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IGNITION CHARACTERISTICS OF COAL SLURRIES IN ETHANOL BLENDED FUEL OIL
NO. 6 AND THEIR STABILITY AND RHEOLOGICAL PROPERTIES

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ABSTRACT

Studies have been carried out on combustion and ignition aspects of coal slurries in fuel oil No. 6 and ethanol blended fuel oil. Results of method of blending fuel oil + ethanol, compatibility of the blends, viscosity of blends as a function of ethanol proportion, rheology and stability characteristics of coal slurries prepared from blends are reported. The rheology, stability and combustion properties of the proposed mixed fuel are compared with the present coal-oil slurries and the advantage of the ethanol blended fuel is highlighted.

Fuel oil No. 6 is highly viscous and found to be immiscible (incompatible) with commercial ethanol. However, it was observed that the compatible (miscible) blends of fuel oil with ethanol which we refer to as ALCOFUELS could be obtained by using coupling agents such as kerosene or lower chain hydrocarbons like hexane. A systematic study of compatibility of the blends using kerosene as a third component was carried out and a ternary diagram with the fuel oil No. 6, ethanol and kerosene showing compatibility/incompatibility region

was obtained. The important observations are: (1) a maximum of 25% by weight of ethanol could be incorporated to obtain a compatible blend in presence of 10-15% of kerosene, (2) there exists a minimum concentration of fuel oil No. 6 (65% by weight) below which compatible blends cannot be obtained at any ratio of ethanol and kerosene; (3) the region of practical interest is about 65 to 70% of fuel oil, 20 to 25% ethanol and 10-15% of kerosene. The viscosities of typical blends with 65% of fuel oil No. 6 at different proportions of ethanol and kerosene (40 to 70 cps) were lower compared to fuel No. 6 (200 to 220 cps.)

Rheological measurements on slurries of coal in alcohol oil blends as a function of coal concentration, blend composition (alcohol: kerosene proportion), type and concentration of surfactants and temperature have been carried out. The results show that ambient viscosities of coal-alcofuel blends with coal concentrations up to 40% are comparable to coal-fuel oil No. 6 slurries 212°F under similar coal loadings. The alcofuel blends with increasing ethanol concentration yield coal slurries of higher viscosities. The viscosity increases rapidly from 40-50% by weight of coal and the slurries behave as Newtonian fluids up to 40 coal loading. Addition of surfactants resulted in lowering of the viscosities of slurries and also imparted stability to the pension. In the present study, typical commercial surfactants of nonionic, cationic and anionic type were employed.

The ignition characteristics of coal-alcofuel slurries have been studied using Differential Thermal Analysis Techniques at high heating rates. The ignition temperature of slurries have been determined.

as a function of coal concentration, and were compared with technical coal-fuel oil No. 6 slurries. The analysis of kinetics (rate and activation energies of ignition) show better combustibility of the blended fuel oil coal slurries compared to the present coal slurries. A possible mechanism of ignition of coal oil and coal oil + alcohol slurries is reported based on the results of ignition temperature measurements at various heating rates.

The present coal oil mixture technology involves preheating of fuel oil No. 6 in order to reduce the viscosity and also employs elevated temperatures (150°F) during processing, storing and pumping. The advantages of the alcofuels as compared to those of fuel oil No. 6 slurries are emphasized in relation to COM technology.

INTRODUCTION

The interest in Coal-Oil Mixtures (COMs) as boiler fuels has been growing rapidly due to the anticipated fuel oil shortage. Coal slurries consisting of fuel oil No. 6 have been tested in utility and industrial boilers which have originally oil fired burners. The flow properties, stability of dispersion during storage and transportation, spray formation and combustion efficiency have been studied extensively as witnessed from the preceeding International Symposia on COM Combustion and also the recent reviews.¹⁻³

In the recent years, considerable amount of success is being achieved in the storage stability and rheological characteristics of COMs. However some of the unfavorable physical properties of slurries such as unusually high viscosity of COM at ambient temperature pose problems to COM handling. It requires preheating of fuel oil No. 6, and maintaining of elevated temperatures ($\approx 150^{\circ}\text{F}$) during processing, storing, transportation and atomization of COM. While marginal viscosity reduction could be achieved by the addition of surfactants-polymers, further viscosity control could be possible probably by incorporating alcohol (ethanol) into the fuel oil. Consequently, the development of a new class of blends containing fuel oil No. 6 and ethanol, referred to as ALCOFUELS was considered essential. Besides the low viscosity, alcofuels have the other advantages such as (1) capacity to extend the fuel oil stock (since fuel grade ethanol could be obtained from biomass conversion) (2) better combustibility and physical properties of the alcohol containing blends and COMs.

The alcofuels and alcofuel COMs differs significantly from coal fuel oil No. 6 mixtures. It also differs from CFOS, (Carbonaceous Fuel-in-Oil Suspensoids) Fuels suggested by Keller.^{4,5} The basic concept involved in the alcofuel COMs is the incorporation of fuel grade ethanol (up to 25% by weight of blend) into fuel oil No. 6 in the presence of coupling agent such as kerosene or n-alkane and obtaining a compatible blend prior to the addition of coal powder. In the absence of a coupling agent, the blend is not compatible (homogeneous). The low viscosity alcofuels so obtained could be used directly in oil fired burners or in COM technology. On the other hand, in the CFOS Fuels, alcohols were introduced either by vapor phase coating of coal particles or in smaller quantities.

The slow transition of boiler fuels from fuel oils to coal liquids or coal powder may involve several intermediate steps such as coal/oil, coal/ oil + alcohol with or without water, and coal-water mixtures.

The blends such as gasoline + ethanol (gasohol), and diesel + ethanol with 10 to 20% of alcohol, presently, are attractive internal combustion engine fuels. The compatibility (miscibility) of ethanol (free of water) with distillates is not a problem, while ethanol and petroleum residuals are found to be not miscible to any extent. Similar incompatibility problems were encountered in mixing of fuel oils with coal liquids.⁶ In general, certain fuel blend incompatibility is experienced while mixing fuels of different origins e.g. alcohols, petroleum liquids, coal liquids, etc. due to the molecular-particle heterogeneity, aromatic/aliphatic content, polarity and molecular weight distribution of molecular species.

The rate of ethanol production from biomass conversion is going to increase in the coming years.⁷ Also, coal liquids are expected to become commercially available in the coming years. However, the quantities will be quite small compared to fossil fuels such as petroleum liquids and some applications would involve blending of different fuels. Therefore, we have undertaken a systematic study of blend compatibility of fuel oil No. 6 and ethanol, and rheology of the blends with varying concentrations of ethanol. We have also investigated the stability and rheological properties of coal dispersions in the fuel oil No. 6 + ethanol blends. The fuel reactivity has been tested by ignition temperature measurements using DTA technique. The major thrust of the present work was to establish the physical properties and combustibility of the coal alcofuel slurry and compare it with the coal-fuel oil No. 6 mixtures which are presently tested in oil fired utility and industrial boilers. Our studies reveal that coal slurry in low viscosity alcofuels could be an attractive boiler fuel in the place of coal fuel oil No. 6 mixture until coal water slurry or coal liquids become commercially available.

EXPERIMENTAL AND ANALYTICAL PROCEDURES

Fuel oil No. 6 employed for blending studies was obtained from Florida Power & Light Co., FLA, having viscosity of 2 Poise at ambient temperature and density 0.98g/cm³. Ethanol, absolute as well as denatured grade were from Fisher Scientific. The kerosene used as the coupling agent was of commercial grade. Coal sample used in the entire study was from a single batch procured from Sanford Power Plant (FP&L Co., FL) having particle size range of 80% of minus 200 mesh

and 20% of minus 325 mesh. COMs with fuel oil No. 6 used for comparative study were also from the same power plant. Surfactants used in the present study were of commercial grade.

Blending of Fuel Oil No. 6 and Ethanol

Fuel oil No. 6 and ethanol were weighed into sample vials and kerosene was added. The sample was vigorously shaken to obtain a homogeneous blend. The compatibility of the blend was tested by centrifuging the sample for 20-30 minutes and measuring the volume of the incompatible liquid, which is transparent, separated at the top of the column. The most compatible blend did not show any supernatant liquid layer at the top. The percentage incompatibility of blends for various ratios of fuel oil and ethanol in the presence of kerosene was carried out and percentage incompatible volume was calculated by

$$V_{\% \text{incomp.}} = \frac{V_{\ell}}{V_{\text{total}}} \times 100 \quad (1)$$

where $V_{\% \text{ incompatible}}$ = percentage incompatibility

V_{ℓ} = supernatant incompatible liquid

V_t = total volume of the blend

The compatibility of the ethanol and fuel oil No. 6 in presence of kerosene was represented in a ternary diagram.

Rheology

Viscosities of the blends and slurry made out of coal alcofuel were measured using Brookfield Cone and Plate Viscometer. Viscometer has the shear rate range from 1.15 to 213 Sec.^{-1} . The dial readings were converted into apparent viscosities by multiplying it with viscometric constant obtained by separate experiments using Newtonian fluids.

The viscosity dependence on temperature was determined by passing water at different temperatures through the jacket enclosing the viscometer cone and plate.

The alcofuel blends were prepared in larger quantities, (1 to 2 Kgs) sonicated, tested for compatibility by aging for months. Such blends were used to prepare coal/oil slurries. All COMs with alcofuels were prepared at ambient temperature unlike the ones with fuel oil No. 6 which required elevated temperature. Mixing and transferring of alcofuel coal slurry was easy even at ambient temperature due to its low viscosity.

