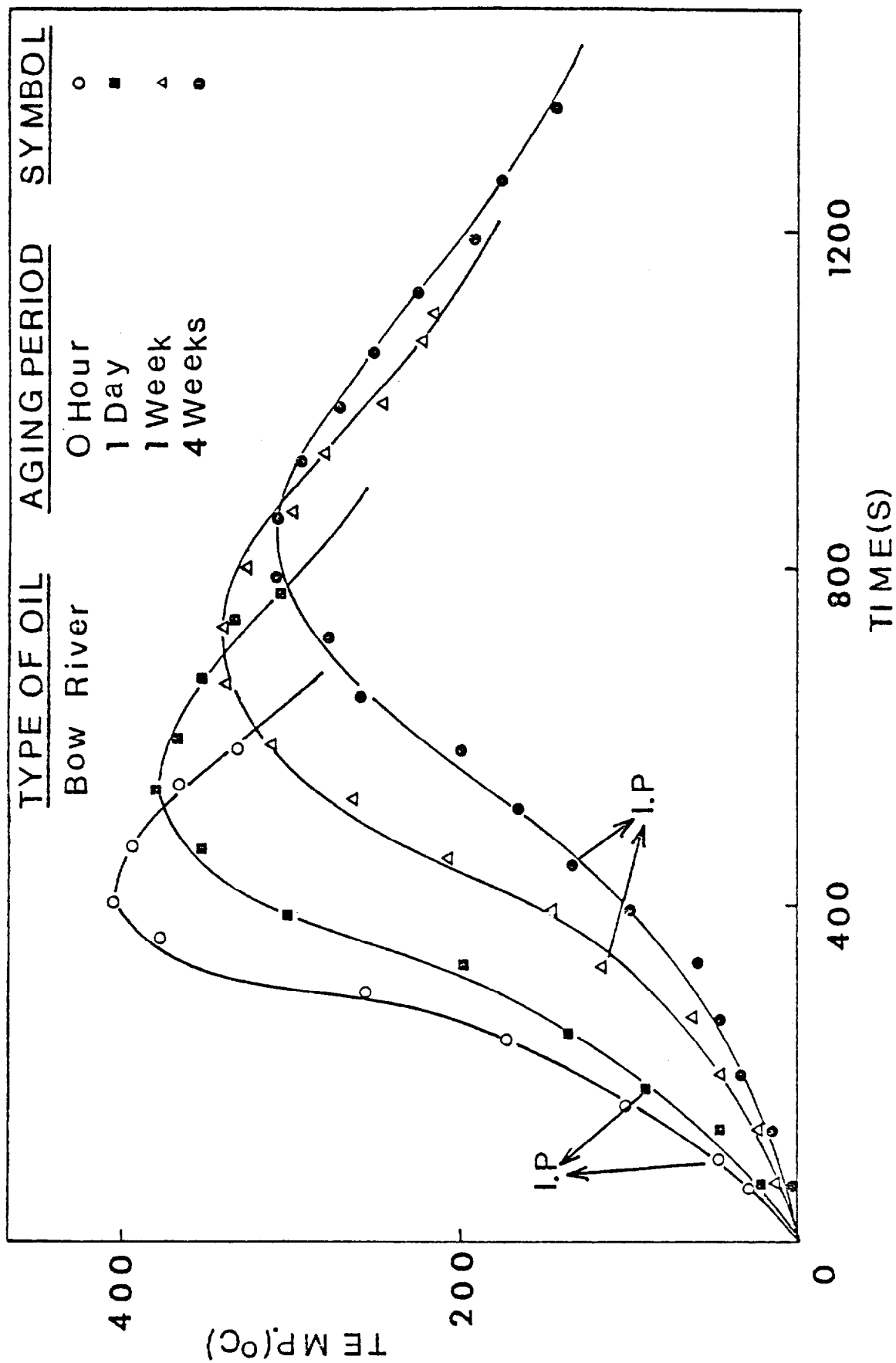


Figure 6. Variation of temperature with burning time for various aging periods
I.P. - Ignition point

