NASA Technical Memorandum 79035

(NASA-TM-79035) EVALUATION OF THE APPLICATION OF SOME GAS CHROMATOGRAPHIC METHODS FOR THE DETERMINATION OF PROPERTIES OF SYNTHETIC FUELS (NASA) 46 p HC A03/MF A01 CSCL 21B G3/25

N79-16930

Unclas
14078

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TECHNICAL PAPER presented at the
Aerospace Meeting
sponsored by the Society of Automotive Engineers
San Diego, California, November 27-30, 1978

EVALUATION OF THE APPLICATION OF SOME GAS CHROMATOGRAPHIC METHODS FOR THE DETERMINATION OF PROPERTIES OF SYNTHETIC FUELS

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ABSTRACT

The purpose of the investigation was to evaluate the applicability, to some synthetic fuels, of some gas chromatographic methods now under development for use with petroleum based fuels. Thirty-two (32) jet and diesel fuel samples which were prepared from oil shale and coal syncrudes were examined. The boiling range distribution of each was determined by gas chromatography, and from that data distillation properties were calculated. The calculated results gave sufficient agreement with the measured values that the equations could be useable in their present form. Bulk fuel properties (°API, flash point, viscosity) were calculated for the sixteen (16) JP-5 and Diesel No. 2 type fuels. The results show that the equations would not give useable results. Capillary column gas chromatography was used to determine the n-alkane content of the eight (8) JP-5 type samples and the results related to the observed freezing points. The results show that the concentrations of the long straight chain molecules in the fuels exert influence on the freezing point but are not the complete controlling factor.

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SUMMARY

Increasingly, attempts are being made to use gas chromatography to provide fuel composition and distillation data for a variety of petroleum fuels. A recent reference describes attempts to obtain a correlation between ASTM Test Method D86, Test for Distillation of Petroleum Products, and ASTM Test Method D2887, Test for Boiling Range Distribution of Petroleum Fractions by Gas Chromatography. Equations were obtained for calculating D86 data points from D2887 data. Equations were also obtained for calculating some bulk fuel properties from the gas chromatography data, and others for substituting D2887 data for D86 data in some correlative equations for estimating the heat of combustion and the hydrogen content. The purpose of this investigation was to evaluate the application of these methods to some synthetic fuels. The equations were applied to 32 fuels, of varying properties, derived from oil shale and coal syncrudes. Volatility correlations and bulk fuel properties were determined. The results show that some of the methods would be applicable in their present form. The equations for obtaining D86 data points from D2887 data, and those using

D2887 data in the correlative equations for estimating heat of combustion and hydrogen content can be applied in their present forms. The use of the other equations to obtain bulk fuel properties (°API, flash point, and viscosity) was not successful.

In another part of the investigation capillary gas chromatography was used to determine the concentrations of the n-alkanes in some of the fuels. Those concentrations were examined for relationships with freezing points, as noted for petroleum fuels. The results show that the concentrations of the long straight chain molecules in the fuels exert influence on the freezing point but are not the complete controlling factor.

INTRODUCTION

Methods of measuring chemical and physical properties of petroleum products, and also correlating them to fuel quality and combustion performance, are constantly being modified, changed and improved. Recently, the use of gas chromatography was introduced to provide fuel composition and distillation data for a variety of fuels. For gasolines, for example, gas chromatographic data has been used to calculate vapor pressure, aniline point, pour point, and octane rating. Presently, though, ASTM Test Method D86, Test for Distillation of Petroleum Products (ref. 1) is used for measuring and controlling the distillation characteristics of many petroleum products. This test is equivalent to a one-plate distillation and only provides a general idea about the true distillation properties of a fuel. The use of gas chromatography, though, shows promise for providing far more information in a much simpler fashion. An ASTM Test Method, D2887, Test for Boiling Range Distribution of Petroleum Fractions by Gas Chromatography (ref. 2) is increasingly being used but has not yet been approved for use in aircraft turbine fuel specifications. The D2887 test method is equivalent to a distillation with over 100 theoretical plates. One restriction in its use has been the lack of a suitable correlation between the D86 and the D2887 tests. Recently, (ref. 3), an attempt has been made to obtain a correlation between D86 and D2887 for jet fuels and obtain D86 data points from D2887 measurements. In addition, equations were generated for calculating bulk fuel properties from the gas chromatography data and the substitution of D2887 data for D86 data in some correlations was examined.

The purpose of this report is to examine the applicability of the gas chromatography methods derived for petroleum fuels to some fuels derived from oil shale and coal syncrudes. These fuels approximated JP-4, JP-5, diesel #2, and broad-specification fuels. The regression equations computed in reference 3 can be used to estimate D86 distillation values from D2887 measurements for both wide-cut and kerosine type aircraft turbine fuels, and appear to have sufficient precision for most purposes. These equations were applied to all of the synthetic fuels. For calculating physical properties, only those equations that gave reasonable accuracy with petroleum fuels were used, namely, flash point, viscosity and API

gravity for kerosine fuels. The equations suggested for use in substituting D2887 data for D86 data in some new correlative methods for estimating the net heat of combustion and the hydrogen content were applied to all of the fuels.

One other use of gas chromatography for determining a physical property was examined in this report. Specifically, for the JP-5 type fuels only, the n-alkane content of each as determined by capillary gas chromatography, and that content related to the freezing point of the fuel.

FUELS

The fuels examined in this work were those prepared from TOSCO shale oil, H-Coal and COED coal syncrudes by the Atlantic-Richfield Company under an NASA contract (ref. 4). Thirty-two jet fuel samples of varying properties were produced by processes commonly in use in petroleum processing - distillation, hydrogenation and catalytic hydrocracking. The processing conditions were those required to meet two levels of specifications regarding aromatic, hydrogen, sulfur and nitrogen contents at two yield levels. Each process stream was split by distillation to give four distillation ranges. The volatility specifications of the fuels produced were approximately those found in the following: (1) JP-4 (Jet B) with a 561K (550°F) end point and 20.7 x 10^3 N/m^2 (3 psi) maximum Reid vapor pressure, (2) JP-5 (Jet A) with a 561K (550°F) end point and a 311K (100°F) minimum flash point, (3) a broad specification fuel incorporating the volatility of a JP-4, 20.7 x 10^3 N/m^2 (3 psi RVP) and the end point of a diesel No. 2, 616K (650°F), (4) Diesel No. 2 with a 616K (650°F) end point and a 311K (100°F) minimum flash point. All the physical and chemical tests required for aircraft turbine fuels were reported by ARCO for the 32 fuels using standard ASTM methods. Sixteen of these fuels were from a TOSCO shale oil syncrude, 8 from an H-Coal syncrude, and 8 from a COED (coal-derived) syncrude. The properties of the fuels obtained are given in Table I. The distillation data, obtained by ASTM D86 are given in Table II. In this method a 100-ml sample is distilled under prescribed conditions, and systematic observations of thermometer readings and volumes of condensate are made. The initial boiling point (IBP) is defined as the thermometer reading that is observed at the instant that the first drop of condensate falls from the lower end of the condensor tube. The percent recovered is the volume in milliliters of condensate observed in the receiving graduate, in connection with a simultaneous thermometer reading. The end point (EP) or final boiling point (FBP) is defined as the maximum thermometer reading obtained during the test.