All the settling tests were carried out in 150 ml graduated cylinders at ambient temperature over a time interval of 150 hours. The samples were drawn from the top of the column at regular intervals and analyzed for coal content by gravimetric method, i.e., by extracting the weighed amount of sample using n-hexane and weighing the dried coal. Typical commercial surfactants such as TRITON X-15, SPAN 20, TERGETOL, TRS 10-80 have been screened for the effectiveness in reducing the settling of coal. Besides, the same set of surfactants were studied in relation to effectiveness on reducing the viscosity of the slurries.

Ignition temperature measurement was carried out employing Differential Thermal Analysis Technique (DuPont Model 900) using a calorimetric cell attachment. A small amount of (20-30 mgs) alcofuel or coal slurry was taken in the sample cup made of aluminum and oxygen was flushed at a constant rate during the linear heating. In the present study, the DTA experiments were carried out only up to 500°C.

DTA curves with sharp ignition peaks were obtained for alcofuel/coal slurry and fuel oil No. 6/coal slurry at different heating rates such as 15, 25, 45, 90°C/minutes. The sample weight and oxygen flux were kept constant in all the experiments. Some isothermal experiments at various temperatures were carried out in order to calculate the activation energy of ignition. However, the results are not reported here since experimental procedure required some modifications. The isothermal experiments required more controlled oxygen atmosphere in order to obtain meaningful ignition delay data.

Results and Discussion

Alcofuel Blends

A ternary diagram illustrating the compatible/incompatible regions for fuel oil No. 6, ethanol and kerosene/n-hexane system is shown in Figure 1. The blends were seen to be compatible over a very narrow range of compositions. The results on blending of the fuel oil with ethanol, could be summarized as:

- . A maximum of 25% by weight of ethanol could be incorporated in to fuel oil No. 6 in the presence of 10 to 15% of kerosene to obtain a compatible (homogeneous) blend.
- . The blends are not compatible below 65% of fuel oil No. 6 even at high concentration of coupling agent (kerosene).
- . The coupling agent concentration is usually low; 5 to 10% of the blend.

- . The range of compositions such as 65 to 90% of fuel oil No. 6, 25 to 5% of ethanol, 10 to 5% of kerosene appear to be practically important.
- . Kerosene or n-hexane was found to have similar effects on blend compatibility.

The origin of compatibility and particle or molecular nature of the blend is not clear so far. However, the facts that kerosene is miscible with ethanol as well as fuel oil No. 6 (ethanol and fuel oil No. 6 are not miscible), suggest that kerosene may function as a coupling agent between the two major components, oil and alcohol. But, at reasonably high concentrations (above 25% by weight) of ethanol, the molecular/particle interaction may result in phase separation due to the relatively polar alcohol molecules. The thickening of the blends which resulted from the increasing ethanol concentration (shown below, equations 2, 3 and 4) further supports the concept of particle-particle (or molecular) interaction. The decrease in incompatible liquid volume separated, resulting when kerosene proportion is increased as shown in Table 1, emphasises the role of coupling agent in imparting compatibility.

Rheology of Blends

The blends containing fuel oil No. 6 and ethanol exhibit Newtonian behavior. The alcofuel containing 65% of No. 6 oil and varying proportions of ethanol and kerosene show increasing viscosities upon increasing alcohol concentration. The compositions (% wt) are as follows:

	Alcofuel A,	Alcofuel B,	Alcofuel C
Fuel Oil No. 6	65	65	65
Ethanol	25	15	10
Kerosene	10	20	25

The flow curves for various alcofuels are as follows (Power Law Model):

$$\tau = 0.053 \gamma^{1.01} \text{ (Alcofuel A)} \quad (2)$$

$$\tau = 0.033 \gamma^{0.99} \text{ (Alcofuel B)} \quad (3)$$

$$\tau = 0.0199 \gamma^1 \text{ (Alcofuel B)} \quad (4)$$

The Power Law index is nearly unity and viscosity varies from 53 cp to 20 cp depending alcohol concentration. Power Law viscosity increases upon increasing ethanol concentration.

Coal-Alcofuel Slurries

Rheology

Viscosity as a function of coal concentration is plotted for coal/ alcofuel and coal/fuel oil No. 6 slurries at ambient temperature for identical coal particle size distribution (Figure 2).

Alcofuel containing slurries exhibit far lower viscosities compared to fuel oil No. 6/coal slurries. In the same Figure is shown the viscosity of fuel oil No. 6 coal slurries at elevated temperature (212°F). The flow properties of the alcofuel slurries at ambient temperature are comparable to fuel oil No. 6 slurries at 212°F.

A comparison of viscosities of various alcofuel coal slurries and fuel oil No. 6 slurry at various coal concentration is presented in Figure 3. Fuel oil No. 6 slurries exhibit the highest viscosity while alcofuel C slurry is the lowest. The coal slurries containing alcofuel A and B exhibit intermediate viscosity values. The compositions of alcofuel A, B and C are shown in the Figure. The viscosity of coal blend slurries appears to increase with increasing alcohol concentration. The Figure 4 illustrates the effect of ethanol on alcofuels and alcofuel/coal slurries (30 and 40% coal). On examining

the effect of increasing concentrations of ethanol, two important observations could be made:

- . Increase in ethanol concentration in the blends results in higher viscosities of blends and coal/blend slurries.
- . The viscosity dependence on ethanol concentration is stronger in coal/blend slurries compared to alcofuel blends.

On examining the marked effect of ethanol on viscosity of coal slurry and marginal effect on blends without coal, it appears that the coal-alcohol interaction may be strong in these alcofuel coal slurries. Similar effect was mentioned by Keller⁴ and other workers.

A graph of viscosity as a function of shear rate for alcofuel, alcofuel/coal slurries (shown in Figure 5) shows that, up to 30% coal, slurries behave as almost Newtonian fluids and alcohol may contribute to nonNewtonian behavior in addition to the effect of coal concentration at higher coal loading (slurries with alcofuel A and B show slight shear thinning behavior even at 30% coal loading). The rheology of concentrated slurries is not reported here.

The surfactants were incorporated into coal alcofuel slurries 30% coal loading with an idea of further reducing the viscosity. Though a limited number of commercial surfactants have been employed and a specific coal sample is used, the results could be useful for further investigation in the field. A decrease in the viscosity is observed when TRS 10-80 (0.25%) is incorporated. The other surfactants employed in the present study are; SPAN 20, TERGETOL (nonionic), and TRTON X-15. The flow curves of alcofuel COMs (30% coal) containing various surfactants, computed using Power Law Model, could be represented as:

$$\tau = 0.226 \gamma^{0.98} \text{ (no surfactant)} \quad (5)$$

$$\tau = 0.213 \gamma^{0.99} \text{ (0.25\% TRITON X-15)} \quad (6)$$

$$\tau = 0.186 \gamma^{0.99} \text{ (0.25\% TERGETOL)} \quad (7)$$

$$\tau = 0.160 \gamma^{0.99} \text{ (0.25\% SPAN 20)} \quad (8)$$

$$\tau = 0.146 \gamma^{0.99} \text{ (0.25\% TRS 10-80)} \quad (9)$$

The Power Law viscosity decreases from 226cp to 146 cp for a slurry containing 0.25% of TRS 10-80. The surfactants decreased the viscosity, and Power Law index was unaffected at lower coal loadings.

The temperature dependence of viscosity of alcofuel and fuel oil No. 6 coal slurry is illustrated in Figure 6. The activation energy of viscosity was calculated using a plot of viscosity versus $1/T$ and is shown in Table 2.

The temperature dependence of viscosity is represented as

$$\eta_s = A \exp(-E/RT) \quad (10)$$

where η_s is the apparent viscosity, E the activation energy and T , temperature, °K. Similar activation energies were reported by Marlow and Rowell¹⁸ in Proceedings of the 3rd International Symposium on COM combustion. The parameter essentially represents the sensitiveness of flow property to heating in COM technology. The rheological measurements carried out at 212°F on coal/fuel oil No. 6 slurries are illustrated in Figure 7. Modeling of rheology of COM containing No. 6 oil has been carried out in detail, could be found in COM symposia volumes and recent literature, e.g. Ghassemzadeh and Carmi⁹. We have compared the rheological behavior of alcofuel COMs with No. 6 oil COM.

Stability of Coal/Alcohol Slurries

The viscosities and densities of alcofuels are lower compared to fuel oil No. 6. Hence, the stability of alcofuel/coal slurries may be lower than fuel oil/coal slurries. However, the presence of coal-alcohol interaction may impart stability/instability. Surfactants such as TRTON X-15, TRS 10-80 TERGETOL, SPAN 20 were found to impart stability to alcofuel/coal slurry (shown in Figure 8). While TRTON X-15 is the most effective of the limited number of surfactants employed, the general concept may be that for a judicious choice of a suitable surfactant for a coal and oil type, it needs further screening of additives.

Ignition and Combustion Characteristics

The burning profiles of fuel oil no. 6, and coal/fuel oil no. 6 slurries are shown in Figure 9. The initial peaks, characteristic of fast exothermic reactions, however, could be considered as the onset of ignition process. Since, we have used Calorimetric Cell in the present study, the subsequent burning shows broad exotherms. Though the coal/oil slurry is a physical mixture, the complicated multiple peaks, resulting in the visible flame suggest that the ignition and combustion processes are complicated by several sequences of reactions. At a reasonably slow heating rate (e.g. $15^{\circ}\text{C}/\text{min}$) we observed distinct flames separated by 10 to 15°C temperature intervals. The fuel oil No. 6 ignited around 275°C at a heating rate of $60^{\circ}\text{C}/\text{min}$. Under similar heating rate, sample weight and oxygen flow rate, coal oil mixture ignited in the region of $290\text{--}400^{\circ}\text{C}$ with several flamelets. For our kinetic analysis, we have considered the initial peak as the onset of ignition process. The ignition temperatures decrease with

the increase in heating rates. Also, the peak temperature representing sudden exothermic reaction decrease with increasing coal concentration.