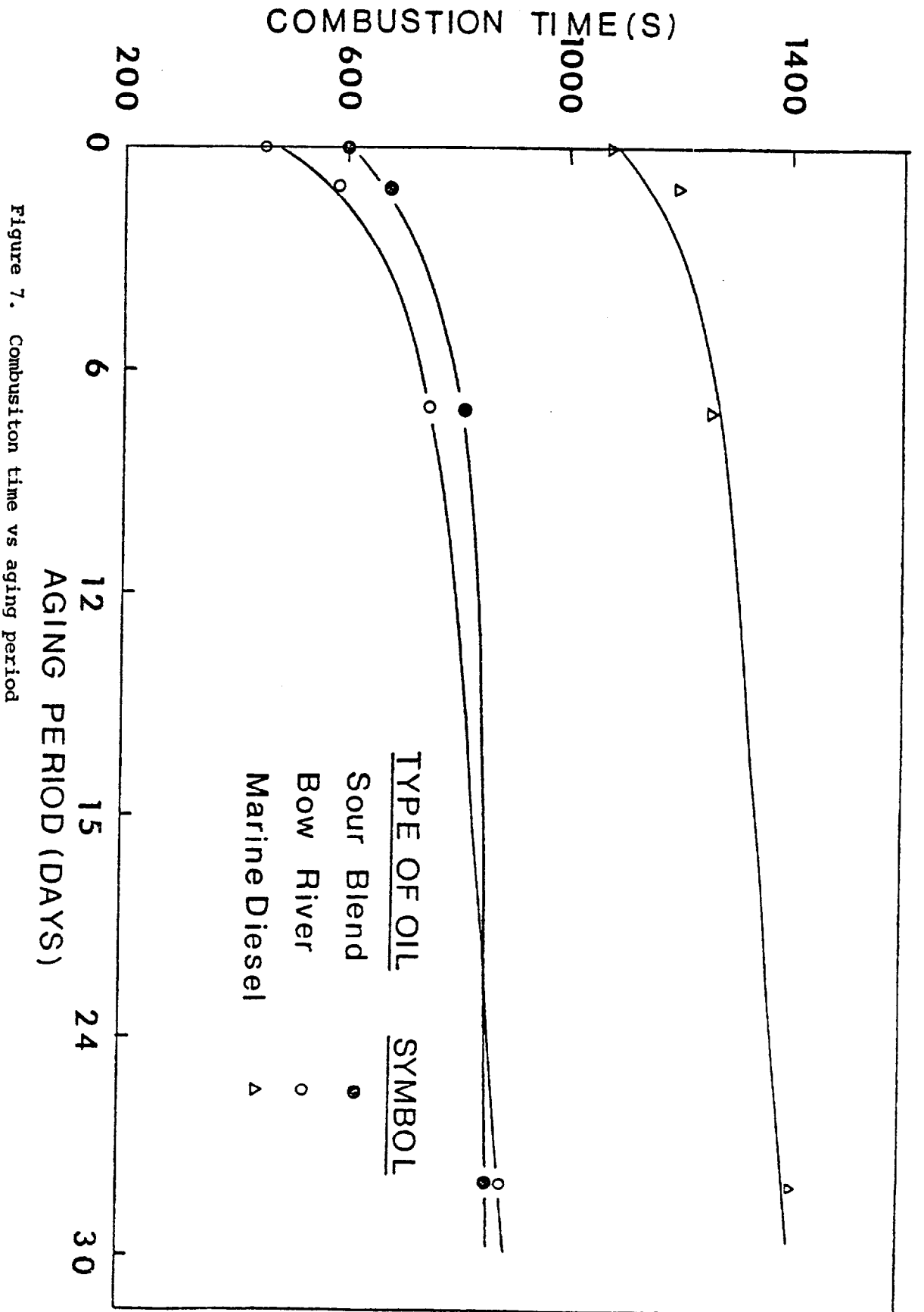


Figure 7. Combustion time vs aging period

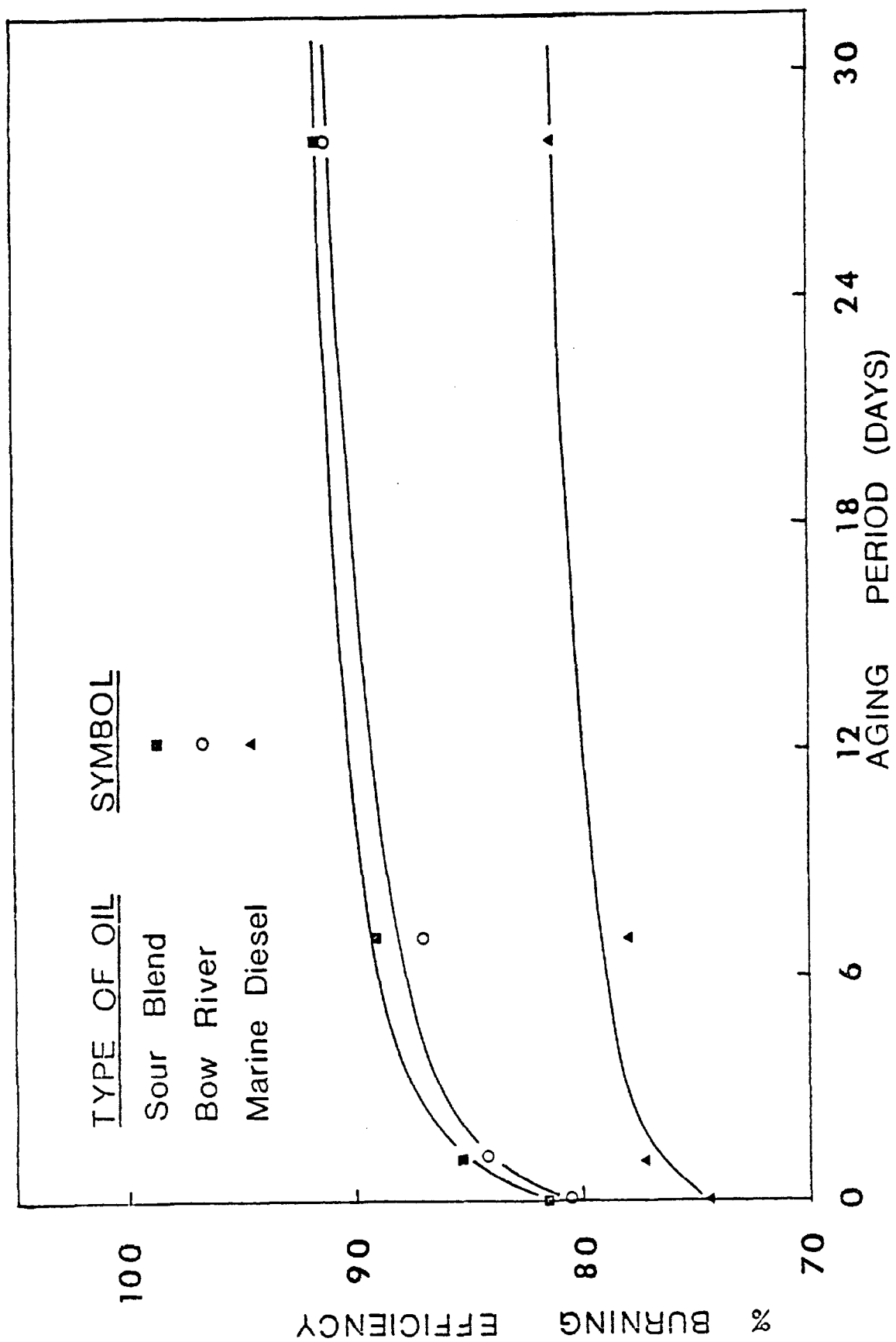


Figure 8. Burning efficiency vs aging period

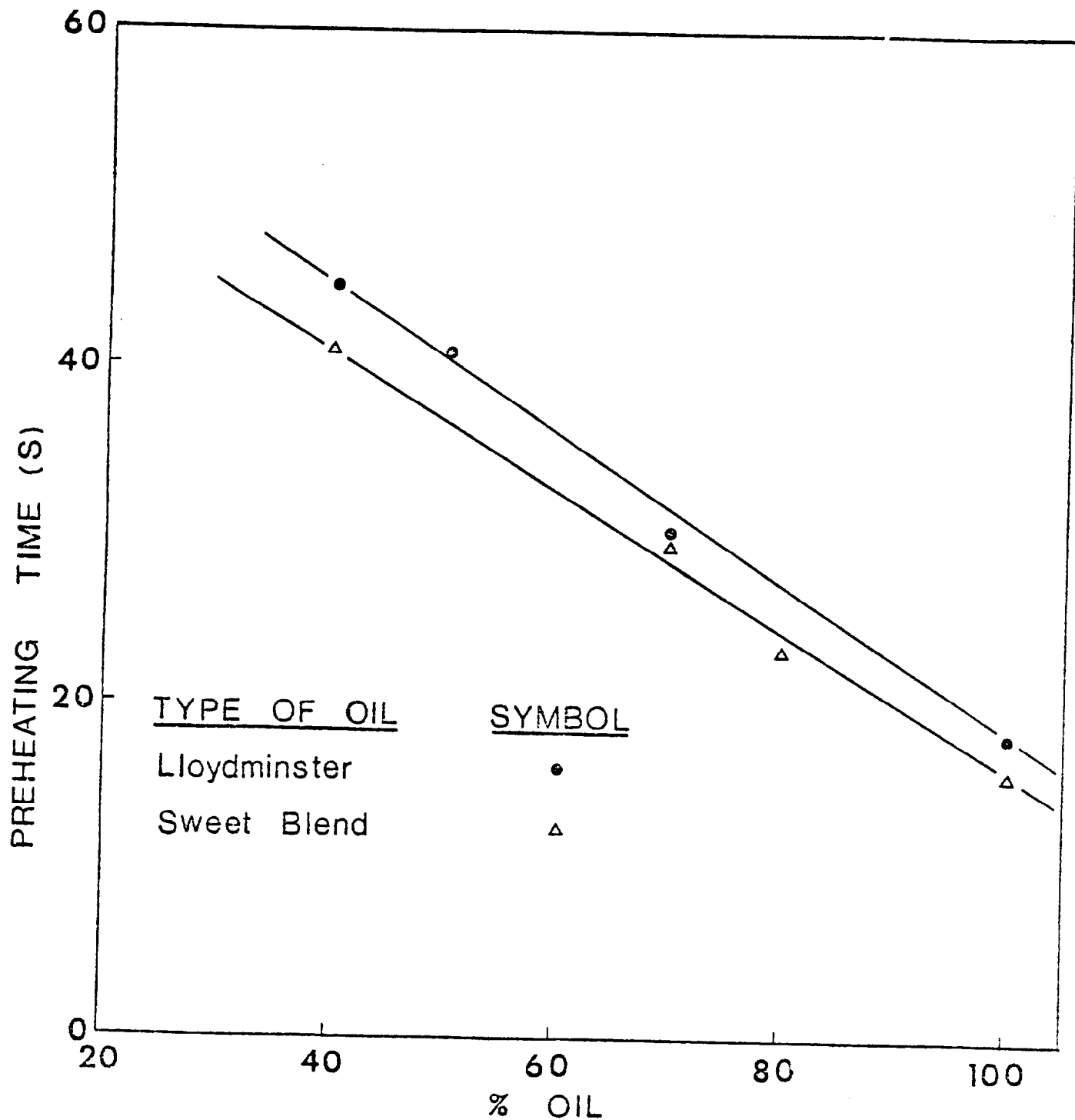


Figure 9. Preheating time vs percent oil present in 2 emulsions

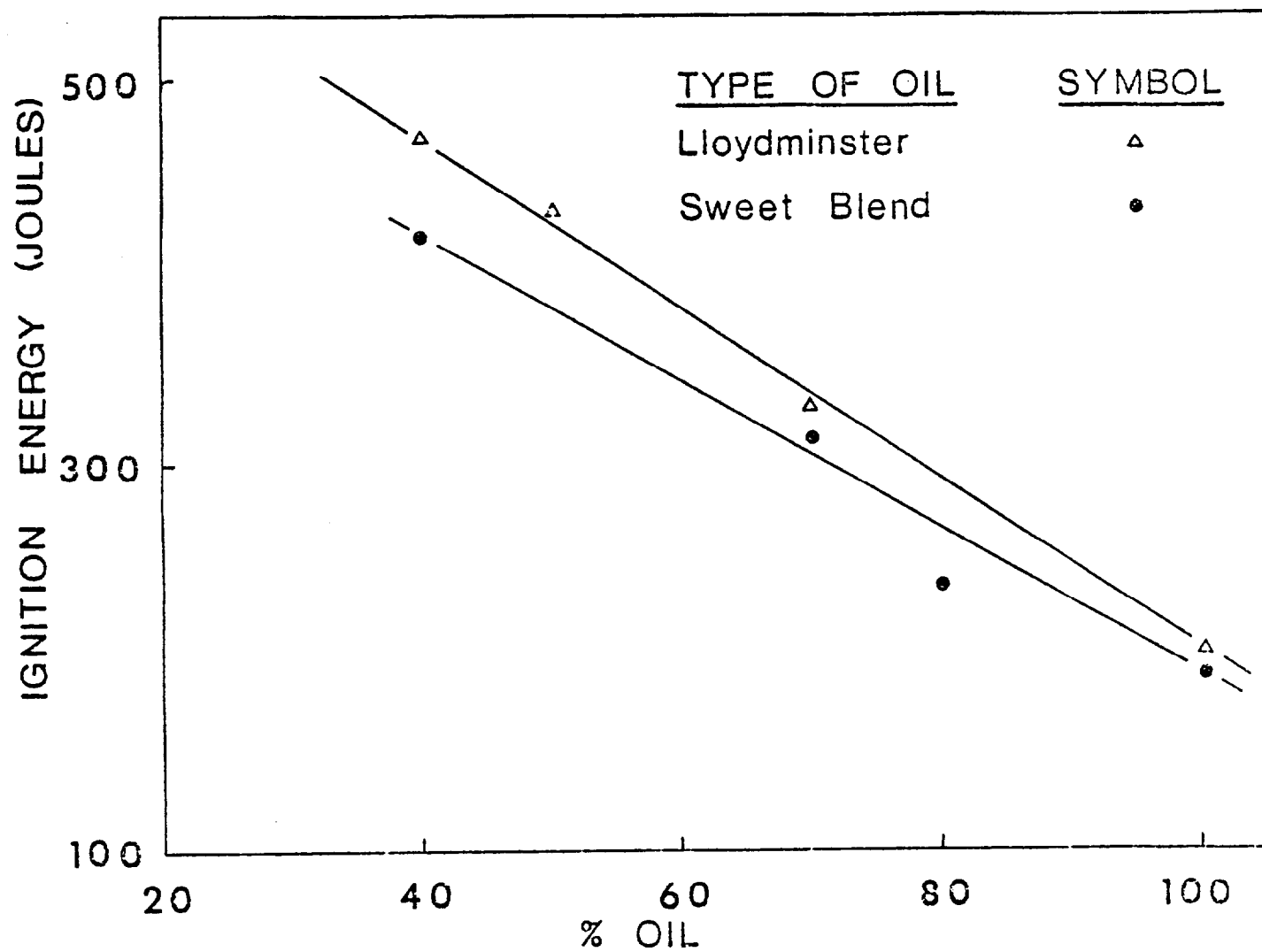


Figure 10. Ignition energy vs percent oil present in 2 emulsions