METHODS FOR DETERMINING JET FUEL PROPERTIES

ASTM D2887 Data

ASTM Test Method D2887, Test for Boiling Range Distribution of Petroleum Fractions by Gas Chromatography, was used to obtain the gas chromatographic data. The data was obtained from the Quality Control Laboratory, AFAPL,

Wright-Patterson Air Force Base. A Perkin-Elmer 900 gas chromatograph with a flame ionization detector was used. SE-30 column packing (3% loading) was used in an 1/8" x 15' column, with the temperature programmed at 8° per minute from 233 to 573K (-40 to 572°F). In this method a sample is introduced to the gas chromatographic column, which separates hydrocarbons in boiling point order. The area under the chromatogram is recorded throughout the run. Boiling temperatures are assigned to the time axis from a calibration curve obtained under the same conditions by running a known mixture of hydrocarbons covering the boiling range expected in the sample. From these data the boiling range distribution is obtained. The data is tabulated as percent recovered at each selected interval and the boiling temperature assigned to that interval from the calibration curve. The results obtained for 31 of the 32 fuels are given in Table III. The initial boiling point (IBP) is defined as the point at which a cumulative area count equal to 0.5 percent of the total area under the chromatogram is obtained. The final boiling point (FBP) is the point at which a cumulative area count equal to 99.5 percent of the total area under the chromatogram is obtained.

EQUATIONS FOR ESTIMATING D86 DATA POINTS (REF. 3)

The equations were generated using a step-wise regression analysis method to obtain the greatest reduction in the error sum of squares. The method determines the optimum independent parameters (i.e., D2887 data points) to calculate the dependent parameter (a preselected D86 data point). In the course of the study, equations were determined for wide-cut fuels only (JP-4 and Jet B), kerosine type fuels only (JP-5 and Jet A), and for both wide-cut and kerosine fuels together. The equations used in this report were those considered by the author of reference 3 to be the most reliable, and preferred for estimating D86 properties from measured D2887 values for any fuel ranging from a wide-cut JP-4 to a narrow-cut kerosine such as JP-5. The equations are shown in Table IV. In order to calculate the initial boiling point (IBP) and final boiling point (FBP), D2887 percent recovered points other than those given in Table III are needed. The temperatures at those points (2%, 97%, and 98%) were obtained by interpolation from a plot of temperature against percent recovered. A typical plot is shown in figure 1. In making such plots the initial boiling point is plotted at 0 and the final boiling point at 100 percent recovered.

EQUATIONS FOR ESTIMATING BULK PROPERTIES OF KEROSINE FUELS (REF. 3)

°API

The equation used to calculate °API values is given in Table V. The values needed are readily obtained from the D2887 data. As noted before, °API is readily measured, but using this equation might have some value since the degree of correlation is high and the standard error of estimate is less than 1 °API.

Flash Point

The flash point equation is also given in Table V. For this equation, D2887 data including IBP and FBP are needed. Also needed is the °API value. This value was calculated from the specific gravity value given in Table I.

Viscosity

The viscosity equation is also shown in Table V. For this one also the °API value is needed in addition to the distillation values.

SUBSTITUTION OF D2887 DATA FOR D86 DATA IN CORRELATIONS

Recently two correlative methods for estimating fuel properties were published by ASTM. They are D3338 for estimating the net heat of combustion and D3343 for estimating the hydrogen content. Both of these new standards need the average D86 distillation temperature (10%, 50%, and 90% recovered) as input data. To use ASTM D2887 in place of the D86 distillation method, a D2887 average distillation temperature which is numerically identical to the D86 average distillation temperature is needed. Statistical methods were used to determine the optimum three or five D2887 distillation data points whose average would best correlate with the 10%, 50%, and 90% recovered average temperature using the D86 distillation method. The use of the following equations was recommended in reference 3:

$$\frac{(10\% + 50\% + 90\%)}{3}\ D86 = \frac{(10\% + 50\% + 95\%)}{3}\ D2887$$

for JP-4, Jet B fuels,

$$\frac{(10\% + 50\% + 90\%)}{3}\ D86 = \frac{(10\% + 50\% + 95\%)}{3}\ D2887 - 2K(3.6°F)$$

for kerosine fuels (Jet A, Jet A-1, JP-5).
For JP-4 fuels no correction factor was needed and the average distillation temperature calculated from the three D2887 data points was within 5.6K (10°F) of the D86 average 95% of the time. For kerosine fuels, a 2K (3.6°F) correction factor was required, and agreement to within 3.3K(6°F) 95% of the time was found.

N-ALKANE CONTENT OF JP-5 TYPE FUELS BY CAPILLARY GAS CHROMATOGRAPHY

The n-alkane content data were obtained from the Naval Research Laboratory, Washington, D.C. Ten-gram fuel samples were fractionated by absorption on activated silica gel. The saturated fraction was eluted from the silica gel with n-pentane which was then evaporated to a volume of 50 ml. One gram of an internal standard was then added for quantitation

of the gas chromatographic analysis. The latter was carried out on an all glass Perkin-Elmer 3920B chromatograph. The 300 ft. glass capillary column had an OV-101 wall coating. A 1.5 microliter sample was split 80:1 in the GC inlet. A standard comprised of n-alkanes was run each day to obtain retention time comparisons.

Four of the saturate fractions were also examined by gas chromatography/mass spectrometry. The presence of a parent peak in this analysis confirmed the identity of peaks thought to be n-alkanes based on GC retention times. The results are given in Table VI.

RESULTS AND DISCUSSION

Comparison of Measured and Calculated D86 Data Points

The D86 distillation test method is equivalent to a one-plate distillation, and as such cannot give accurate data in regard to the effective distribution of the boiling points of the sample. For a more accurate determination a laboratory fractionating distillation, commonly called "true boiling point" is used. There is no standard procedure, and columns with considerably different efficiencies (from 20 to 100 theoretical plates) have been used. This method determines the distribution more accurately but yet has difficulty in establishing the initial and final boiling points. In looking at the data from the two methods, there is usually agreement somewhere around the midpoint of the range. The D2887 method is equivalent to a distillation with over 100 theoretical plates, and agrees very well with the "true boiling point" distillation method. And, again, in comparing data from D86 and D2887, agreement occurs somewhere about the mid-range with the GC data giving lower IBP and higher FBP. A typical set of curves for the two methods is shown in figure 2. There is still concern over the fairly wide spread in values at the initial and at the final boiling points, though it is recognized that a good bit of the difference may lie in the fact that the initial and final boiling points are defined differently in the two methods. It is not surprising then that the standard errors of estimate in the estimating equations are largest at the initial and final boiling points.