In the Figure 10, the burning profiles of alcofuel and coal/alcofuel slurries are shown. The alcofuel ignites at 225°C at a heating rate of 65°C/min. while coal/alcofuel slurries ignite at higher temperatures. The peak temperature increases with increasing coal concentration as in the case of fuel oil No. 6 slurries (Figure 11). The multiple flames are observed in the case of alcofuels, stretching from 222-300°C. At this stage, we could attribute the phenomena to various components of alcofuels having varying degrees of reactivity, e.g. ethanol and kerosene are more reactive compared to fuel oil No. 6. However, as seen from burning profiles in Figure 10, the combustion of coal/alcofuel slurry is complicated by the sharp ignition peaks and broad exotherms above 400°C. Also, it was observed that significant condensed phase burning is involved in the COM combustion process carried out at slow heating rates.

The kinetic analysis of different fuels was carried out using dynamic DTA curves at different heating rates obtained under similar experimental conditions such as sample weight, and oxygen flow rate. We employed Kissinger method¹⁰ of fitting the data into kinetic equation irrespective of the order of reaction. Kissinger showed that the activation energy, E and the "order of reaction" n, obeying Arrhenius equation,

$$\frac{dx}{dt} = A(1-x)^n \exp (-E/RT) \quad (11)$$

could be determined from DTA curve. In the above equation x is fraction reacted at time t , A is constant and R is gas constant. According to Kissinger's method the slope of the line $\ln(\beta/T_C^2)$ against $1/T_C$ is $-E/R$, where β is heating rate $^{\circ}\text{K}/\text{sec}$, T_C is the peak temperature $^{\circ}\text{K}$, E is the activation energy, cal/mole and R in $\text{cal}/\text{deg mole}$, irrespective of order of reactions. The method of Kissinger is not very accurate and may give large errors for a slight error in peak temperature measurement. In our present analysis, as the ignition peaks are very sharp, the method may yield useful information regarding activation energy. While absolute predictive information may be difficult to obtain, relative trend could be easily extracted. For comparing the reactivity of fuel oil, alcofuels and coal oil slurries, relative information is all that matters. Figure 12 shows a plot of $\ln(\beta/T_C^2)$ versus $1/T_C$ for alcofuel, coal/alcofuel slurries, fuel oil No. 6 and coal/No. 6 oil slurries. The activation energy calculated using the least square fitting technique is shown in Table 3. The alcofuel and alcofuel COMs up to 40% coal have similar activation energies, considering the difference of 1-5 kJ as error involved in the method of analysis. The alcofuels being more reactive compared to coal, the rate determining steps may be mostly in the ignitions of alcofuel as seen from similar activation energies. However, at very high coal-loading, the activation energy may involve the breaking of coal structure as well; probably the values may be higher. Similar explanation holds good in the case of fuel oil No. 6 and coal oil slurries. The comparison of ignition behaviors of fuel oil, alcofuels and coal slurries in these fuels suggests that:

1. Up to 40% of coal loading, the ignition of the liquid fuel or alcofuel appears to control the ignition process.
2. The ignition process, at a molecular level, in the case of fuel oil and alcohol appears to be the same as shown by similar E values of all the systems.
3. Though the key process (s) may be the same the alcofuels COMs are more reactive compared to fuel oil No. 6 and COMs as shown from higher apparent reaction rates.

As far as the fundamental understanding of COM ignition is concerned, there are a few approaches made in this direction employing DTA and TG techniques.¹¹⁻¹³ However, kinetic analysis of the data obtained by slow heating rate experiments have not been carried out so far.

The schematic diagrams illustrating the present COM technology and proposed alcofuel COM technology are shown in Figure 13 and 14 respectively in order to highlight the advantages of the proposed slurry fuel.

Conclusions

1. Alcofuels are homogeneous (compatible) blends of fuel oil No. 6 and ethanol in the presence of a coupling agent, kerosene. The typical alcofuel may contain fuel oil No. 6, 65, ethanol 25, and kerosene 10% by weight.
2. Alcofuels have far lower viscosities, (≈ 40 cp) compared to No. 6 oil (≈ 200 cp). The viscosity of alcofuel increases with increasing ethanol concentration. These blends are Newtonian fluids.
3. The viscosity of coal alcofuel slurries are considerably lower than coal/No. 6 oil slurries. However, the ambient viscosity of the new class of slurries are comparable to coal No. 6 oil mixture at 212°F.

4. Coal alcofuel slurries are typical Newtonian fluids below 30% coal and above 30% coal are seen to be shear thinning type. The addition of typical commercial surfactants lowered the slurry viscosity and increased the stability of the dispersion, e.g. TRITON X-15 was found to be most effective in stabilizing and TRS 10-80 was better thinning agent. The rapid increase in viscosity of the alcofuel slurry with ethanol concentration at higher coal loading probably suggests the existence of strong interaction of coal-alcohol in the dispersion.

5. The ignition peaks of alcofuels and coal-alcofuel slurries are sharp. In the burning profile, multiple flames are observed. The alcofuel COMs are more reactive than No. 6 oil COMs as seen from lower ignition temperatures of the former under similar conditions. The peak temperatures increased with coal concentration and decreased with heating rate.

6. The activation energy of ignition of alcofuels and coal/alcofuel mixtures are similar up to 40% loading. This probably would mean that the oil burning controls the ignition process. Similar mechanism appears to be true in the case of Coal/No. 6 oil system.

7. The advantages of current COM technology and the proposed COM technology are highlighted.

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Table 1 Compatibility of Fuel Oil No. 6 with Ethanol

Blend Composition (% Weight)		Ethanol to Kerosene Ratio	Incompatible Volume	
Fuel Oil	Ethanol + Kerosene		V_{ℓ} (ml)	$V_{\%}$ incomp.
65	35	10.6	0.2	2.0
		6.0	0.1	1.0
		2.5	<0.05	<0.05 Compatible
		1.33	0	0
70	30	14.0	0.3	3.0
		5	0.1	1.0
		2.75	<0.05	<0.5 Compatible
		1.0	0	0
75	25	4.0	0.1	1.0
		3.0	<0.05	<0.5 Compatible
		1.0	0	0
100				

*Total volume of blends, $V = 10$ ml in each case.

Table 2 Activation Energy of Viscosity of Various Slurry Fuels

COMs Containing 50% Coal and 50% wt. of	Activation Energy, E (Kcal/mole)
Alcofuel A	10.5
Alcofuel B	7.5
Alcofuel C	8.8
Fuel Oil No. 6	7.2

Table 3 Activation Energy of Ignition of Various Slurry Fuels

<u>Fuels</u>	<u>Activation Energy, E, (Kcal/mole)</u>
Alcofuel	17.60
Fuel Oil No. 6	16.63
30% Alcofuel COM	16.41
40% Alcofuel COM	10.43
40% Fuel Oil No. 6 COM	15.00

Figure Captions

1. Compatibility of fuel oil No. 6 + ethanol + kerosene/n-hexane
2. Apparent viscosity versus coal concentration for No. 6 oil COM and alcofuel COM.
3. Apparent viscosity as a function of coal concentration for No. 6 oil and alcofuels COM.
4. Effect of ethanol concentration in blends on alcofuels and alcofuel COMs.
5. Viscosity versus shear rate for alcofuels and alcofuel COMs.
6. Viscosity of 50% coal loaded No. 6 oil COM and alcofuel COM as a function of temperature.
7. Viscosity versus shear rate for fuel oil No. 6 COMs. at 212°F.
8. Effect of surfactants on stability of alcofuel COMs.
9. Burning profiles (DTA) and ignition temperatures of fuel oil No. 6 and No. 6 oil COMs.
10. Burning profiles (DTA) and ignition temperatures of alcofuel and alcofuel COMs.
11. Ignition/exothermic peak temperatures of COMs as a function of coal concentration.
12. Activation energy of ignition for fuel oil No.6, alcofuels and COMs.
13. Current COM technology.
14. Proposed COM technology.