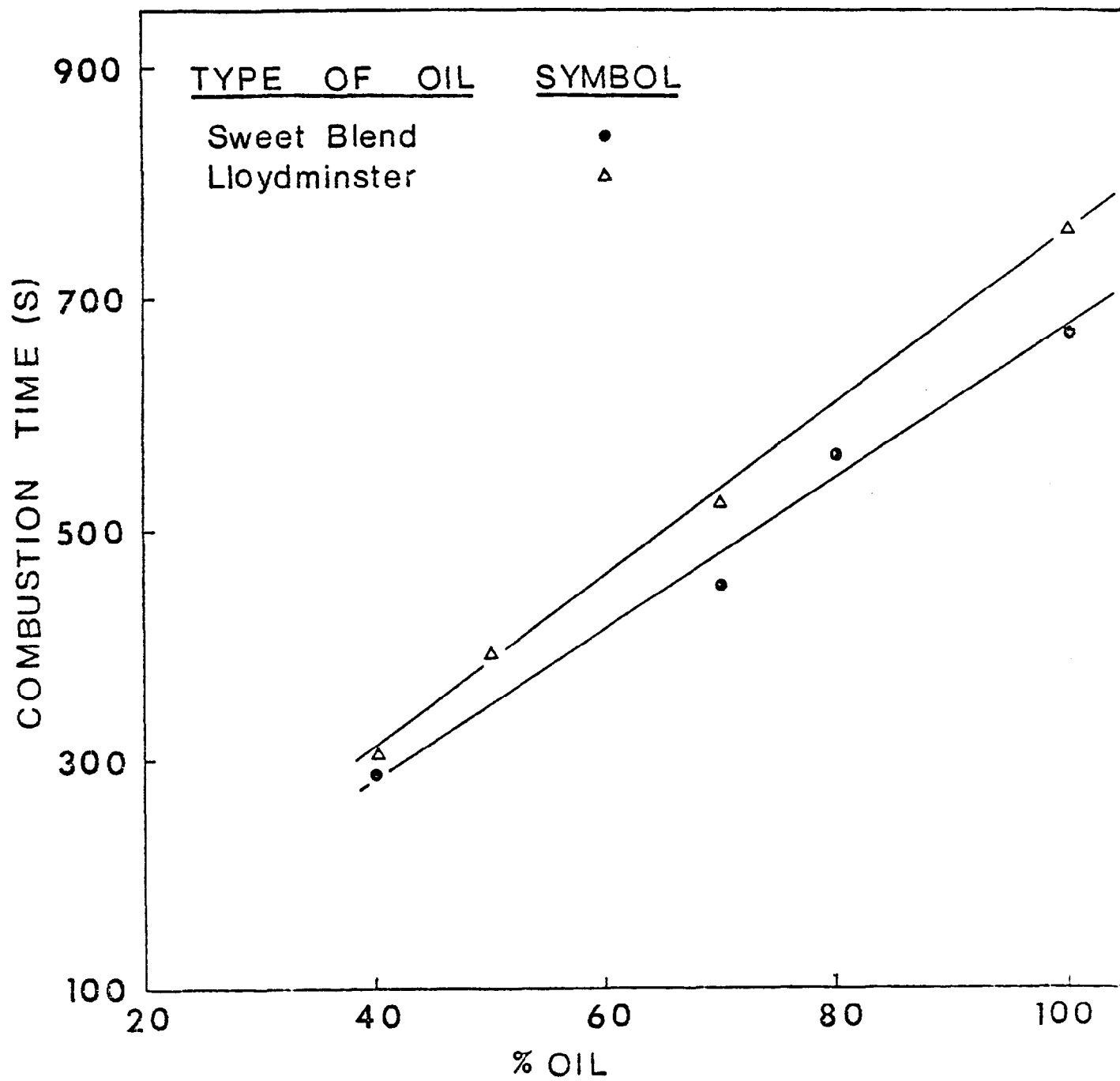


Figure 11. Combustion time vs percent oil present in 2 emulsions

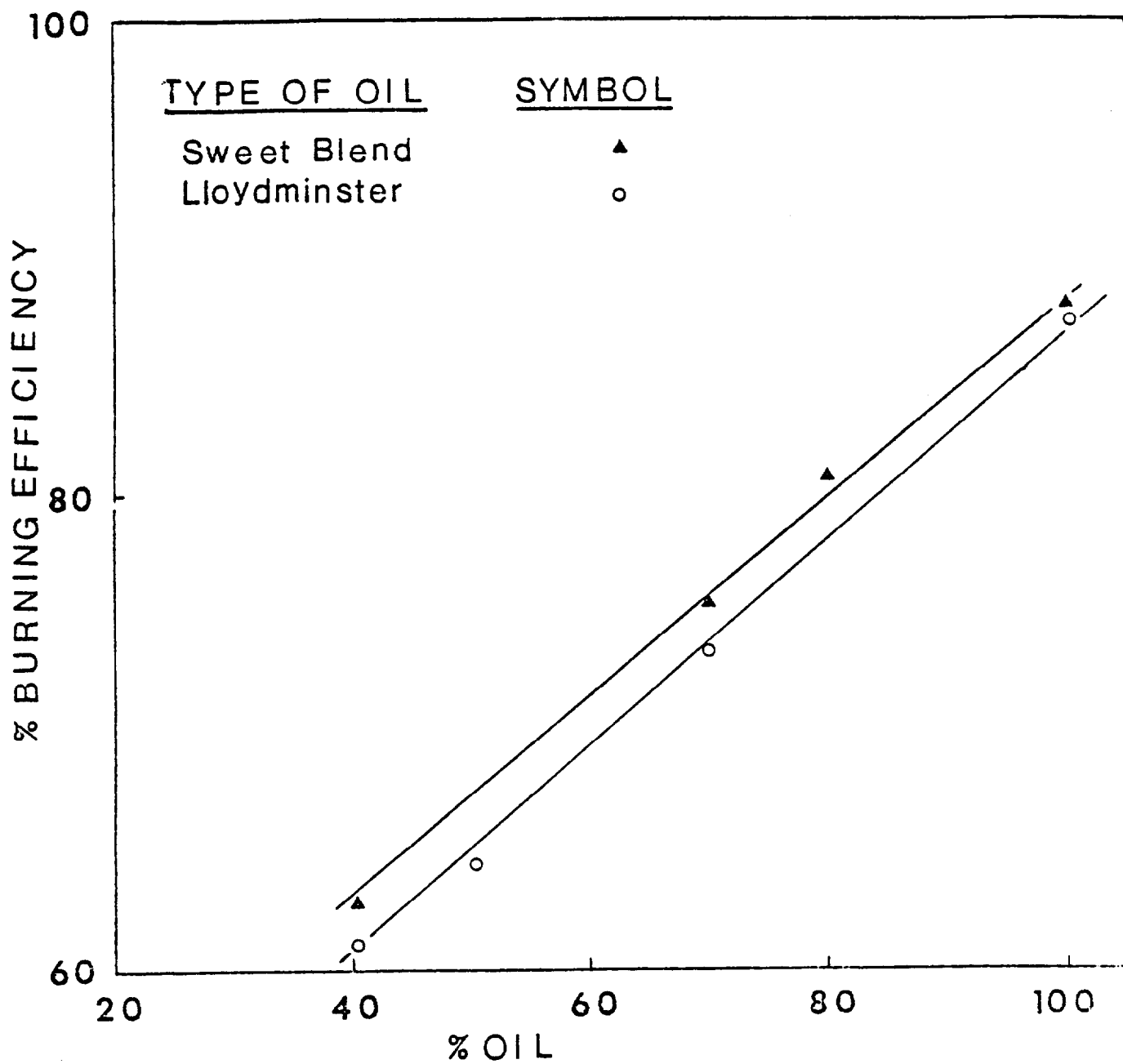
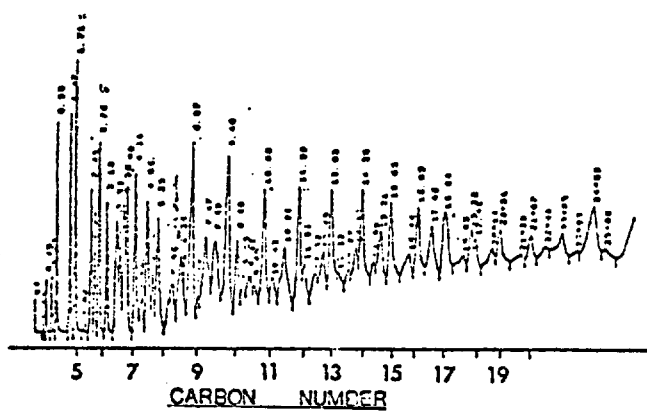
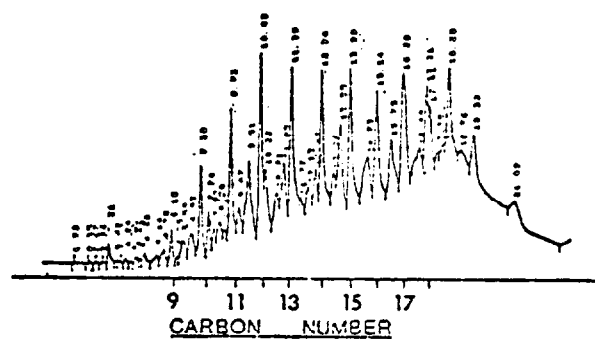


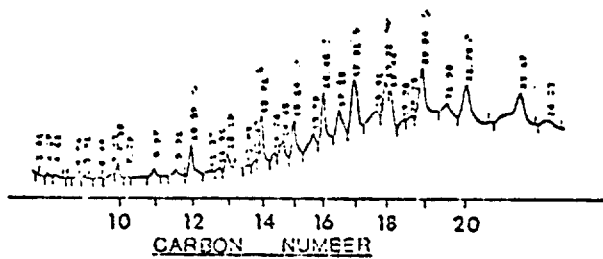
Figure 12. Burning efficiency vs percent of oil present in 2 emulsions