The data from the equations in Table IV are given in Table VII and plotted against the measured values in figures 3-10. The error bar for one standard error of estimate is included. The data used to generate these equations were from JP-4 and JP-5 fuels, but in this report they are applied to all the fuels, JP-4 JP-5, Diesel No. 2, and broad-specification. The data for the JP-4 type samples prepared from shale are shown in figure 3, and it can be seen that in three of the four instances, both the initial and the final boiling points are within one standard error of estimate. Further, with the exception of one sample practically all of the other values are within one standard error of estimate. For the two fuels prepared from H-Coal (fig. 4), the results are similar. The initial

boiling points are within a standard error of estimate, while the final boiling points are well without. The latter is also true for the 90 percent points. For the other points, they are mostly just outside of one standard error of estimate. The results for the fuels prepared from the COED crude are not unlike those from the H-Coal source, though in this case the agreement is quite a bit better. The initial boiling points are just beyond one standard error of estimate, and the final boiling points are also without. In contrast, the 90 percent points are within the estimate and the remaining points are mostly within. In contrast, the 90 percent points are within the estimate and the remaining points are mostly within.

In figure 5 the results for the JP-5 type fuels prepared from shale are shown. For all four fuels the initial and the final boiling points are within one standard error of estimate. This is also true of the 90 percent points. Three of the four 50 percent points are within one standard error, while three of the four ten percent points are without. All of the 20 percent points are outside of the standard error. The results for the coal-derived fuels, shown in figure 6, are somewhat more varied. The initial boiling points are within one standard error of estimate, but one of the final boiling points does not meet that criterion. For the COED samples, the 90 percent points are within the error, but for the H-Coal samples they are not. For the remaining points, in most instances the measured values are close to but not within one standard error of estimate, with the most serious error occurring at the 10 percent points. No clear distinction can be seen between the shale and coal samples, and the results indicate that the method should be useful with these JP-5 type samples.

In figure 7 are plotted the results for the Diesel #2 type fuels prepared from oil shale syncrude. It was noted before that the equations being used were not generated from any #2 fuels but would be applied to them nevertheless. It is perhaps not surprising then that the final boiling points are close to but not within one standard error. There is good agreement at the 90, 50, and 20 percent points for two of the three samples, with one showing a large error at the 20 percent point, and all showing large errors at the 10 percent points. By contrast, though, the initial boiling points were in good agreement with the measured values. Some of the results for the coal samples shown in figure 8 are abbreviated because of the foaming encountered with the D86 measurement. For the H-Coal sample, the initial boiling point is within the error criterion, but the other points are not. For the similar COED sample, all of the points are within one standard error of estimate. For the full range COED sample, only the initial and 50 percent points are within the error.

In figure 9 are the results for the broad-specification type fuels prepared from oil shale. For three of the four fuels the initial boiling point is within one standard error of estimate, while the reverse is true for the final boiling points. For the 90 percent points two are within and two are outside of the error. A similar pattern holds for the remaining points for these fuels. In figure 10 it is immediately apparent that the agreement for the final boiling point with both H-Coal samples is not good. The 90 percent point for both is also outside of one standard

error of estimate, while for the remaining points some are within and some are not. It can be seen in figure 10, also, that the large error at the final boiling point is not repeated for the COED samples. The 90 percent points are both outside but close to one standard error, and for the most part the agreement of the other points are good.

The differences between the calculated and measured values for the D86 data points are shown in figure 11. For the JP-4 type fuels, it can be seen that more of the points for shale fell within one standard error of estimate than did those for coal. And for the shale results most of the points that were without were from one fuel. More work with the JP-4 type fuels derived from shale would show whether the method is generally useful, as is indicated, or whether we would see more points outside of the one standard error of estimate. For the JP-5 type fuels no clear distinction can be seen between the shale and coal samples, and the results indicate that the method should be useful with these JP-5 type samples. The differences found for the diesel #2 and the broad-specification fuels are also plotted in figure 11, and it can be judged that this method can be applied to fuels other than the JP-4 and JP-5 types even using the equations in their present form. It would be preferable of course to modify them as necessary as input data from higher boiling fuels becomes available. Further, new calibration standards that would include compounds more prevalent in the coal syncrudes should be examined.

Calculation of Bulk Fuel Properties

Bulk properties of Diesel #2 fuels were also calculated together with the JP-5 fuels. The °API data, measured and calculated are shown in Table VIII and plotted in figure 12. The agreement between the two is not good. Further, a clear separation between the shale and coal samples is observed, with the shale fuels showing calculated values lower than the measured and the coal derived fuels showing values higher than the measured ones. The reasons for the results are not clear. It appears that the volatility of the coal samples are comparable to those from shale, but the densities of the coal samples are much higher than those of similar petroleum products. There may be effects of components in the fuel that are volatile but attract enough in the liquid to give high densities. In determining the reasons for the results, attention would have to be given to the calibration curves used for the D2887 data, and consider the possibility of having a separate set for shale, coal and petroleum fuels. The results from the calculation of the flash points of the Jet A type samples are given in Table VIII, and plotted in figure 13 against the measured values. It can be seen that in all instances that the calculated values are all much higher than the measured values. The equation obviously could not be applied in its present form to give meaningful results. The input to the equation involves the IBP, FBP, 5 percent off, 25 percent off, and density, and it is not obvious where modifications should be made. In Table VIII also are the results for the diesel #2 type fuels also, and the plot also in figure 13. As noted before, the

equations were generated from kerosine fuels, but nevertheless were applied to the diesel type, and in this instance the agreement appears to be no worse than it is with the Jet A samples. The values for the COED samples are in least agreement, the values for the shale samples are somewhat close in some instances, and those for the H-Coal samples somewhere in between.

The results for the calculation of viscosity from the equation in Table V are shown in Table VIII, and plotted against the measured values in figure 14. The measured values for the four Jet A type fuels from shale are not much different from each other and the calculated values are in good agreement, close to or within one standard error of estimate. The values for the coal-derived fuels are more varied. It should be noted, though, that the measured values for the COED samples are not far apart. One value for an H-Coal sample may be suspect. It appears, then, that the equation is not useful with the coal samples, though some samples fall not far outside one standard error of estimate. The results for the calculation of Diesel #2 fuels were not included since a number of the measured values were reported as being solid at 239K(-30°F).

Substitution of D2887 Data for D86 Data in Correlations

The two recently published standards for estimating the net heat of combustion and for estimating the hydrogen content are anticipated to be widely used in aircraft turbine fuel specifications. It was of particular interest then to test the applicability of substituting the D2887 data for the D86 using the synthetic derived fuels. Again the method was applied to all of the fuels not limiting the application to just the JP-4 and JP-5 fuels. The data derived is given in Table IX and plotted in figure 15. The dotted lines show an interval of 5.6K(10°F) for the JP-4 and broad-specification fuels, and a 3.3K(6°F) interval for the JP-5 and diesel #2 type fuels. For the JP-4 fuels, with one exception, all of the values were within the 5.6K(10°F), 95% of the time expectation. For the broad-specification fuels, three of the values are outside of the 5.6K(10°F) expectation. It should be noted however, that the results can be viewed as a shifting of the data to the left as a result of shifting to the higher final boiling point. The coal samples which had low D2887 values when compared to the D86 shifted to values about comparable, while the shale samples which were more comparable shifted to D2887 values which were higher than the D86 values. The relative positions of the coal and shale samples did not change. A similar pattern is noted for the JP-5 and Diesel #2 fuels, though fewer points are available for comparison. For the JP-5 fuels, most of the shale values are within the 3.3K(6°F) expectation, while most of the coal values are not. In going to the higher temperatures in the No. 2 fuels, the shale values are shifted and, perhaps fortuitously, the D2887 values agree very well with the D86 values. The lone coal value is now close to being within expectation, where with the JP-5 samples those coal values were not within expectation. The results suggest that the D2887 substitution would be acceptable for shale samples of either

JP-4 or JP-5. There would be some question in regard to the use with coal samples of JP-5, though it seems that the substitution would be useful with coal samples of JP-4. The results are also favorable for considering the use of the method with fuels of higher boiling point and broadened specification.