ETHANOL

PERCENTAGE WEIGHT

INCOMPATIBLE
REGION

PERCENTAGE WEIGHT

n-HEXANE

KEROSENE

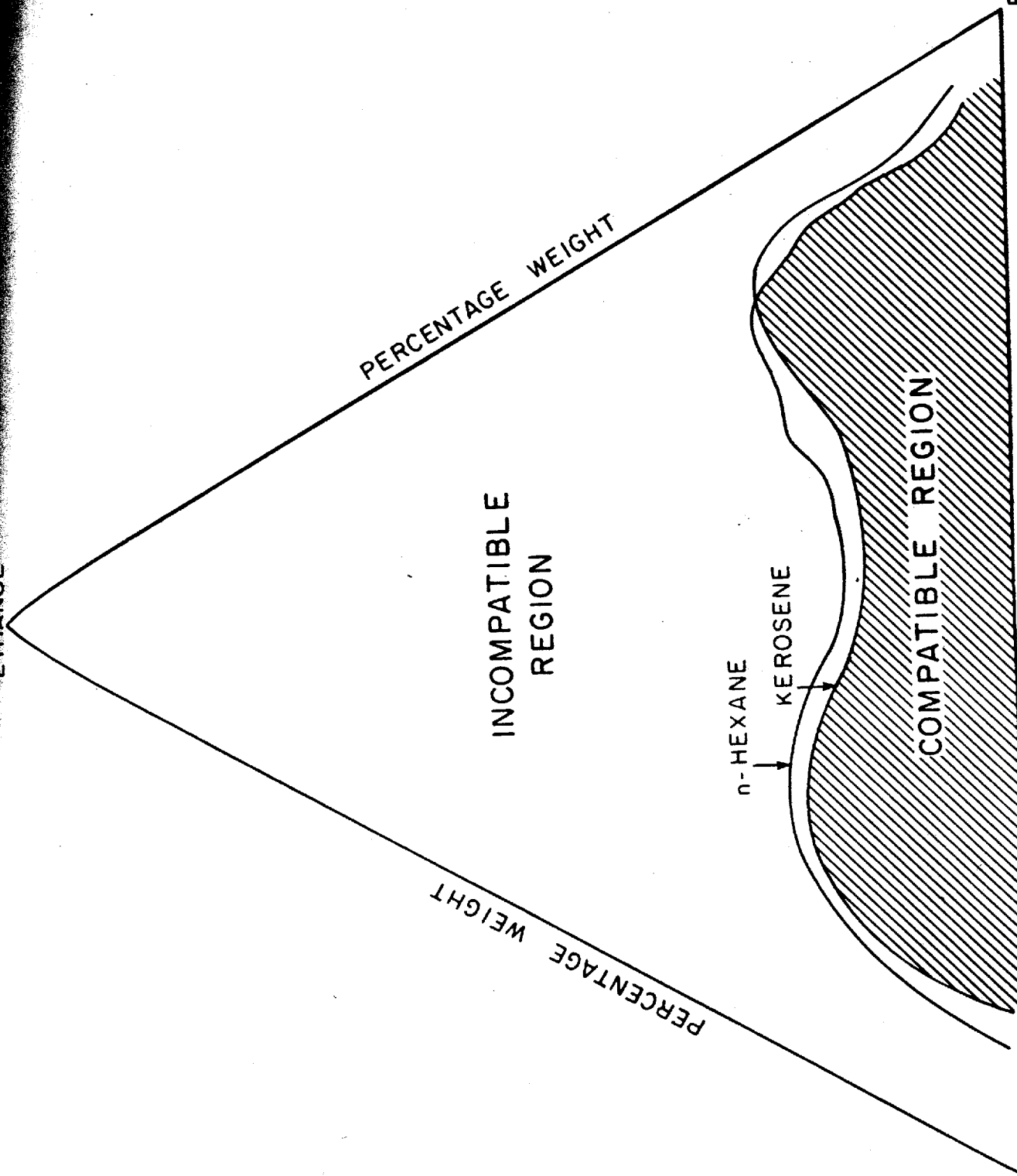
COMPATIBLE REGION

PERCENTAGE WEIGHT

FUEL OIL
NO. 6

COUPLING AGENT

(n hexane or
kerosene)



Shear rate, 1.15 sec^{-1}

\triangle No. 6 Oil COM Alcofuel composition (% Wt.)
 \circ Alcofuel COM, Fuel oil 65
 Ethanol 25
 Kerosene 10

VISCOSITY, CP

100000

10000

1000

100

10

0

10

20

30

40

50

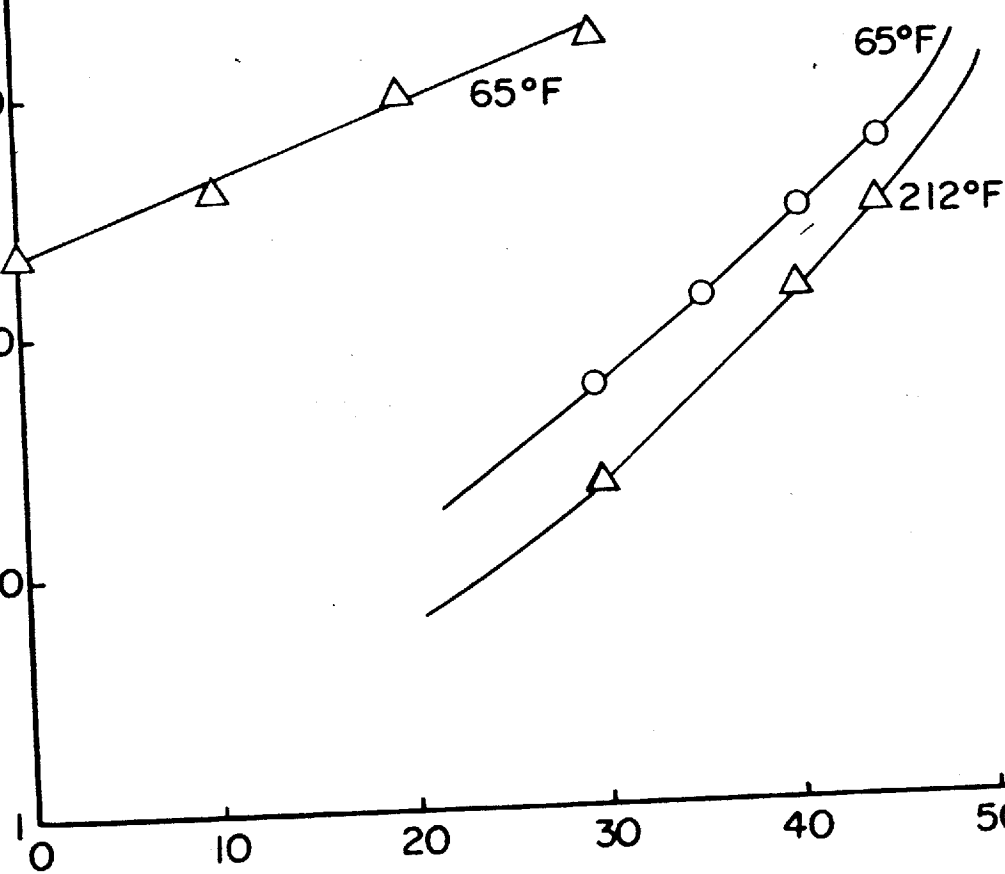
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CONCENTRATION OF COAL, (% WEIGHT)

65°F

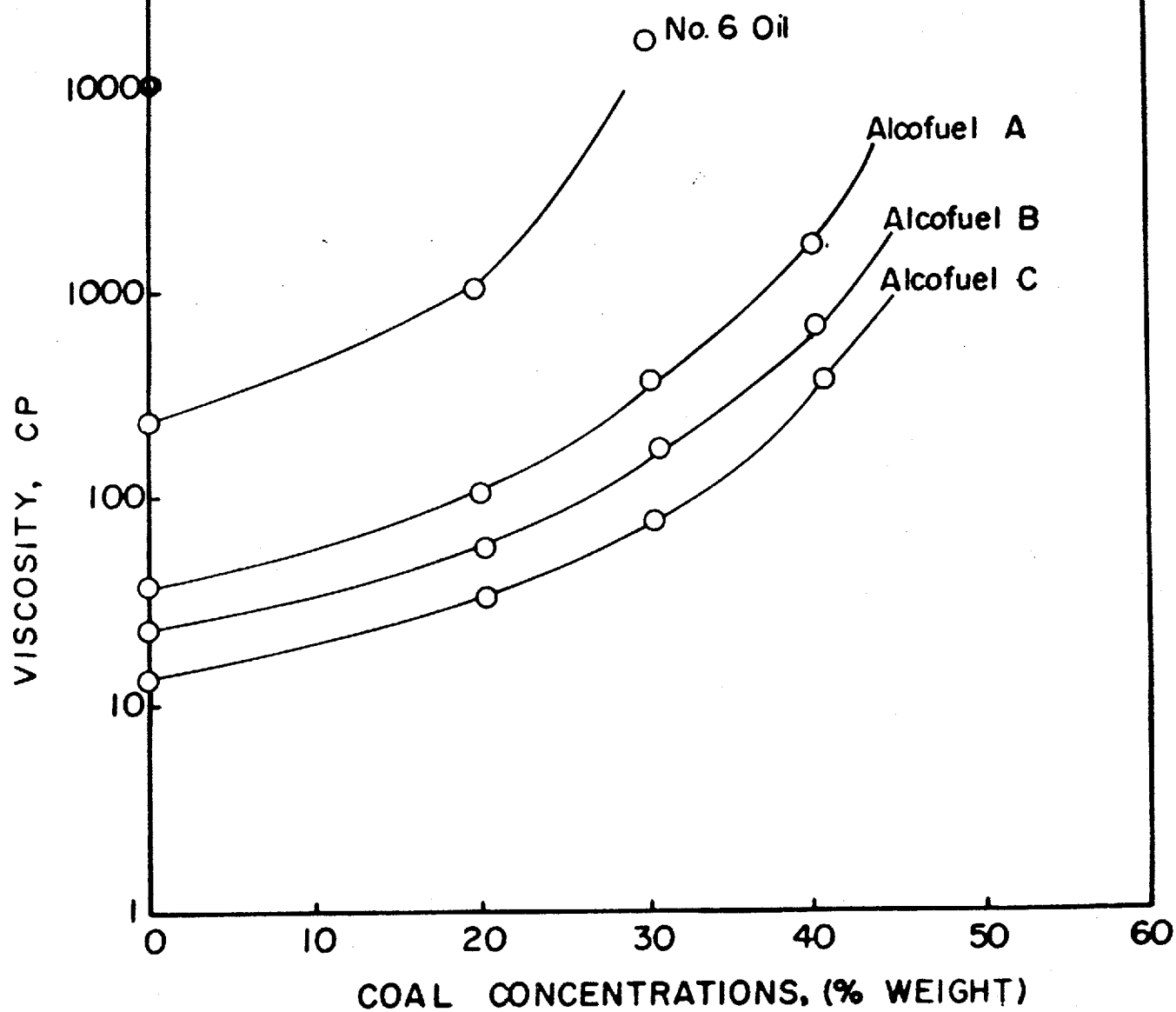
65°F

212°F



Shear rate 1.5 sec^{-1}
Temperature 65°F
Alcofuel compositions (%Wt)