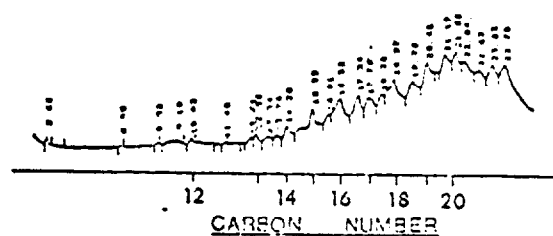
Fresh crude oil



Crude oil aged 1 month

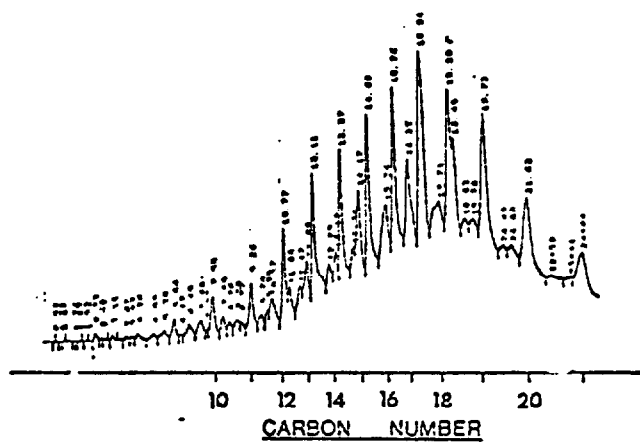


Residue of fresh crude oil

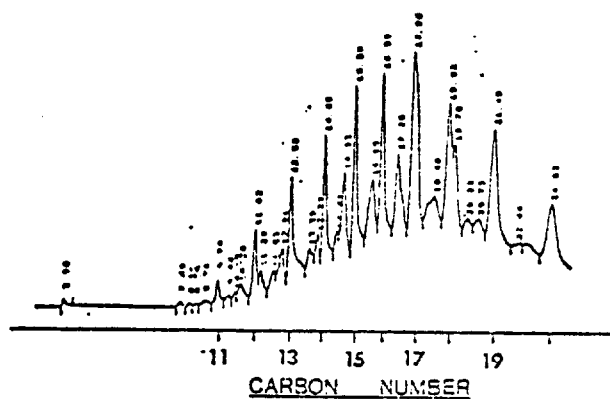


Residue of crude oil
aged 1 month

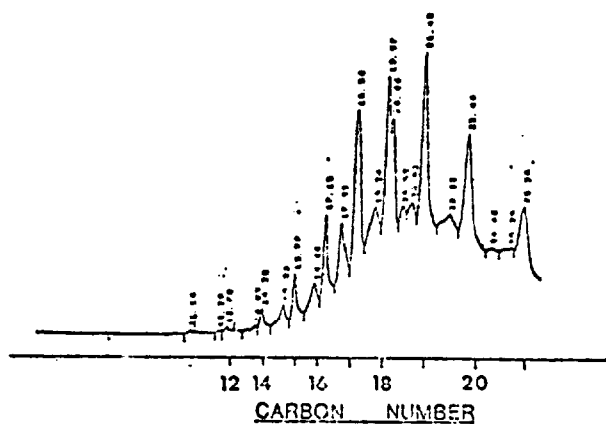
Figure 13. Gas chromatographic analysis of sour blend crude oil