N-Alkane Content-Freezing Point Relationships

The n-alkane content of the JP-5 type fuels was determined as described and the results of that determination are given in Table VI. One of the methods suggested for estimating freezing points of jet fuel fractions is based on a linear relationship between the experimental freezing points and the total content of the last three members of the n-paraffin series in the fuel (ref. 5). A plot of the sum of the C_{14} to C_{17} n-alkanes concentation against freezing points is shown in figure 16. A 'reasonable' straight line can be fitted to the data for the shale and the COED fuels. No attempt was made to establish a fit, but just to show that some points readily fit and some do not. Other work has found that the saturate fraction of fuels exerted the greatest influence on freezing point, but that the aromatic fraction was also important. That statement would seem to accurately describe the results found here. In a recent report on properties and composition of jet fuels derived from alternate energy sources (ref. 6), it was reported that the total n-alkane concentration did not afford a significant relationship with freezing point. The freezing point did show some dependence on the amount of the larger hydrocarbons present. That dependence was tested against a model which equates the dissolution of a solid in a liquid to form an ideal solution with the melting of pure solute at the lowered temperature where solution is taking place. It was found that a plot of the logarithm of the C_{16} concentration ($\log[\%C_{16}]$) of those jet fuels against the reciprocal of the temperature of the freezing point gave a reasonable adherence to a solubility plot. This was in agreement with previous work with model fuel systems which showed that the largest n-alkane present had a marked control over the freezing point of a fuel. In figure 17 the solid line is the plot of the mole % $[C_{16}]$ against freezing point in a commercial kerosine type solvent. The solid squares are from JP-5 samples, described in reference 5, from oil shale, tar sands, and coal. The samples derived under the program in this report exhibit a similar trend but are displaced to lower freezing points. The results could be described as anomalous, and join other anomalous freezing point behavior found in other studies, or it could be concluded that n-alkanes exert control over the freezing point of jet fuels, but that the relationship between composition and freezing point is not completely defined by the concentration of the largest n-alkane in these samples.

CONCLUDING REMARKS

It was the purpose of this report to test the applicability of some gas chromatographic methods for measuring volatility and other properties of petroleum fuels to fuels from other sources. The results show that for a variety of fuels from two primarily different sources that some of the methods would be applicable in their present form. It should be remembered, though, that the equations used appeared to have sufficient precision for most purposes, but that the author of reference 3 believed that additional data was needed to increase the statistical validity of the equations. Nevertheless, those equations dealing solely with volatility, i.e., getting D86 data from D2887 data, and using D2887 data in the correlative equations, can be applied in their present forms. In general, also, the shale-derived fuels fit somewhat better than the coal-derived fuels. By contrast, the attempt to determine bulk fuel properties from the suggested equations was not successful. Modification of the equations or changes in the underlying calibration curves are needed.

ACKNOWLEDGMENT

The author thanks the following laboratories for supplying the indicated data:

Quality Control Laboratory, AFAPL, Wright-Patterson Air Force Base, Ohio - D2887, Boiling Range Distribution by Gas Chromatography.

Naval Research Laboratory, Chemistry Division, Fuels Section, Washington, D.C. - N-Alkane Content - Capillary Gas Chromatography.

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TABLE I. - PROPERTIES OF SOME SYNCRUDE JET FUELS

Fuel number	Specific gravity KG/M^3	°API	Flash point K (°F)	Freezing point K (°F)	Viscosity at 239 K (-30°F), CS
1	794.5			225 (-54)	4.736
2 Shale	791.4			229 (-47)	5.059
3 IBP-561 K	787.4			222 (-59)	4.093
4 (550°F)	787.4			223 (-58)	4.326
Coal IBP-561 K (550°F)					
5 H-Coal	841.3			211 (-79)	5.162
6	831.4			207 (-86)	6.264
7 COED	827.0			216 (-70)	5.586
8	816.5			215 (-72)	5.565
9 Shale	806.8	43.9	311 (100)	229 (-47)	6.781
10 394 - 561 K	802.2	44.9	312 (102)	231 (-44)	6.990
11 (250-550°F)	805.4	44.2	312 (102)	227 (-50)	6.918
12	803.5	44.6	309 (96)	226 (-52)	7.060
Coal 394-561 K (250-550°F)					
13 H-Coal	856.5	33.7	309 (96)	217 (-68)	6.785
14	846.8	35.6	314 (106)	225 (-54)	9.102
15 COED	849.3	35.1	313 (104)	221 (-62)	9.851
16	836.8	37.6	314 (106)	220 (-64)	9.676
17 Shale 394-616 K	817.0		315 (108)	258 (+5)	solid
18 (250-650°F)	808.1	43.6	312 (102)	258 (+5)	solid
19	814.6	42.2	314 (106)	255 (-1)	solid
20	810.0	43.2	312 (102)	254 (-3)	solid
Coal 394-616 K (250-650°F)					
21 H-Coal	865.4	32.0	312 (102)	237 (-32)	16.99
22	848.8	35.2	312 (102)	246 (-17)	15.91
23 COED	858.6	33.3	319 (114)	256 (+2)	solid
24	845.8	35.8	313 (104)	239 (-30)	19.25
25 Shale	804.0			255 (0)	solid
26 IBP-616 K	797.7			256 (+1)	solid
27 (650°F)	797.2			251 (-8)	solid
28	793.6			250 (-9)	solid
Coal IBP-616 K (650°F)					
29 H-Coal	849.3			251 (-8)	solid
30	833.8			255 (0)	9.757
31 COED	835.8			242 (-23)	solid
32	825.5			242 (-23)	solid

TABLE II. - FUEL DISTILLATIONS (ASTM D-86) DATA FOR SOME SYNCRUDE JET FUELS

	Shale IBP - 561 K (IBP - 550°F)						Coal IBP - 561 K (IBP - 550°F)					
Fuel No.	1		2		3		4		5 H-Coal	6	7 COED	8
	K	°F	K	°F	K	°F	K	°F	K °F	K °F	K °F	K °F
IBP	374	213	380	224	350	170	369	204	380 225	380 224	360 189	360 189
5%	400	261	405	269	384	231	389	240	400 261	394 250	390 243	390 243
10	408	275	410	279	394	249	403	266	410 278	403 266	400 261	400 260
15	412	283	419	295	403	266	411	281	417 292	411 280	406 274	405 270
20	423	302	426	308	412	283	419	295	425 305	419 295	415 288	415 288
30	437	327	440	332	428	311	435	324	439 331	437 327	437 328	435 323
40	449	349	450	351	443	338	450	350	452 355	457 364	459 366	455 359
50	466	379	467	381	459	367	466	380	464 375	470 386	477 400	474 394
60	482	408	483	410	477	400	482	409	475 395	480 404	491 425	489 421
70	497	435	499	438	494	429	497	436	486 416	491 425	505 449	500 441
80	511	460	512	462	510	458	512	463	502 444	505 449	515 467	511 461
90	524	484	527	489	526	488	528	491	524 484	530 495	526 487	525 486
95	533	500	537	507	537	507	539	511	547 526	542 516	535 503	536 505
EP	545	521	554	537	549	528	552	534	557 543	558 545	553 536	557 544