	A	B	C
No.6 Oil	65	65	65
Ethanol	25	15	10
Kerosene	10	20	25



Temperature, 65°F
Shear rate, 1.15 sec⁻¹

VISCOSITY, CP

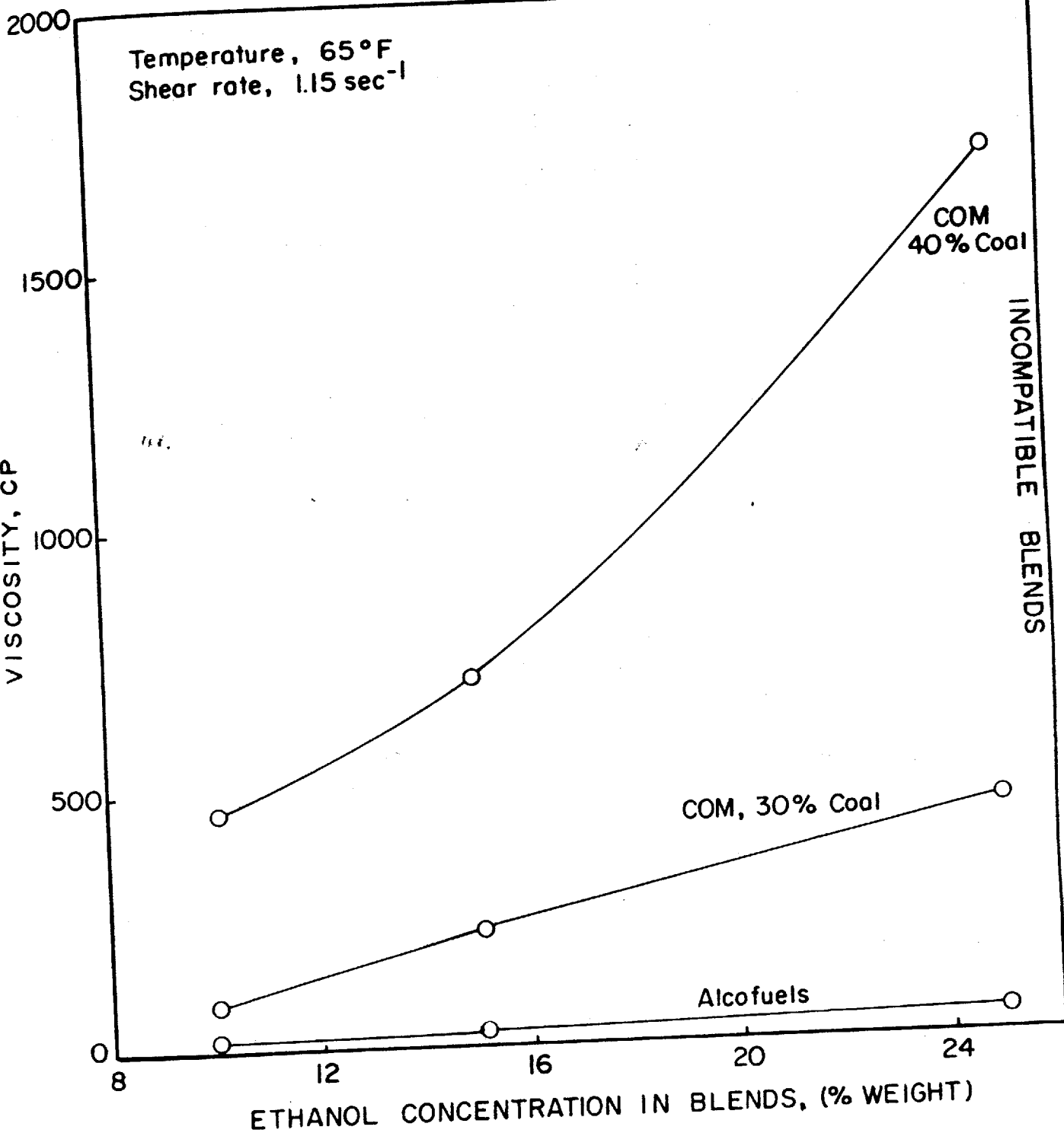
INCOMPATIBLE BLENDS

COM
40% Coal

COM, 30% Coal

Alcofuels

ETHANOL CONCENTRATION IN BLENDS, (% WEIGHT)