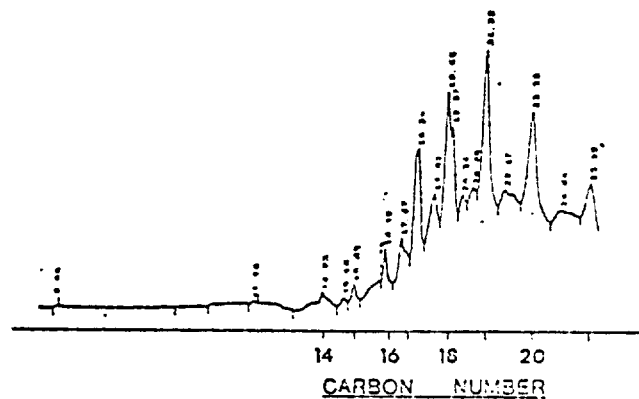
Fresh marine diesel oil



Diesel oil aged 1 month



Residue of fresh diesel oil



Residue of diesel oil
aged 1 month

Figure 14. Gas chromatographic analysis of marine diesel oil

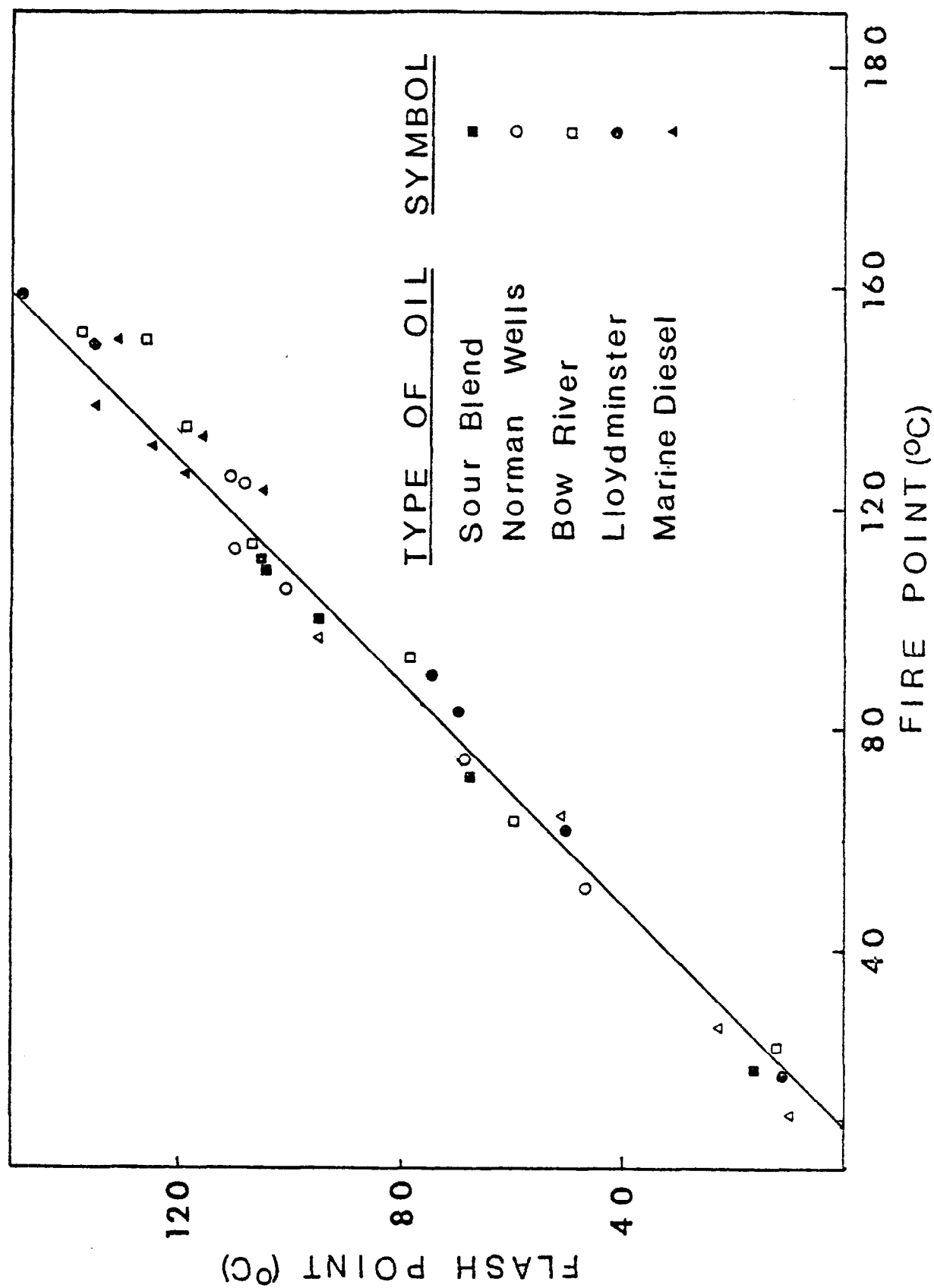
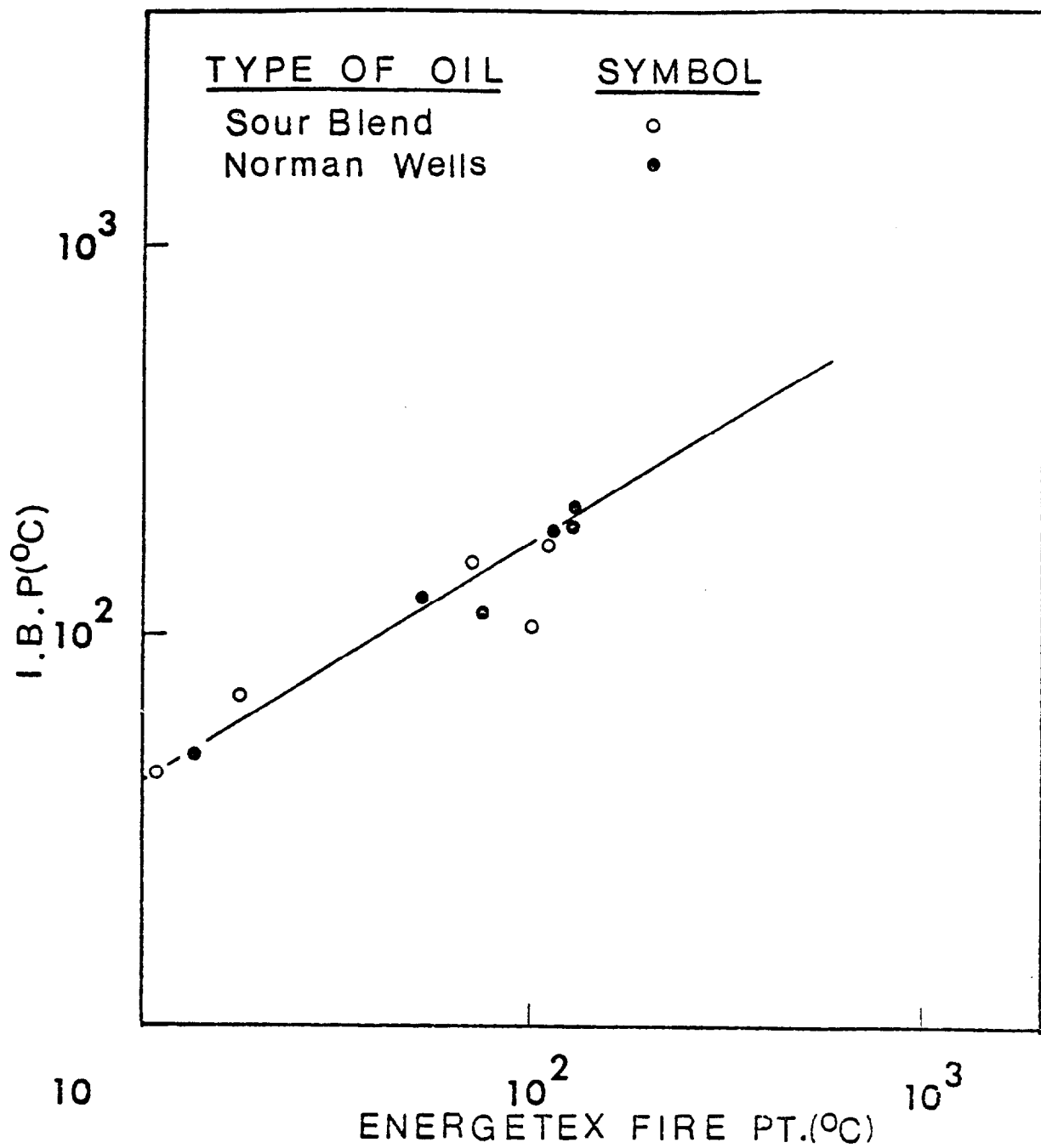
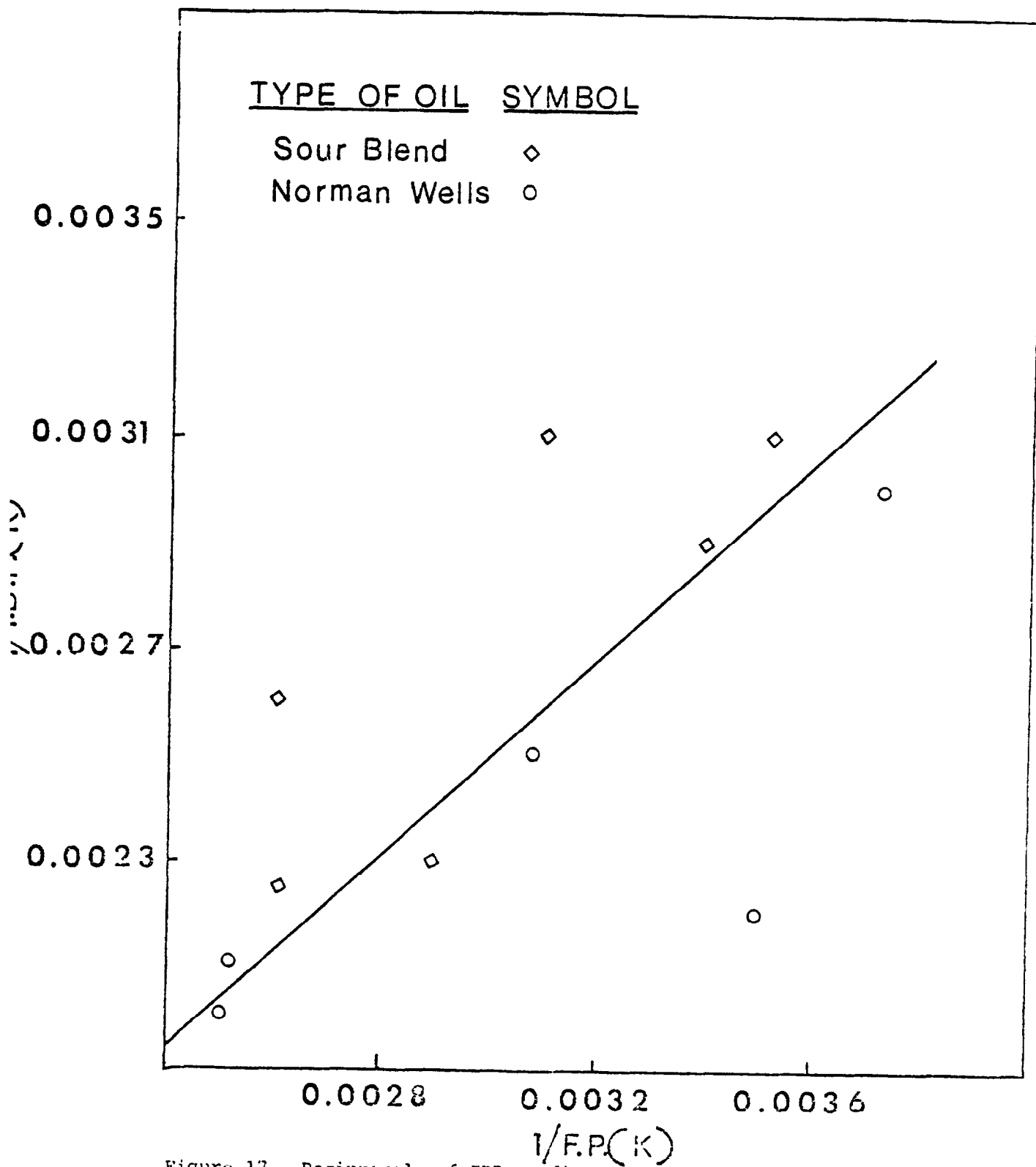