	Shale 394 - 561 K (250-550°F)						Coal 394 - 561 K (250-550°F)					
Fuel No.	9		10		11		12		13 H-Coal	14	15 COED	16
	K	°F	K	°F	K	°F	K	°F	K °F	K °F	K °F	K °F
IBP	425	305	424	304	423	302	425	306	416 290	424 304	424 304	427 309
5%	435	324	434	322	433	320	435	323	432 319	438 329	442 336	439 331
10	438	329	436	326	434	321	438	329	437 328	443 338	447 345	443 338
15	443	338	441	335	440	332	444	339	441 334	447 346	452 355	449 349
20	445	341	447	345	443	338	446	343	444 339	452 355	457 364	455 359
30	450	351	454	358	452	354	456	361	453 356	461 371	470 387	466 379
40	464	375	466	379	463	374	467	381	462 372	470 387	482 409	477 400
50	476	397	478	401	476	397	479	403	470 387	479 402	494 429	489 420
60	489	421	491	425	490	422	491	425	481 406	487 418	502 445	498 437

TABLE II. - Continued.

Fuel No.	9		10		11		12		13 H-Coal	14	15 COED	16		
	K	°F	K	°F	K	°F	K	°F	K	°F	K	°F	K	°F
70	502	445	504	448	504	447	504	448	496	434	499	438	511	461	507	454
80	514	465	516	469	516	469	516	470	500	440	512	462	520	477	517	471
90	526	487	529	493	530	494	530	495	516	469	532	499	529	493	529	492
95	534	501	538	509	539	510	540	512	535	504	544	519	537	507	539	510
EP	543	518	550	531	550	530	552	535	550	531	545	522	551	532	551	533

Shale
394 - 616 K
(250 - 650°F)

Coal
394 - 616 K
(250 - 650°F)

Fuel No.	17		18		19		20		21 H-Coal	22	23 COED	24		
	K	°F	K	°F	K	°F	K	°F	K	°F	K	°F	K	°F
IBP	425	305	424	303	422	301	424	304	No		424	304	425	305	425	305
5%	436	325	436	326	435	323	437	327	Result		436	325	439	330	439	330
10	441	334	439	330	436	326	441	334			440	332	445	342	444	340
15	444	340	446	343	443	338	445	341	Too		444	340	454	358	451	352
20	451	353	450	351	449	349	451	352	Much		449	349	461	371	465	377
30	463	374	462	372	461	370	462	373	Foaming		457	363	476	398	474	393
40	480	404	477	400	476	398	477	400			466	379	493	428	487	417
50	498	437	495	431	495	431	494	429			475	395	505	450	500	440
60	515	468	511	461	512	463	512	462			489	429			540	512
70	532	499	529	493	531	496	530	494					Too		552	534
80	551	532	548	527	550	531	549	528			Too		Much		570	567
90	576	578	573	572	575	575	573	572			Much		Foaming		580	584
95	592	606	590	602	590	602	587	598			Foaming				589	601
EP	596	613	596	613	593	608	594	609							593	608

TABLE II. - Concluded.

	Shale IBP - 616 K (IBP - 650°F)						Coal IBP - 616 K (IBP - 650°F)			
Fuel No.	25		26		27		28		29 H-Coal 30				31 COED 32			
	K	°F	K	°F	K	°F	K	°F	K	°F	K	°F	K	°F	K	°F
IBP	372	211	377	219	349	168	352	175	376	218	383	230	362	192	360	188
5%	402	264	404	267	385	234	389	241	399	258	402	265	392	246	392	247
10	412	283	414	285	396	254	400	261	406	272	411	280	403	266	402	264
15	419	295	423	302	408	275	409	277	411	281	416	290	413	284	411	280
20	430	314	431	316	418	293	420	297	422	301	425	305	424	303	422	300
30	445	342	445	342	435	324	438	329	439	331	439	330	447	345	444	339
40	465	377	465	377	454	357	456	361	455	360	454	357	472	390	467	381
50	486	415	482	409	475	395	475	395	469	384	468	383	491	425	486	416
60	505	450	502	445	497	435	497	436	483	410	482	409	508	455	501	443
70	525	485	521	478	519	474	519	474	499	438	497	436	522	480	517	471
80	545	522	542	516	541	515	541	514	521	479	521	478	539	510	535	503
90	574	573	569	564	569	564	568	563	559	547	557	544	564	556	562	553
95	590	603	587	597	586	595	585	594	604	628	599	619	584	591	582	589
EP	594	610	594	610	591	605	592	607	624	663	615	648	591	605	592	606

TABLE III. - BOILING RANGE DISTRIBUTION BY GAS CHROMATOGRAPHY (ASTM D 2887) DATA FOR SOME SYNTHETIC JET FUELS

IBP - 561 K (IBP - 550°F)

Shale

Recovered	Fuel No.	1		2		3		4
%	K	°F Temp	K	°F Temp	K	°F Temp	K	°F Temp
IBP	333	140.9	337	147.1	300	80.5	300	79.9
5	371	208.0	372	209.9	361	190.3	361	189.5
10	389	241.1	391	243.5	374	213.1	375	215.6
15	404	267.4	405	268.9	390	242.9	392	245.9
20	413	283.4	414	285.6	403	265.7	406	270.2
25	422	299.1	423	301.2	412	282.9	415	287.2
30	428	311.7	431	316.3	421	297.3	422	301.9
35	437	327.8	439	331.0	429	313.3	433	319.1
40	446	344.0	447	345.4	438	329.3	441	335.0
45	453	356.0	456	361.4	447	344.9	449	349.4
50	406	378.9	468	382.3	456	361.4	460	368.9
55	474	393.4	477	398.9	468	382.2	469	385.1
60	486	414.6	488	418.5	478	400.4	480	405.0
65	492	426.6	495	431.2	488	419.7	489	421.3
70	502	444.9	504	448.4	498	437.0	499	438.3
75	509	457.2	512	462.0	507	454.0	507	454.0
80	520	476.1	523	481.2	518	473.2	518	473.0
85	527	489.8	532	497.2	527	490.0	527	489.2
90	538	503.2	542	515.7	539	510.7	538	509.7
95	547	525.9	554	537.8	552	533.2	551	532.2
FBP	569	564.5	618	652.8	577	579.6	572	570.1

H-Coal

COED

Recovered	Fuel No.	5		6		7		8
%	K	°F Temp	K	°F Temp	K	°F Temp	K	°F Temp
IBP	344	160.3	344	159.5	322	120.5	319	114.1
5	372	210.5	367	201.6	364	196.2	364	195.3
10	377	219.7	375	215.8	376	216.7	375	215.9
15	396	253.4	394	249.6	391	244.6	391	243.8
20	407	272.6	406	271.6	404	267.2	399	259.0
25	419	294.5	424	303.7	416	289.4	413	284.4
30	430	314.1	437	328.0	429	312.2	424	303.2
35	440	331.7	446	342.3	442	335.8	438	329.9
40	447	345.4	453	356.4	454	357.3	449	349.5

TABLE III. - Continued.