Temperature, 65°F

VISCOSITY, CP

SHEAR RATE, SEC⁻¹

30% Alcofuel A, COM

Fuel oil No.6

30% Alcofuel B, COM

Alcofuel C, COM

Alcofuel A

Alcofuel B

Alcofuel C

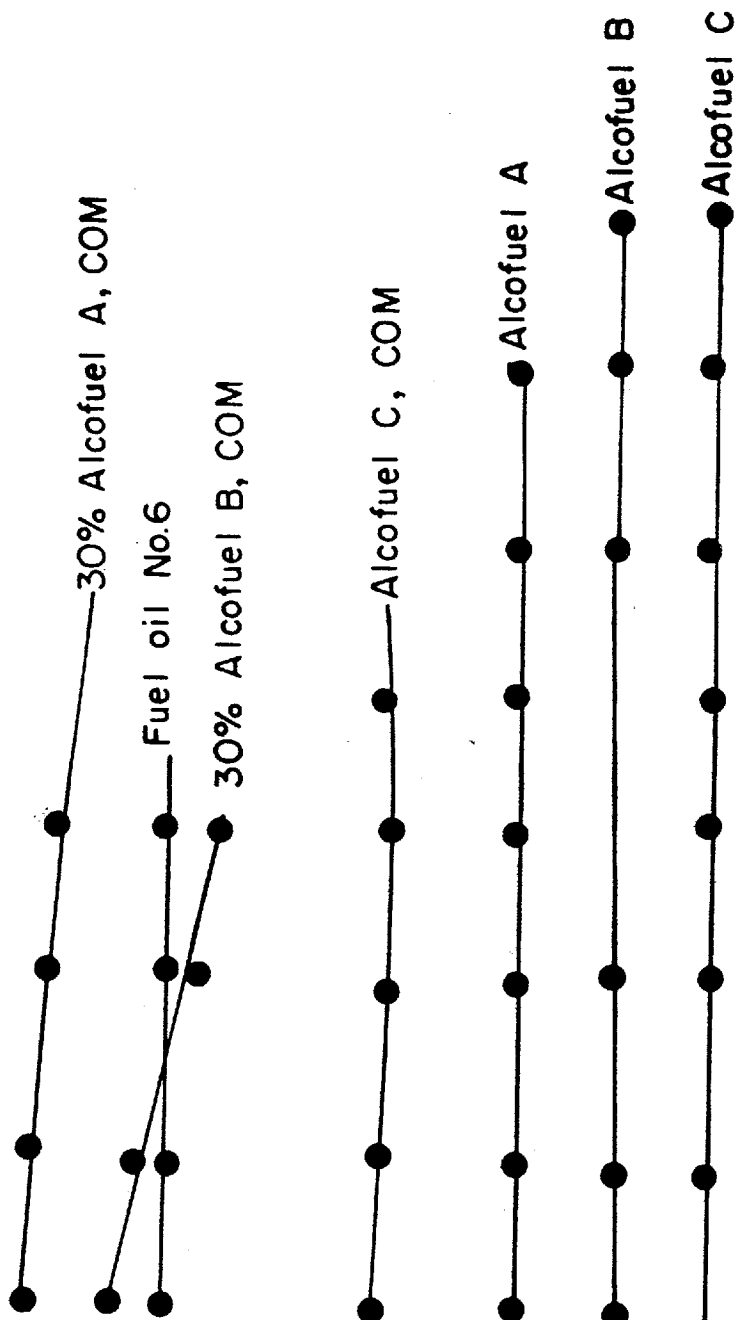
1000

100

10

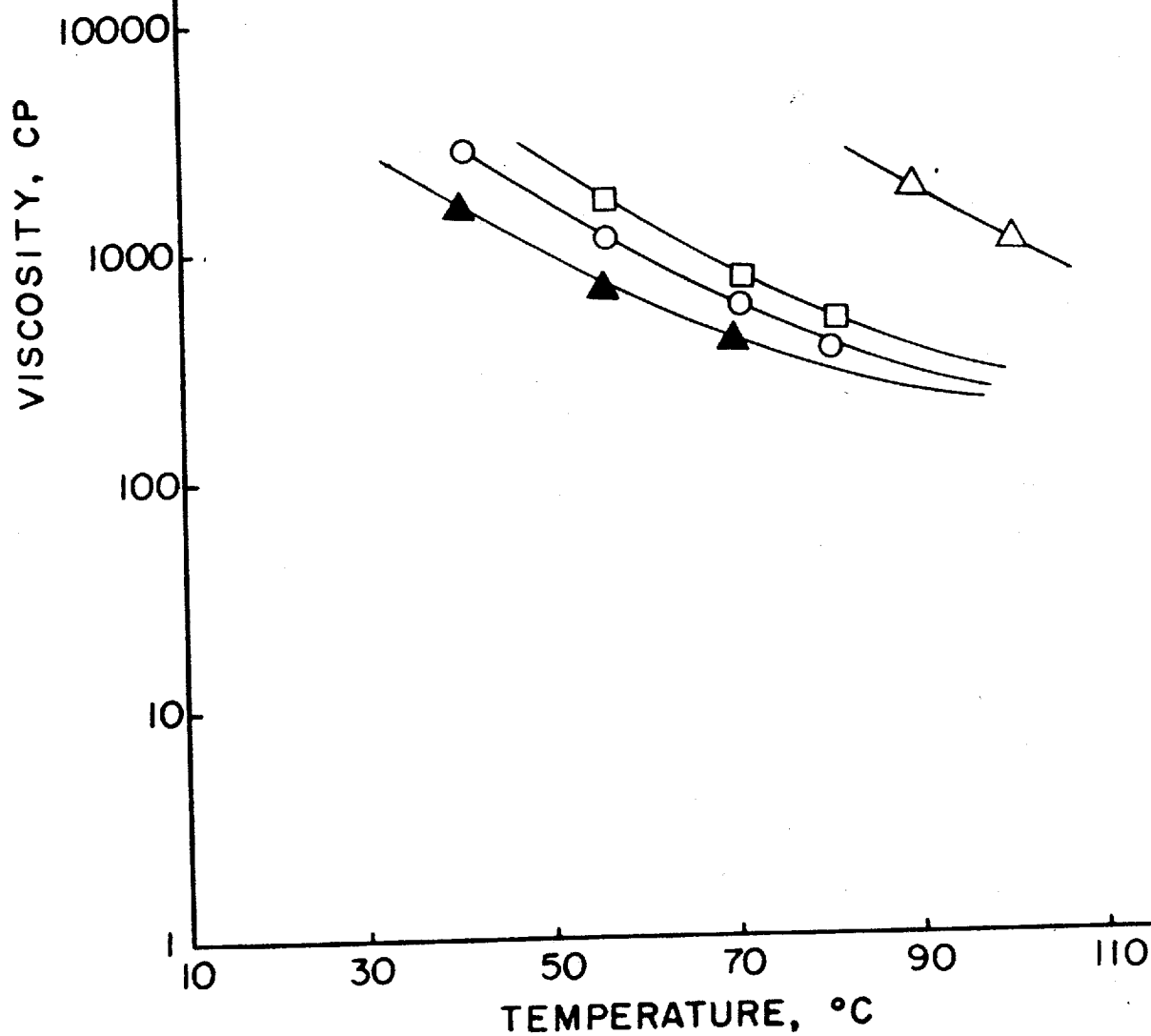
100

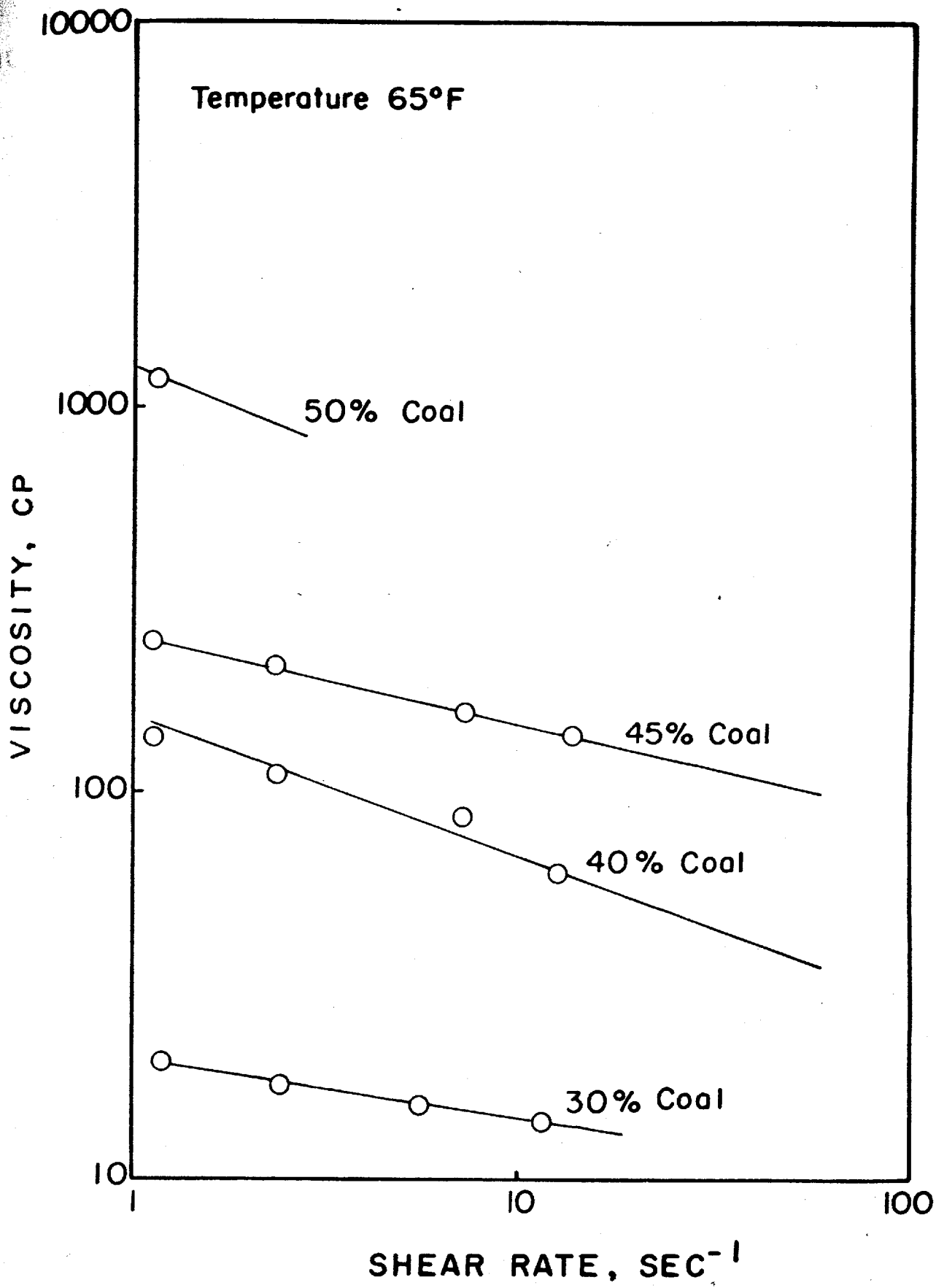
1000



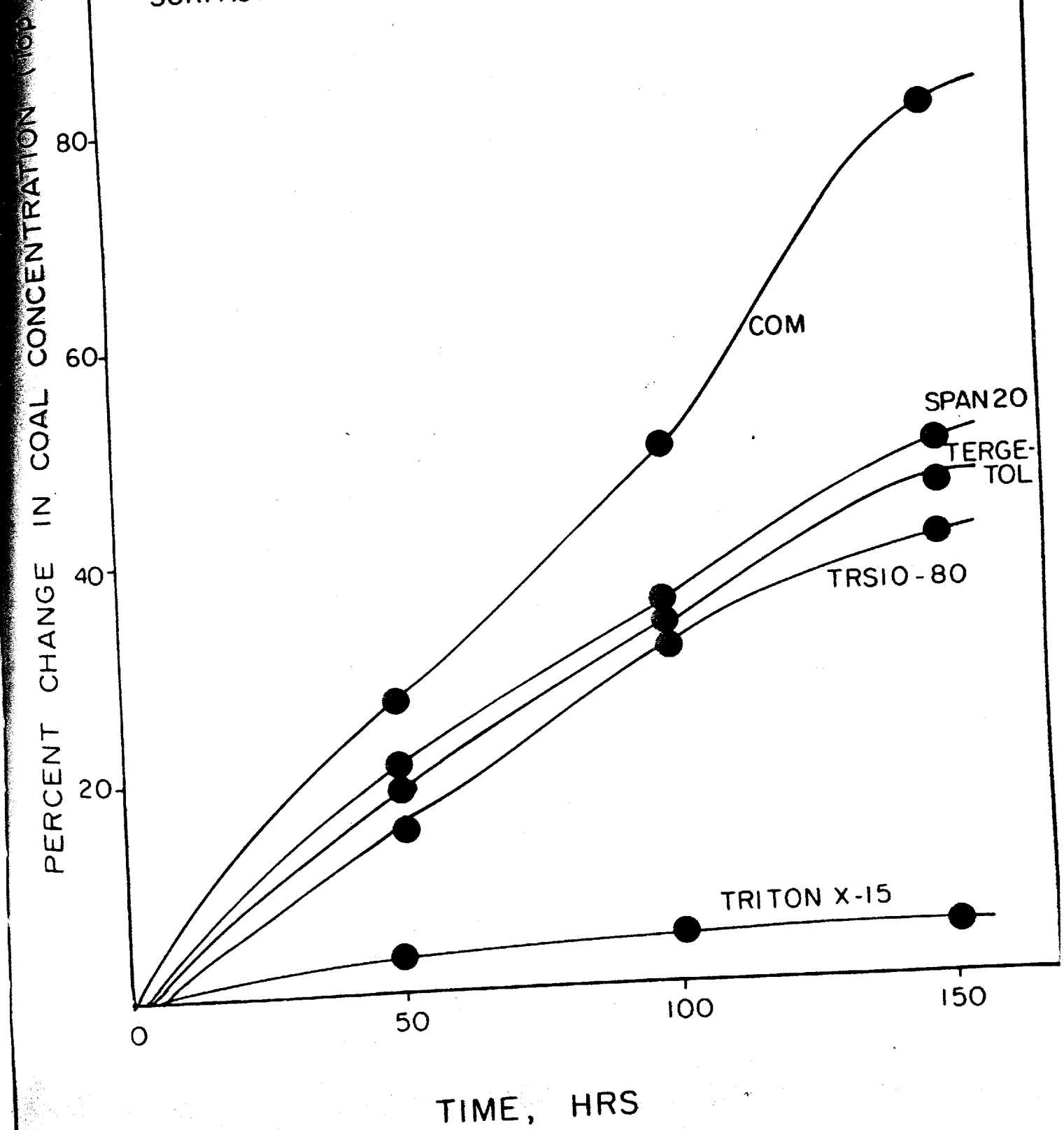
Shear rate 1.15 sec^{-1}
COM composition (% weight)
50% Coal and