Figure 15. Flash point vs fire point (Energetex data)
(The line is fire point = flash point + 9)





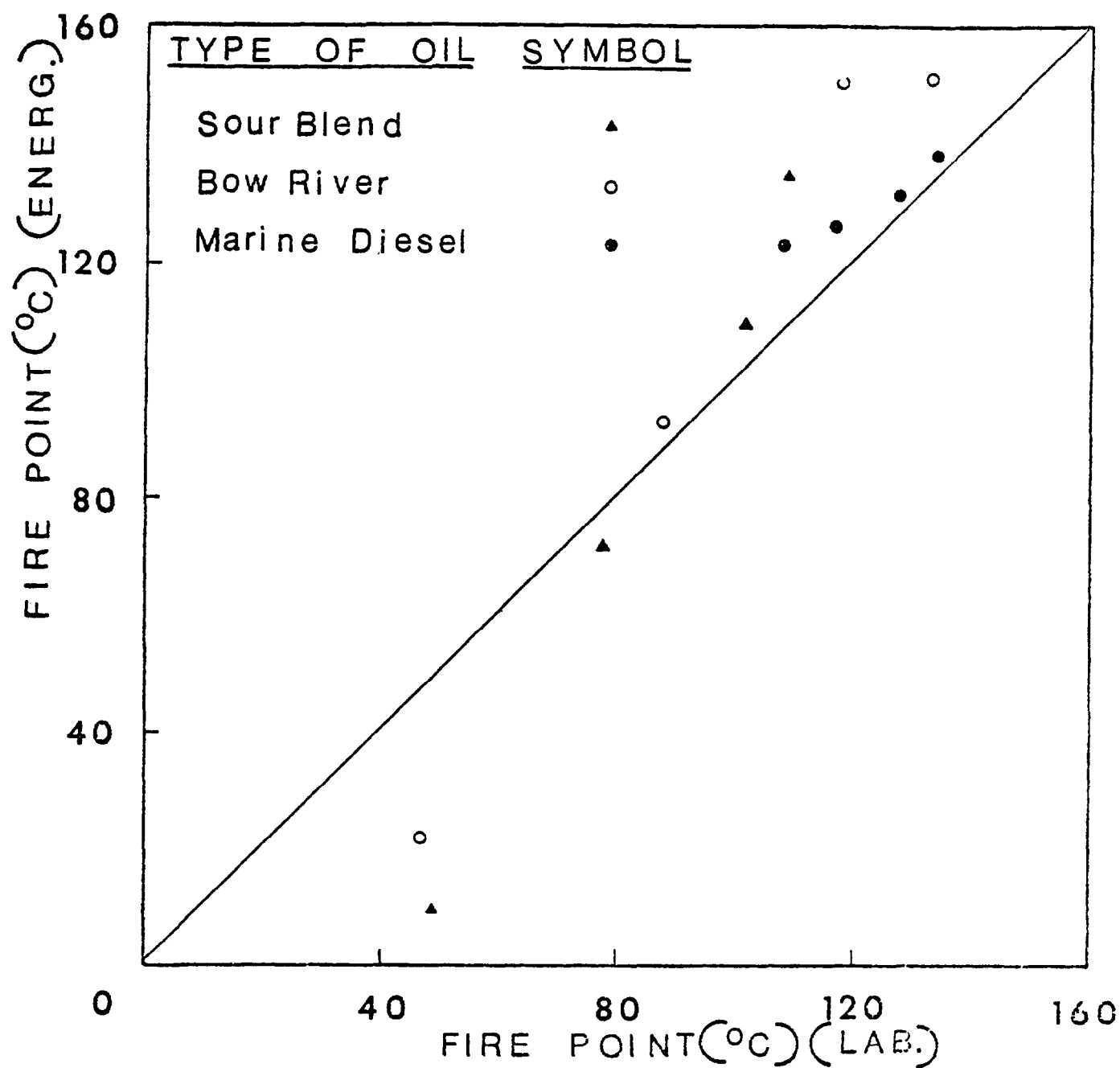


Figure 18. Energetex' fire point vs laboratory fire point

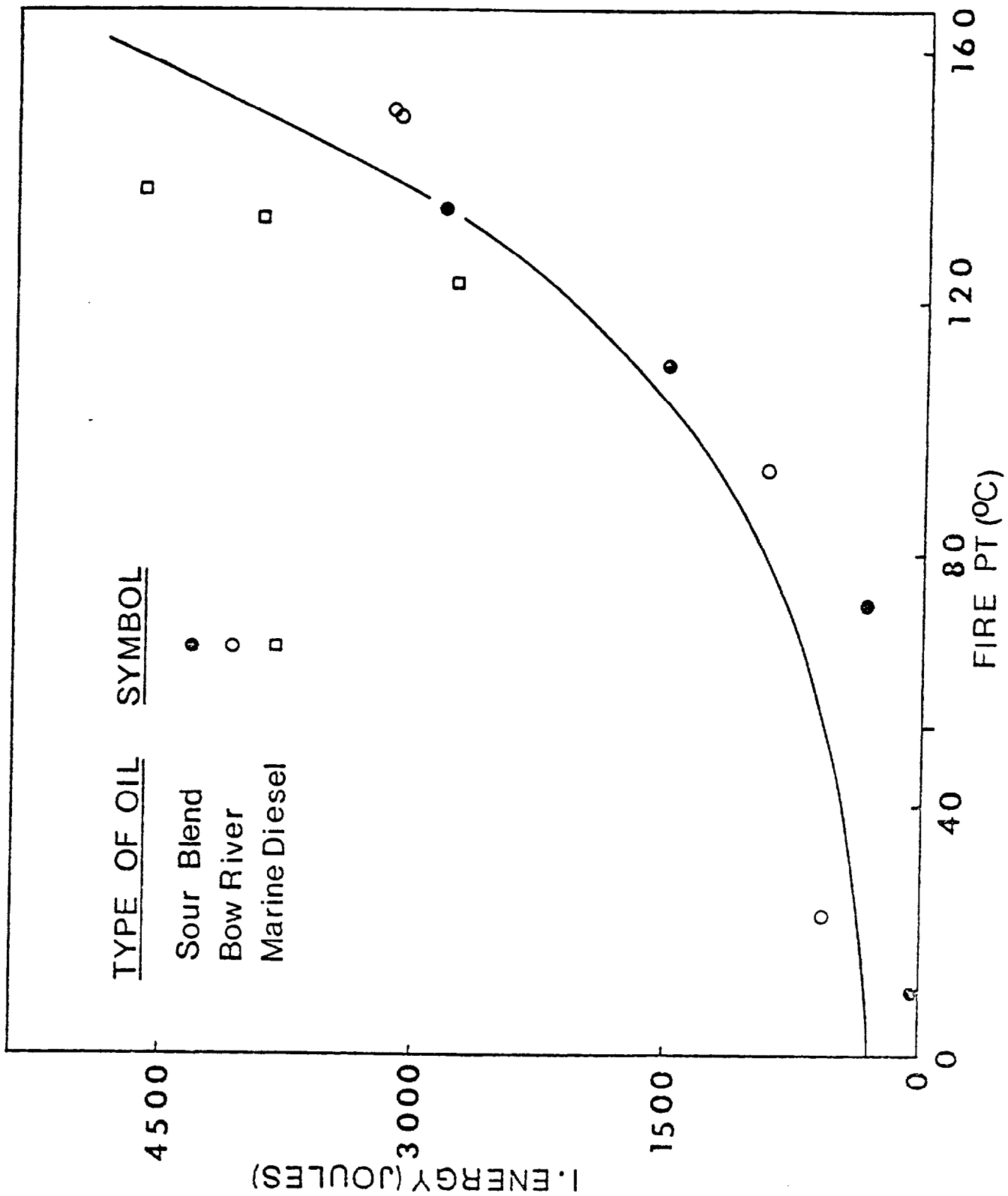


Figure 19. Plot of ignition energy vs Energetex fire point

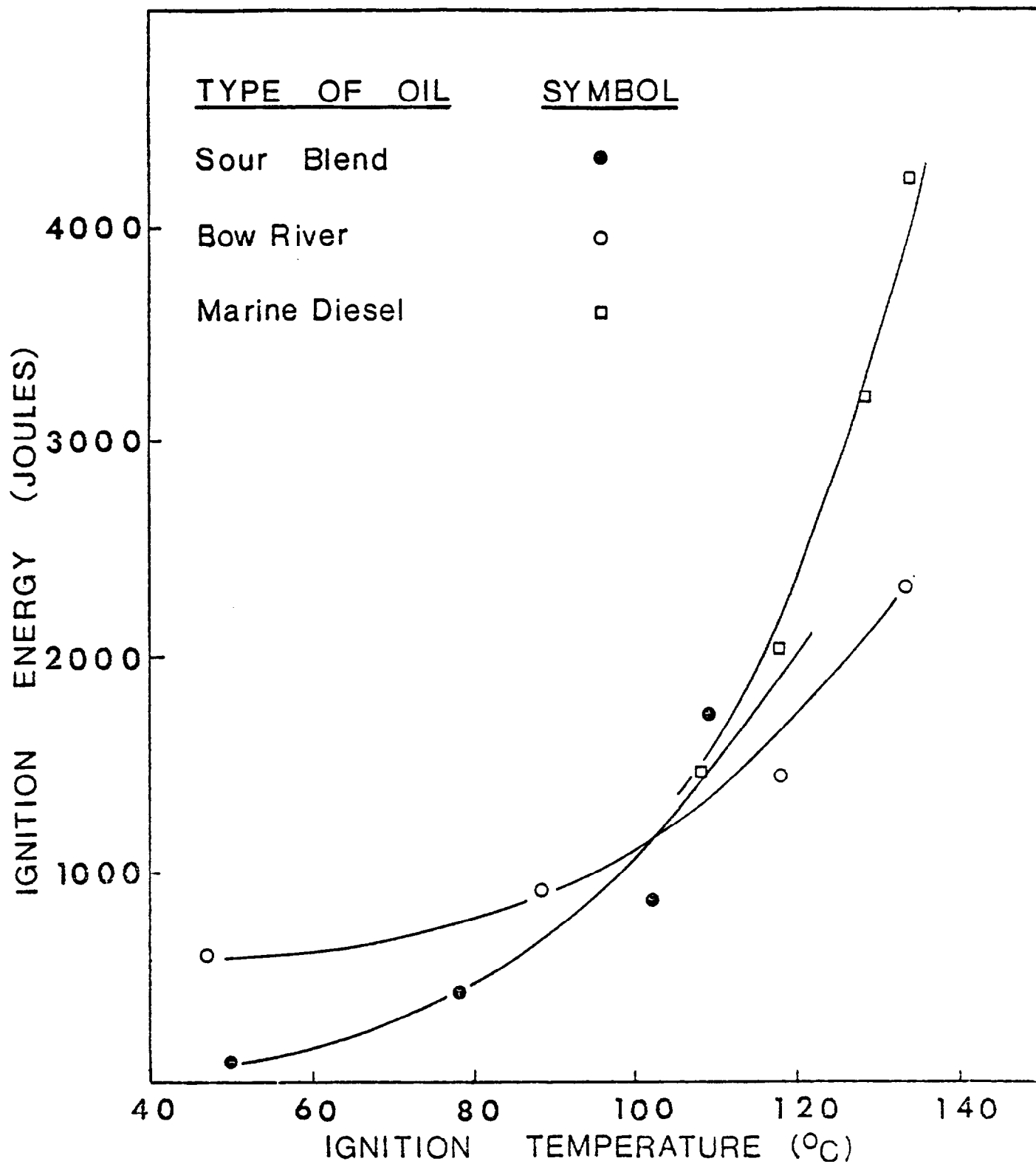


Figure 20. Ignition Energy versus laboratory ignition temperature

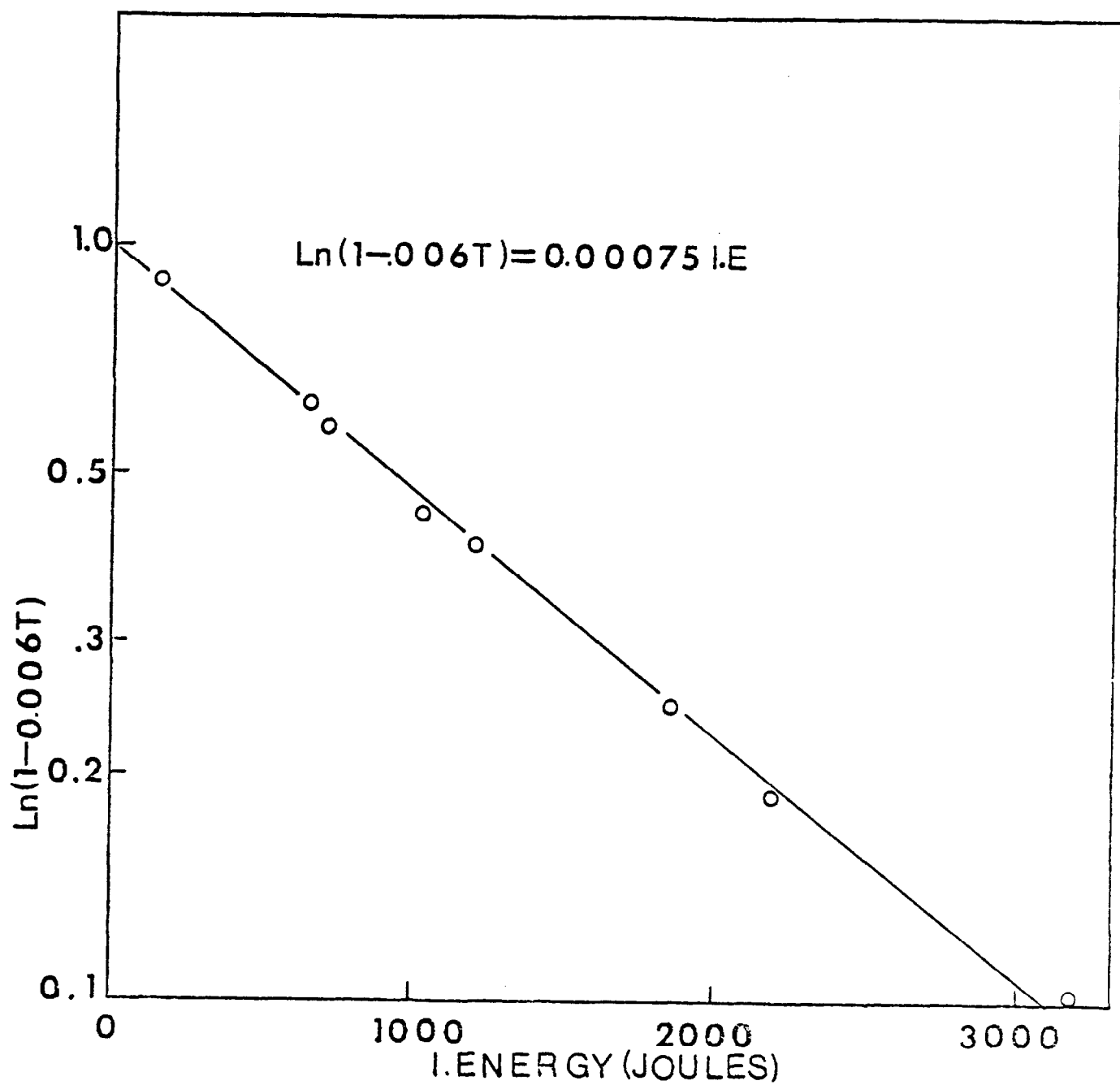


Figure 21. Correlation of fire point with ignition energy

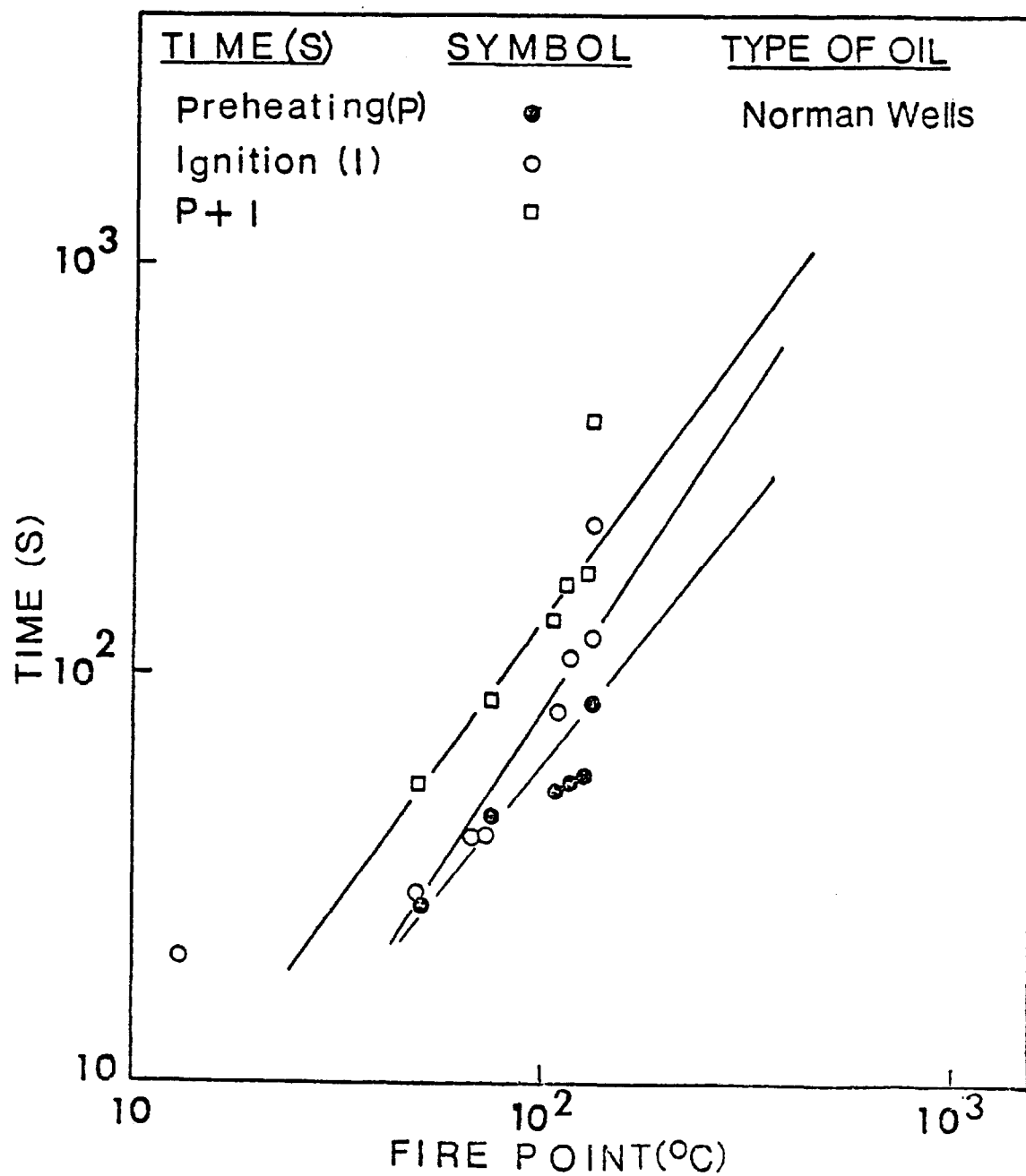


Figure 22. Time vs fire point

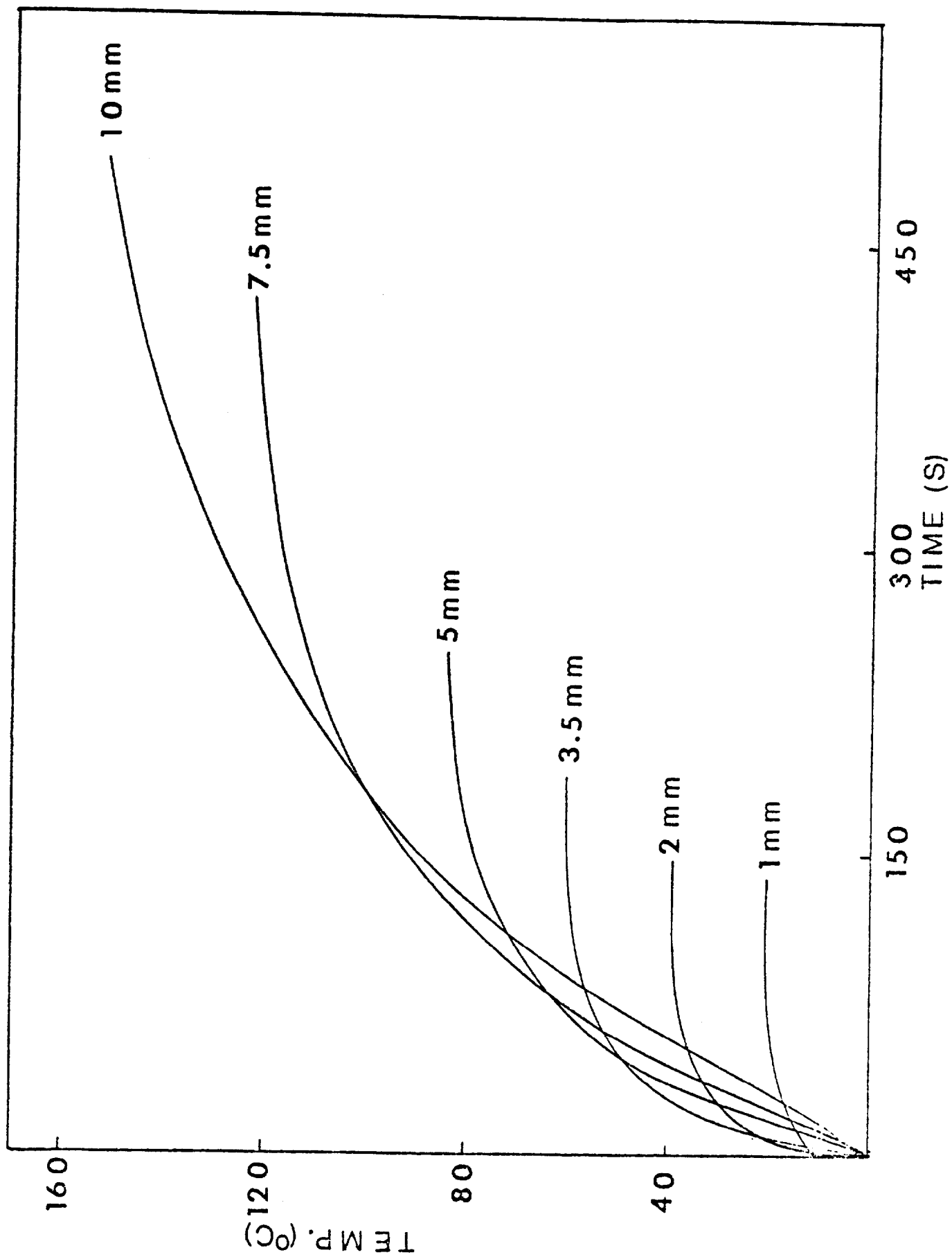


Figure 23. Temperature versus time for various oil thicknesses

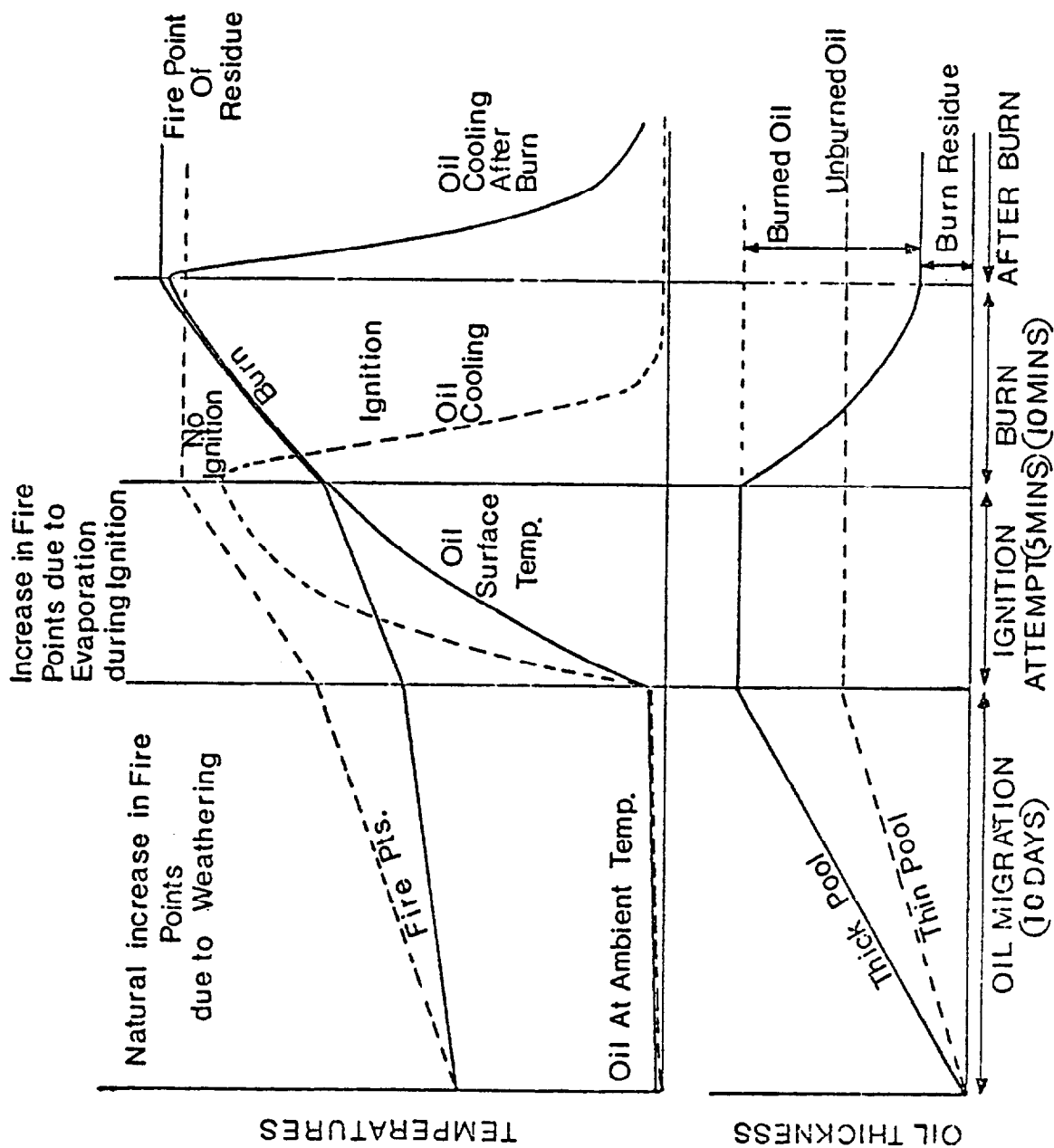


Figure 24. Schematic diagram illustrating oil migration, ignition attempt, and burning for successful and unsuccessful ignition

TABLE 1

OIL TYPE	PERIOD	IGNITION TIME (SECS)	IGNITION ENERGY (Joules)	BURNING TIME (SECS)	OIL TEMP. (°C)			FLAME TEMP. (°C)			RESIDUAL OIL THICKNESS (mm)	EFFECT OF BURNING
					INITIAL	MAXIMUM	FINAL	INITIAL	MAXIMUM	FINAL		
SOUR BLEND	1 day	30	115	600	49	406	321	330	768	621	1.5	81.5
	1 week	115	430	680	78	380	282	314	735	583	1.1	85.3
	1 month	230	850	810	102	350	238	312	703	560	0.9	89.2
	1 year	460	1740	860	109	292	191	292	692	521	0.6	91.7
BOM DIESEL	1 day	105	610	450	47	404	336	328	823	653	1.3	80.5
	1 week	175	913	590	88	382	302	321	809	632	1.1	84.4
	1 month	320	1451	750	118	338	218	312	792	582	0.9	87.0
	1 year	450	2378	890	133	324	150	301	760	570	0.7	91.6
MARINE DIESEL	1 day	260	1450	1080	108	395	362	321	808	546	2.2	74.5
	1 week	370	2025	1200	117	373	333	311	797	539	2.0	77.2
	1 month	550	3200	1260	128	358	287	291	768	523	1.9	78.0