Recovered	Fuel No.	5		6		7		8
%	K	°F Temp	K	°F Temp	K	°F Temp	K	°F Temp
45	454	357.8	457	363.6	465	377.1	458	365.7
50	460	368.5	465	377.8	474	394.2	468	382.6
55	467	381.6	469	385.3	484	411.2	477	398.1
60	474	393.2	476	396.9	493	427.3	484	412.8
65	479	402.8	484	412.5	502	444.7	492	426.3
70	488	418.7	493	428.7	509	457.0	502	444.1
75	497	434.6	504	448.2	517	471.6	510	458.5
80	507	452.7	513	464.9	525	485.3	519	475.3
85	577	471.3	522	481.0	532	497.1	527	489.7
90	529	492.1	532	497.2	538	509.9	537	506.2
95	543	517.5	544	519.8	547	525.8	548	527.2
FBP	569	564.2	568	562.4	593	608.2	584	591.4

394 - 561 K (250 - 550°F)

Shale

Recovered	Fuel No.	9		10		11		12
%	K	°F Temp	K	°F Temp	K	°F Temp	K	°F Temp
IBP	390	242.4	390	242.8	390	242.2	389	241.6
5	406	271.7	406	271.4	406	270.6	406	270.1
10	414	286.4	414	286.4	414	285.2	414	285.2
15	423	301.1	422	301.0	421	297.3	421	297.5
20	429	312.2	429	312.3	427	308.4	427	309.6
25	436	326.0	437	326.5	435	323.8	436	324.7
30	445	341.7	445	342.0	442	337.0	443	338.3
35	450	350.4	451	351.5	449	348.1	449	349.7
40	460	368.8	461	369.1	458	364.1	458	365.6
45	468	383.9	469	384.4	467	381.5	467	381.9
50	477	399.9	478	400.8	475	395.0	475	395.3
55	488	417.9	488	418.2	484	412.6	484	412.2
60	493	427.7	493	428.5	492	425.1	491	424.4
65	502	444.0	502	444.9	501	441.6	499	439.9
70	508	455.4	509	456.1	508	454.7	507	453.4
75	516	469.7	518	472.8	517	470.3	516	468.3
80	524	484.6	526	486.6	525	485.7	524	484.5
85	532	498.3	535	503.4	534	502.3	533	500.5
90	541	518.5	543	518.2	543	517.6	542	516.8
95	550	530.1	555	539.7	554	538.2	554	537.5
FBP	569	565.0	598	617.5	591	603.9	575	575.1

TABLE III. - Continued.

H-Coal COED

Recovered	Fuel No.	13		14		15		16
%	K	°F Temp	K	°F Temp	K	°F Temp	K	°F Temp
IBP	375	215.3	390	242.1	391	243.6	391	243.7
5	403	265.6	404	268.5	407	272.7	407	272.5
10	412	282.3	419	294.7	418	292.6	418	292.8
15	423	301.4	429	312.6	429	312.4	428	311.7
20	431	316.5	440	332.4	440	332.9	440	332.3
25	439	331.6	447	344.3	450	350.3	448	348.0
30	446	343.1	453	356.6	458	364.9	456	361.0
35	453	355.2	457	362.5	467	381.5	465	377.0
40	456	361.9	464	375.9	475	395.4	471	387.3
45	464	375.2	468	382.7	483	409.8	478	400.5
50	469	384.9	473	391.6	490	422.4	484	412.0
55	474	394.8	479	402.1	498	437.0	490	422.3
60	480	404.0	487	416.6	506	450.9	497	435.6
65	487	417.6	494	430.9	511	460.0	505	449.2
70	496	432.1	504	448.2	518	472.2	511	460.6
75	503	446.9	512	462.6	524	483.9	519	474.1
80	512	462.6	519	475.7	529	493.4	526	486.4
85	522	480.5	527	489.9	536	504.1	532	498.3
90	532	498.8	536	506.0	542	515.8	541	513.3
95	545	521.8	549	528.1	549	529.7	551	532.4
FBP	569	565.2	578	581.8	584	591.5	581	585.6

394 - 616 K (250 - 650°F)

Shale

Recovered	Fuel No.	18		19		20
%	K	°F Temp	K	°F Temp	K	°F Temp
IBP	390	242.7	390	242.6	389	241.3
5	407	273.2	407	272.6	407	272.1
10	417	291.2	416	289.6	416	289.2
15	424	304.4	424	303.5	423	303.0
20	436	324.1	435	323.3	434	321.7
25	446	342.4	445	341.3	443	338.7
30	453	355.3	453	355.4	452	353.2
35	466	378.6	465	377.4	462	372.8
40	474	394.0	474	393.9	471	388.9

TABLE III. - Continued.

Recovered	Fuel No.	18		19		20
%	K	°F Temp	K	°F Temp	K	°F Temp
45	486	415.6	486	415.1	483	409.8
50	493	427.9	494	429.6	491	424.6
55	503	446.3	504	443.7	501	443.1
60	511	459.8	513	464.8	509	457.7
65	522	480.4	524	484.7	521	479.0
70	531	497.0	536	504.1	532	497.2
75	542	516.7	546	522.9	543	517.4
80	556	541.7	559	547.8	557	543.2
85	569	565.1	574	573.8	571	567.4
90	587	598.0	590	602.7	588	598.4
95	604	627.2	605	629.7	603	626.5
FBP	629	673.6	635	683.0	631	675.7

H-Coal COED

Recovered	Fuel No.	21	22		23		24	
%	K	°F Temp	K	PF Temp	K	°F Temp	K	°F Temp
IBP	388	239.1	389	240.6	392	246.4	388	288.5
5	405	269.6	405	269.1	413	288.6	408	275.6
10	418	293.4	420	296.3	424	304.4	422	299.1
15	429	312.5	429	312.5	439	331.4	436	324.2
20	439	330.6	439	331.6	451	352.4	446	343.5
25	446	343.9	446	342.5	461	370.7	456	360.7
30	453	357.0	453	355.2	471	388.2	466	378.4
35	459	366.8	456	361.3	480	404.9	473	391.3
40	467	380.5	463	374.8	489	420.1	481	406.7
45	473	391.9	468	382.2	498	436.6	488	418.6
50	478	400.2	473	391.9	507	452.2	496	432.8
55	486	415.7	480	404.6	512	463.0	504	448.8
60	495	431.3	489	420.9	521	478.0	512	462.4
65	504	447.1	500	440.2	527	489.8	521	478.0
70	513	463.8	509	457.8	534	502.3	528	491.3
75	523	482.1	519	474.5	542	516.1	537	507.3
80	533	500.7	528	492.0	552	534.1	548	527.6
85	547	524.3	541	514.3	568	562.5	567	560.1
90	566	559.5	562	552.1	583	590.5	582	588.7
95	591	608.2	587	596.4	602	624.0	601	622.9
FBP	662	731.9	664	735.2	630	674.6	629	673.8

TABLE III. - Continued.