- Alcofuel A
- Alcofuel B
- ▲ Alcofuel C
- △ Fuel oil No.6

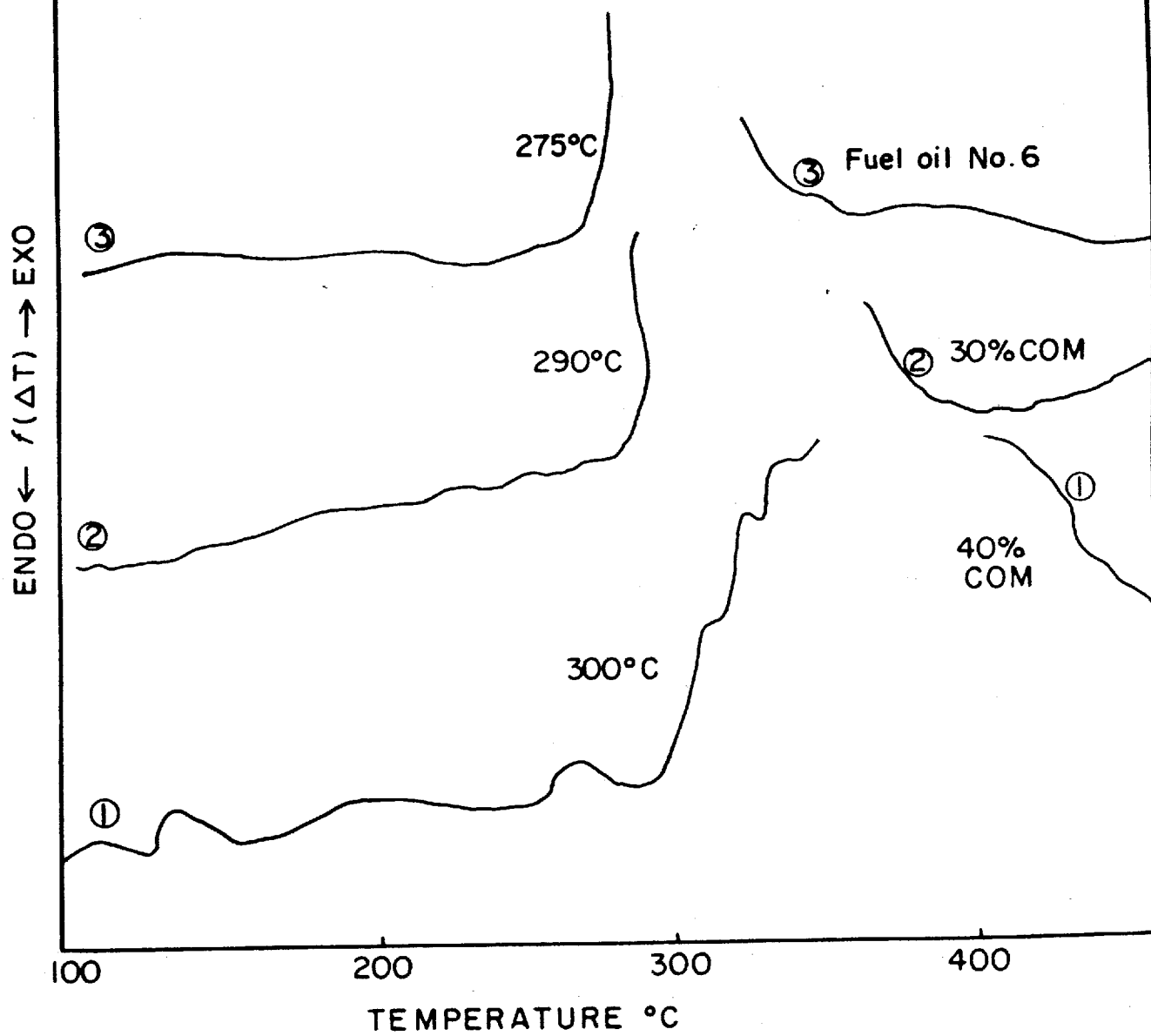




COM OF ALCOFUEL CONTAINING 30% COAL, 0.25%
SURFACTANTS, TEMPERATURE, 65°F

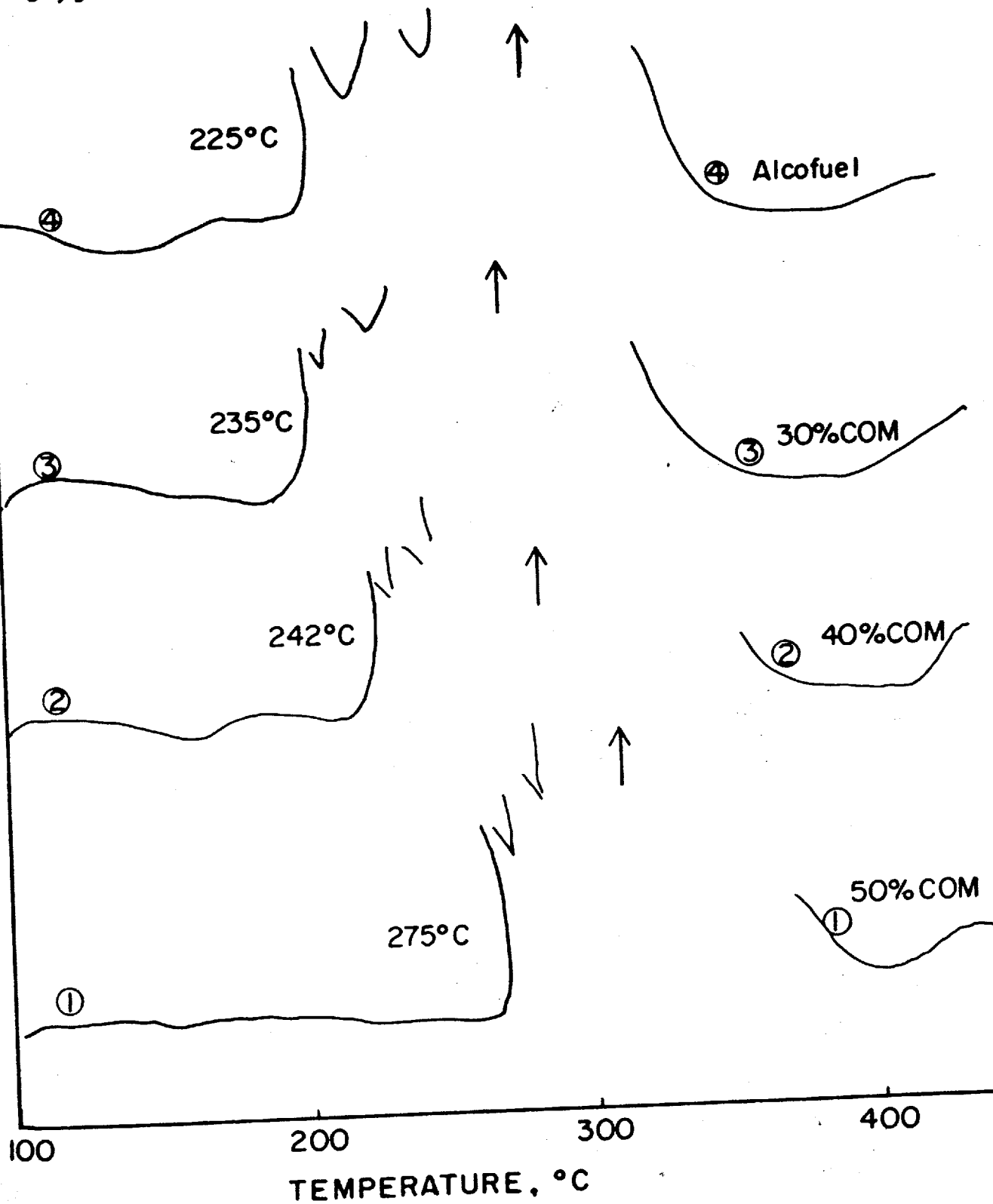


Heating rate, 60°C/min.
Sample weight 25mgs.
Oxygen atmosphere



Heating rate 60°C/min.
Sample size 25 mgs
Oxygen atmosphere

ENDO ← f(ΔT) → EXO



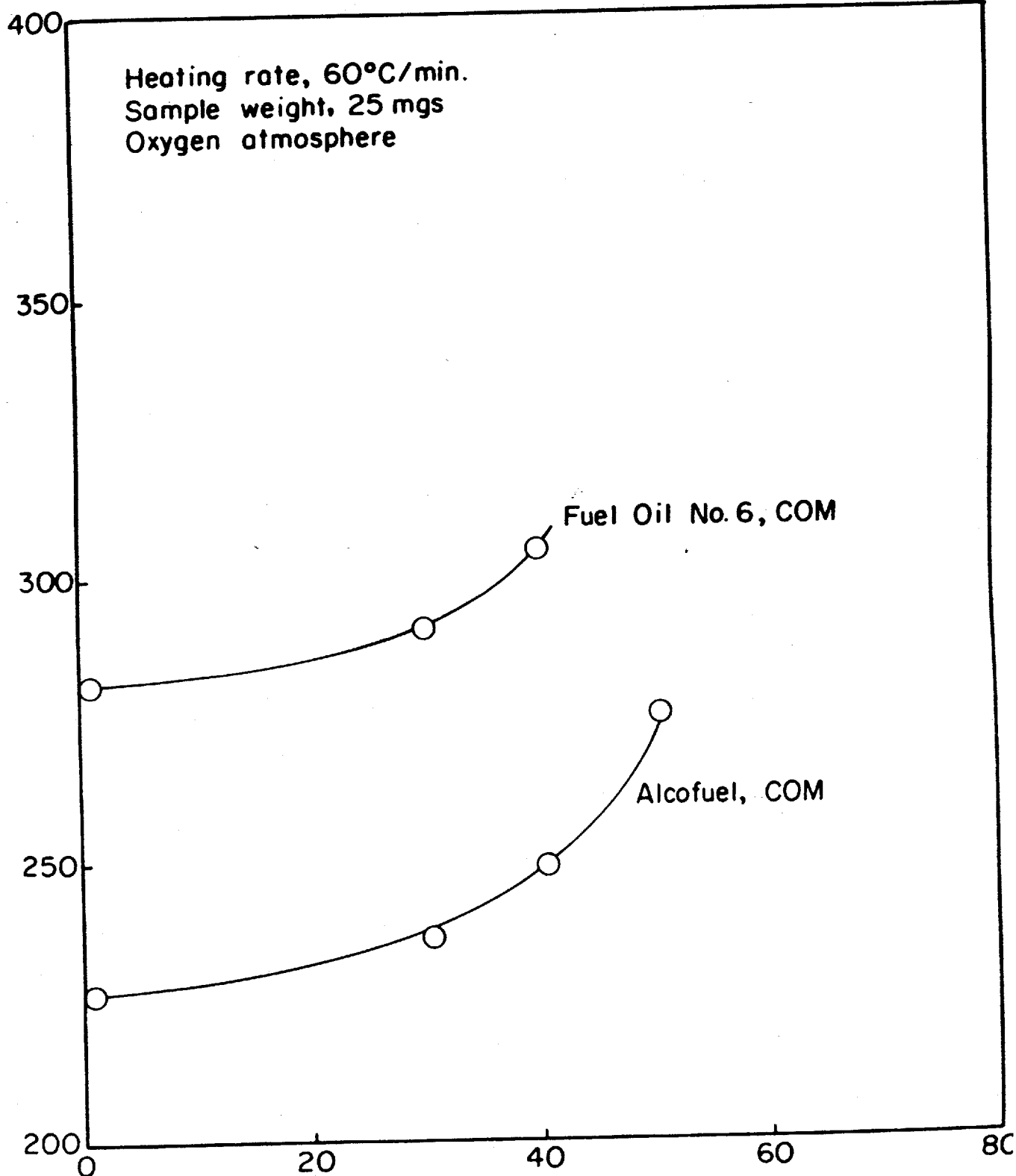
Heating rate, 60°C/min.
Sample weight, 25 mgs
Oxygen atmosphere