	1 year	720	4225	1410	134	337	202	282	728	510	1.7	81.3
BUNKER - C	1 day	370	1531	780	79	419	318	353	828	637	1.9	79.6
	1 week	560	2318	930	432	392	273	329	813	624	1.6	82.3
SWEET BLEND	1 day	16	192	670	28	398	261	339	842	639	0.9	88.2
NORMAL WELLS	1 day	33	234	680	37	392	252	334	797	695	1.0	88.1
WATER-PROOFING	1 day	19	204	760	33	415	302	338	773	609	1.0	87.4

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OIL TYPE	WATER / OIL %	IGNITION TIME (SECS)	ENERGY INPUT (DOULES)	BURNING TIME (SECS)	OIL TEMP (°C)			FLAME TEMP (°C)			BURNING EFFICIENCY (%)
					INITIAL	MAXIMUM	FINAL	INITIAL	MAXIMUM	FINAL	
SWEET BLEND	80/20	23	233	560	34	374	240	320	768	472	81.5
"	70/30	29	314	450	43	322	203	307	663	410	75.6
"	40/60	41	432	285	52	309	187	300	640	403	63.2
LL-00D	70/30	30	333	525	39	380	252	313	702	450	73.5
"	50/50	41	432	395	44	353	200	302	643	393	64.6
"	40/60	45	417	305	51	315	175	287	630	379	61.2
WEXBURN - MIDDLE	40/60	210	1959	550	63	317	202	317	682	383	64.8
NORMAN WELLS	80/20	42	312	510	43	331	201	321	701	455	80.6

OIL TYPE	WEATHER - %	IGNITION TIME (Sec)	IGNITION TEMP (°C)	BURNING TIME (Sec)	OIL TEMP (°C)			FLAME TEMP (°C)			KEROSENE THICKNESS (mm)	BURNING EFFICIENCY %
					INITIAL	MAXIMUM	FINAL	INITIAL	MAXIMUM	FINAL		
ALBERTA CRUDE OIL	0	10	175	740	170	419	284	339	840	632	2.3	72.4
"	10	39	298	910	33	407	287	327	828	628	2.4	71.5
"	20	72	380	1150	65	383	273	323	811	613	1.9	74.0
"	25	133	510	1278	79	382	271	313	793	602	1.8	74.3
"	30	163	697	1480	118	371	260	298	782	582	1.7	76.8
"	35	205	830	1610	133	368	254	299	771	513	1.5	80.3
"	40	235	915	1593	148	369	253	279	712	530	2.8	68.0
"	45	280	1156	1603	156	351	252	282	749	519	3.4	64.5
"	50	310	1238	1598	159	350	248	280	750	510	3.2	62.5