Recovered	Fuel No.	25		26		27		28
%	K	°F Temp	K	°F Temp	K	°F Temp	K	°F Temp
IBP	337	146.7	335	143.1	300	79.6	300	80.1
5	376	216.7	373	211.4	362	198.0	363	194.7
10	403	266.6	395	251.8	378	222.3	381	225.3
15	416	288.2	409	277.5	396	253.2	397	254.7
20	424	304.4	419	295.4	409	277.9	410	278.9
25	437	327.8	429	313.5	419	295.1	420	296.5
30	447	345.6	439	331.8	431	315.9	431	316.0
35	459	367.9	448	347.4	441	334.6	441	334.4
40	471	387.1	461	371.0	451	352.8	457	352.4
45	484	412.7	472	389.6	465	377.7	464	375.3
50	493	427.8	486	414.1	476	397.6	475	394.8
55	504	447.8	493	428.7	488	420.0	487	417.8
60	513	463.3	504	448.6	501	441.2	497	435.6
65	526	486.6	514	465.5	511	459.5	508	454.5
70	534	502.7	526	486.3	524	483.5	521	477.7
75	544	520.2	537	507.1	536	506.0	533	499.8
80	559	546.9	550	530.4	551	531.7	546	522.8
85	574	573.2	566	558.7	567	560.9	562	553.0
90	591	603.9	582	589.0	585	594.0	580	584.0
95	607	633.7	602	625.6	603	626.4	601	622.7
FBP	642	696.0	630	674.1	641	694.8	630	674.2

H-Coal COED

Recovered	Fuel No.	29		30		31		32
%	K	°F Temp	K	°F Temp	K	°F Temp	K	°F Temp
IBP	347	164.8	347	164.9	317	110.3	316	109.1
5	373	212.3	373	211.9	366	198.2	365	197.1
10	388	238.1	385	233.6	379	223.1	378	220.2
15	403	265.3	398	258.0	395	251.7	394	249.7
20	414	285.4	412	281.4	411	279.3	408	274.5
25	427	310.0	424	304.3	424	304.1	422	300.8
30	438	329.2	435	323.9	441	333.8	439	330.5

TABLE III. - Concluded.

Recovered	Fuel No.	29		30		31		32
%	K	°F Temp	K	°F Temp	K	°F Temp	K	°F Temp
35	447	344.6	444	339.3	454	357.8	452	353.5
40	454	358.4	452	354.3	467	380.3	462	373.0
45	461	370.9	456	361.2	477	398.9	471	388.5
50	469	384.5	464	376.0	488	418.7	481	406.7
55	475	396.0	469	384.1	499	438.3	489	420.7
60	483	410.3	476	397.0	508	455.0	499	439.5
65	493	427.9	486	415.1	517	470.6	509	456.1
70	503	445.8	497	435.5	526	486.5	519	474.5
75	513	465.0	509	457.3	533	500.8	528	490.7
80	525	485.8	520	477.6	543	517.3	539	510.1
85	538	509.4	532	498.8	557	542.7	555	538.8
90	557	543.5	551	531.2	576	577.4	576	576.1
95	584	592.7	578	581.2	597	615.5	596	613.4
FBP	657	722.9	653	715.7	629	672.9	626	666.6

TABLE IV. - EQUATIONS FOR ESTIMATING D86 DATA FOR BOTH JP-4 AND KEROSENE FUELS (REF. 3)

Equations - Independent Variables are D2887 Percent Recovered Points (D86 Calculated Points in K, D2887 Percent Points in K)

	Correl. coeff.	Std. error of est., K(°F)
IBP_{D86} = 15.04 + 0.816[1.8(2%) - 459.72] + 0.378[1.8(10%) - 459.72] - 0.182[1.8(65%) - 459.72] + 0.089 [1.8(98%) - 459.72]	0.996	4.6(8.31)
$10\%_{D86}$ = 61.03 + 0.154[1.8(5%) - 459.72] + 0.675[1.8(10%) - 459.72] - 0.082[1.8(15%) - 459.72] + 0.316 [1.8(35%) - 459.72] - 0.125[1.8(90%) - 459.72]	0.997	3.2(5.72)
$20\%_{D86}$ = 37.48 + 0.251[1.8(10%) - 459.72] + 0.210[1.8(20%) - 459.72] + 0.572[1.8(35%) - 459.72] - 0.081 [1.8(90%) - 459.72]	0.998	2.3(4.13)
$50\%_{D86}$ = 17.56 - 0.064[1.8(5%) - 459.72] + 0.182[1.8(35%) - 459.72] + 0.625[1.8(50%) - 459.72] + 0.209 [1.8(65%) - 459.72] + 0.046[1.8(FBP) - 459.72]	0.997	2.2(3.94)
$90\%_{D86}$ = - 12.36 - 0.077[1.8(25%) - 459.72] + 0.457[1.8(75%) - 459.72] - 0.624[1.8(85%) - 459.72] + 0.890[1.8 (90%) - 459.72] + 0.319[1.8(95%) - 459.72]	0.992	3.3(6.00)
FBP_{D86} = 106.57 + 0.219[1.8(65%) - 459.72] - 0.375[1.8(85%) - 459.72] + 0.759[1.8(97%) - 459.72] + 0.165 [1.8(98%) - 459.72]	0.960	5.1(9.17)

TABLE V. - EQUATIONS FOR ESTIMATING BULK PROPERTIES OF KEROSENE FUELS (REF. 3)

Equations	Correl. coeff.	Std. error of est.
°API = 100.42 - 0.147[1.8(10%) - 459.72] + 0.306 [1.8(20%) - 459.72] - 0.195 [1.8(35%) - 459.72] - 0.098[1.8(65%) - 459.72]	0.950	0.97(°API)
Flash Point (K) =-29.63 + 0.210[1.8(IBP - 459.72] + 0.191[1.8(5%) - 459.72] + 0.257 [1.8(25%) - 459.72] - 0.049 [1.8(FBP) - 459.72] - 0.458(API)	0.989	1.1K(2.1°F)
Viscosity = 22.58 + 0.042[1.8(10%) - 459.72] + 0.027 [1.8(50%) - 459.72] + 0.027[1.8(97%) - 459.72] - 0.184(API)	0.991	0.3(CS)