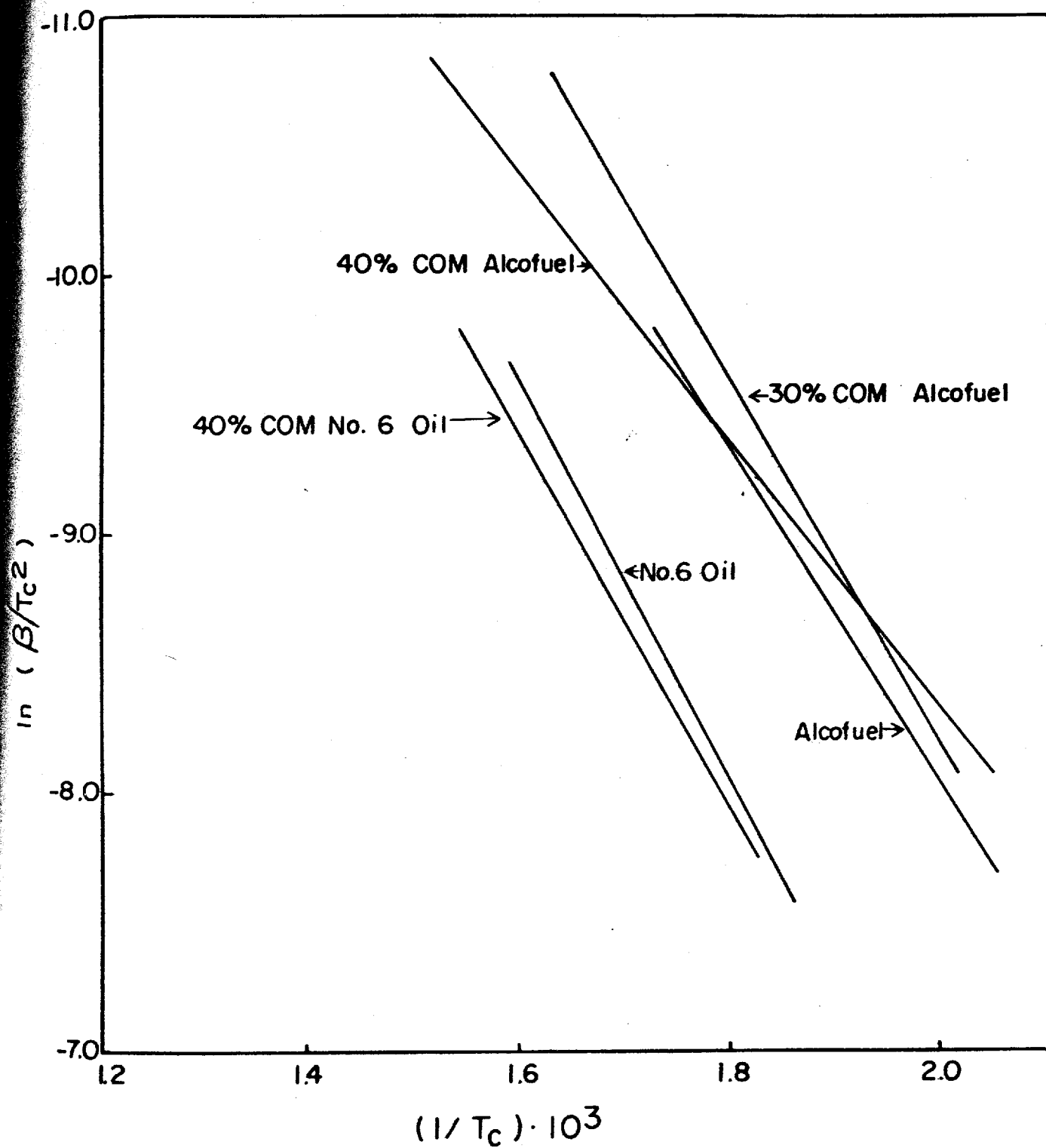
IGNITION/EXOTHERMIC PEAK TEMPERATURE, °C

Fuel Oil No. 6, COM

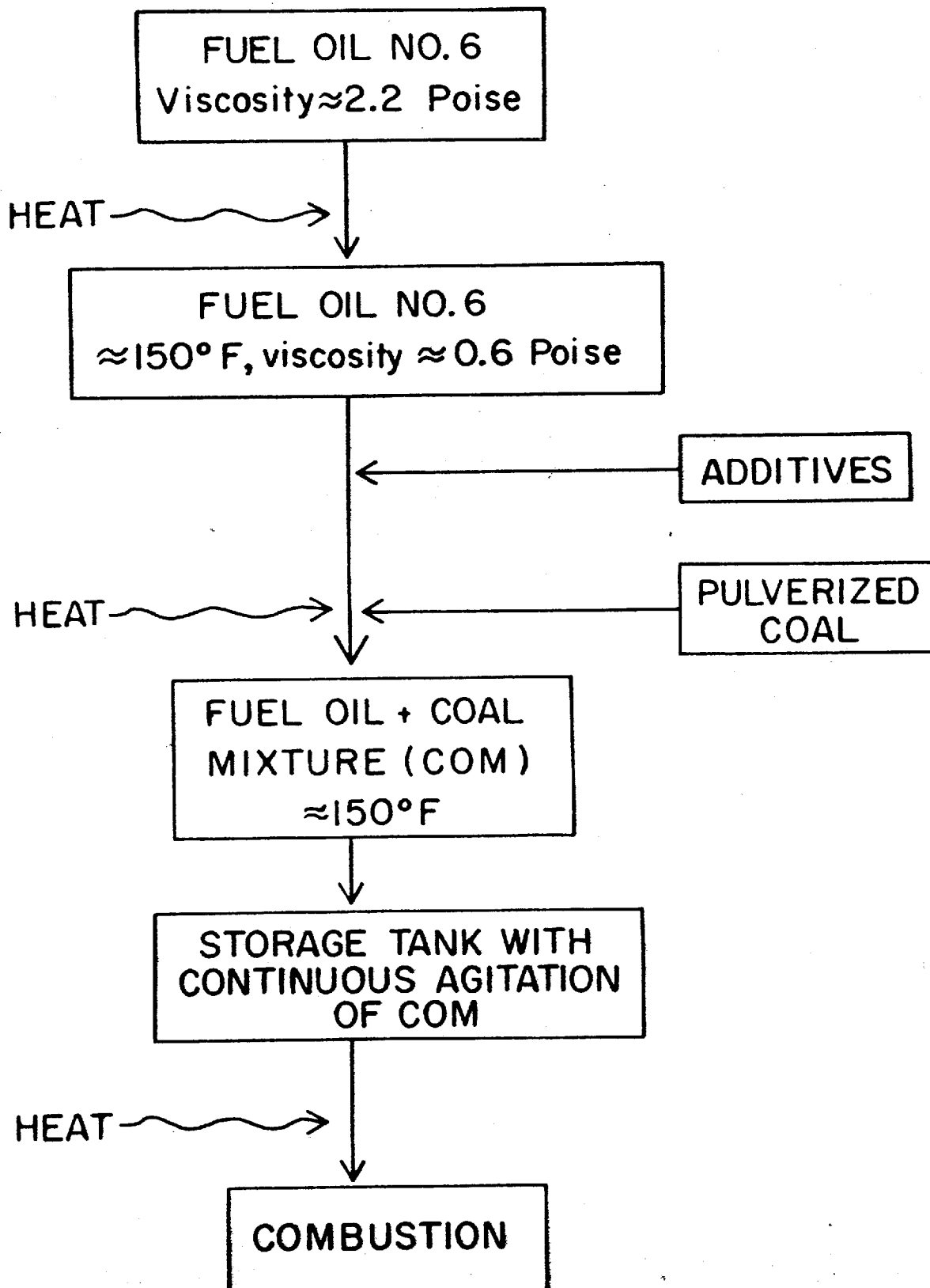
Alcofuel, COM

CONCENTRATION OF COAL, (% BY WEIGHT)





CURRENT STATUS OF COM TECHNOLOGY



PROPOSED ALCOFUEL COM TECHNOLOGY