TABLE 4

CYCLE OIL WATER %	IGNITION TIME (SECS)	IGNITION ENERGY (Joules)	BURNING TIME (SECS)	OIL TEMP. (°C)		FLAME TEMP. (°C)			EFFICIENCY GIL BURNING %
				INITIAL	MAXIMUM	FINAL	INITIAL	MAXIMUM	FINAL
90/10	16	167	630	19	378	221	305	752	520
80/20	19	202	590	22	305	203	295	718	521
70/30	25	252	495	28	280	182	296	702	483
60/40	32	290	420	30	255	173	282	673	462
50/50	47	338	340	33	220	162	271	661	445
40/60	51	402	220	38	188	149	261	639	403
30/70	57	456	185	49	170	125	254	591	396

ALBERTA REFINERY

TABLE 5

OIL TYPE	AGING PERIOD	PRE HEAT-ING TIME (S)	IGNITION TIME(S)	P + I TIME(S)	FLASH POINT (°C)	FIRE POINT (°C)	I. B. P. (°C)
SOUR BLEND	0 HOURS	NIL	NIL	NIL	—	105	45
"	6 HOURS	12	29	41	16	18	70
"	1 DAY	NIL	65	65	68	72	153
"	2 DAYS	295	275	570	95	100	105
"	1 WEEK	257	170	427	105.0	110	170
"	2 WEEKS	278	245	523	105.5	109	96
"	4 "	292	291	583	—	135	90
HOPMAN WELLS	0 HOURS	0	22	22	—	135	50
"	6 HOURS	26	28	54	47	51	125
"	1 DAY	45	40	85	69	74	115
"	2 DAYS	51	80	131	101	105	55
"	1 WEEK	55	110	165	110	112	180
"	2 "	55	115	170	109	124	190
"	4 "	183	237	420	111	125	215
BOW RIVER	0 HOURS	0	0	0	12	22	75
"	6 HOURS	26	35	61	60	63	130
"	1 DAY	0	140	140	78	93	75
"	2 DAYS	—	75	75	107	113	155
"	1 WEEK	91	411	502	126	151	216
"	2 "	80	430	510	119	134	225
"	4 "	193	123	316	137	151	185
LLLOYD MINSTER	0 HOURS	0	0	0	11	17	55
"	6 "	64	62	126	51	62	125
"	1 DAY	—	120	120	70	84	160
"	2 "	40	47	87	75	90	108
"	1 WEEK	—	—	—	136	150	203
"	2 "	135	150	285	126	142	200
"	4 "	457	386	843	148	159	100
MARTIN SUSSEL	0 HOURS	0	150	150	105	123	225
"	6 "	153	117	270	119	126	219
"	1 DAY	155	250	405	116	133	210
"	2 "	282	391	673	125	131	200
"	1 WEEK	155	840	995	131	150	—
"	2 "	130	421	551	135	136	80
"	4 "	137	854	991	135	138	220