Distillation Points (IBP, 5%, 10%, etc.) are from D2887 Test, K

API = Gravity in °API

TABLE VI. - n-ALKANE CONTENT OF JP-5 TYPE JET FUELS

294 - 561 K (250-550°F)

	n-Alkane Concentration (wt. percent)											
Fuel No.	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	Total
9	-	1.24	4.52	3.80	3.25	2.44	2.25	1.85	1.99	0.77	0.02	22.13
10	-	1.18	4.29	3.58	2.91	2.30	2.03	1.65	1.71	1.14	0.03	20.82
11	-	1.10	3.50	3.07	2.45	2.06	1.92	1.50	1.62	0.98	0.02	18.21
12	-	0.83	2.95	2.83	2.37	2.08	1.79	1.55	1.42	0.88	0.01	16.71
13	tr	0.64	0.64	0.14	0.78	0.75	0.54	0.26	0.19	0.16	0.16	4.25
14	tr	0.60	0.54	0.17	1.34	0.84	0.56	0.35	0.17	0.23	-	4.80
15	-	0.37	0.43	0.53	0.74	0.96	1.35	1.21	1.15	0.32	0.01	7.06
16	-	0.39	0.48	0.63	0.86	0.97	1.27	1.16	1.10	0.47	0.07	7.38

TABLE VII. - D86 DATA POINTS CALCULATED FROM EQUATIONS OF TABLE IV

Shale
IBP-561K(IBP-550°F)

Recovered %	Fuel No. 1 K	°F	2 K	°F	3 K	°F	4 K	°F
IBP	376	(218)	377	(219)	348	(167)	355	(179)
10	407	(274)	408	(276)	393	(249)	396	(253)
20	424	(304)	425	(306)	413	(285)	416	(290)
50	467	(381)	471	(388)	460	(368)	462	(373)
90	526	(488)	531	(496)	528	(492)	528	(491)
FBP	542	(516)	550	(531)	544	(520)	543	(519)

Coal
IBP-561K(IBP-550°F)

	5		6		7		8	
IBP	379	(223)	376	(217)	366	(199)	366	(200)
10	402	(264)	401	(263)	398	(258)	400	(260)
20	422	(300)	424	(304)	418	(294)	421	(299)
50	461	(370)	466	(380)	469	(385)	476	(398)
90	518	(473)	520	(477)	526	(488)	528	(492)
FBP	540	(513)	540	(512)	545	(522)	547	(525)

Shale
394-561K(250-550°F)

	9		10		11		12	
IBP	421	(299)	420	(297)	423	(302)	422	(300)
10	432	(318)	432	(318)	431	(316)	431	(317)
20	441	(334)	441	(334)	439	(331)	440	(332)
50	476	(397)	478	(401)	475	(395)	474	(394)
90	528	(492)	532	(498)	531	(497)	531	(496)
FBP	544	(520)	548	(527)	548	(528)	547	(526)

Coal
394-561K(250-550°F)

	13		14		15		16	
IBP	416	(290)	425	(306)	422	(301)	422	(301)
10	432	(318)	437	(327)	438	(330)	439	(331)
20	443	(338)	448	(348)	452	(355)	453	(357)
50	468	(384)	473	(393)	484	(412)	490	(422)
90	520	(477)	525	(486)	529	(493)	530	(495)
FBP	542	(516)	546	(523)	547	(525)	547	(526)

TABLE VII. - Concluded.

Shale
394-616K(250-650°F)

Recovered %	Fuel No. 18 K	°F	19 K	°F	20 K	°F
IBP	425	(305)	425	(305)	424	(304)
10	433	(320)	432	(318)	431	(316)
20	448	(347)	447	(345)	445	(342)
50	496	(433)	497	(435)	493	(429)
90	576	(577)	577	(580)	575	(576)
FBP	587	(598)	588	(599)	587	(597)

Coal
394-616K(250-650°F)

	22		23		24	
IBP	428	(311)	427	(310)	425	(306)
10	434	(322)	442	(337)	438	(329)
20	446	(343)	461	(371)	456	(361)
50	478	(402)	507	(454)	498	(437)
90	555	(539)	571	(569)	569	(565)
FBP	589	(601)	584	(592)	586	(596)

Shale
IBP-616K(IBP-650°F)

	25		26		27		28	
IBP	382	(229)	379	(223)	349	(169)	353	(177)
10	417	(292)	409	(277)	395	(252)	397	(255)
20	438	(330)	430	(314)	419	(295)	420	(297)
50	497	(436)	488	(419)	481	(407)	480	(404)
90	578	(582)	572	(570)	575	(575)	570	(567)
FBP	590	(602)	585	(593)	585	(593)	583	(590)

Coal
IBP-616K(IBP-650°F)

	29		30		31		32	
IBP	387	(238)	384	(232)	366	(199)	360	(189)
10	407	(274)	422	(301)	401	(262)	399	(259)
20	427	(310)	425	(306)	427	(310)	425	(306)
50	475	(395)	469	(385)	492	(426)	500	(440)
90	550	(531)	544	(520)	569	(565)	567	(561)
FBP	592	(607)	580	(585)	586	(595)	585	(593)

TABLE VIII. - FUEL PROPERTIES FOR JP-5 AND DIESEL #2

CALCULATED FROM THE EQUATIONS OF TABLE V

	Fuel No.	°API	Flash Point K °F	Viscosity, CS at 239K(-30°F)
Shale 394-561K (250-550°F)	9	42.0	316(109)	6.82
	10	41.7	314(106)	6.99
	11	41.7	314(106)	6.90
	12	41.9	315(108)	6.74
Coal 394-561K (250-550°F)				
H-Coal	13	45.6	315(108)	8.00
	14	45.9	320(116)	8.56
COED	15	39.8	321(119)	9.42
	16	41.5	320(117)	8.70
Shale 394-616K (250-650°F)	18	35.9	316(109)	
	19	35.7	315(108)	
	20	36.7	315(107)	
Coal 394-616K (250-650°F)				
H-Coal	21	43.1	316(110)	
	22	44.7	315(108)	
COED	23	---	323(123)	
	24	38.4	320(116)	

TABLE IX. - D2887 AND D86 - AVERAGE DISTILLATION TEMPERATURES,

Fuel No.		K(°F) D2887 $\frac{(10\% + 50\% + 95\%)}{3}$	D86 $\frac{(10\% + 50\% + 90\%)}{3}$
	IBP-561K (IBP-550)		
1	Shale	467(382.0)	466(379)
2		471(387.9)	468(383)
3		461(369.2)	460(368)
4		462(372.2)	466(379)
5	H-Coal	460(368.6)	466(379)
6		461(371.1)	467(382)
7	COED	464(378.9)	468(383)
8		466(375.2)	466(380)
	394-561K (250-550)	$\frac{(10\% + 50\% + 95\%)}{3}$ - 2K(3.6° F)	
9	Shale	478(401.7)	480(404)
10		481(405.5)	481(407)
11		479(402.5)	480(404)
12		479(402.4)	482(409)
13	H-Coal	473(392.7)	475(395)
14		478(401.2)	485(413)
15	COED	484(411.3)	490(422)
16		482(408.8)	487(417)
	394-616K (250-650)		
18	Shale	503(445.2)	502(444)
19		503(446.0)	502(444)
20		502(443.2)	502(445)
24	COED	504(448.0)	508(455)
	IBP-616K (IBP-650)	$\frac{(10\% + 50\% + 95\%)}{3}$	
25	Shale	501(442.7)	491(424)
26		494(430.5)	488(419)
27		486(415.4)	480(404)
28		485(414.3)	481(406)
29	H-Coal	480(405.1)	478(401)
30		476(396.9)	478(402)
31	COED	488(419.1)	486(416)
32		485(413.4)	483(411)

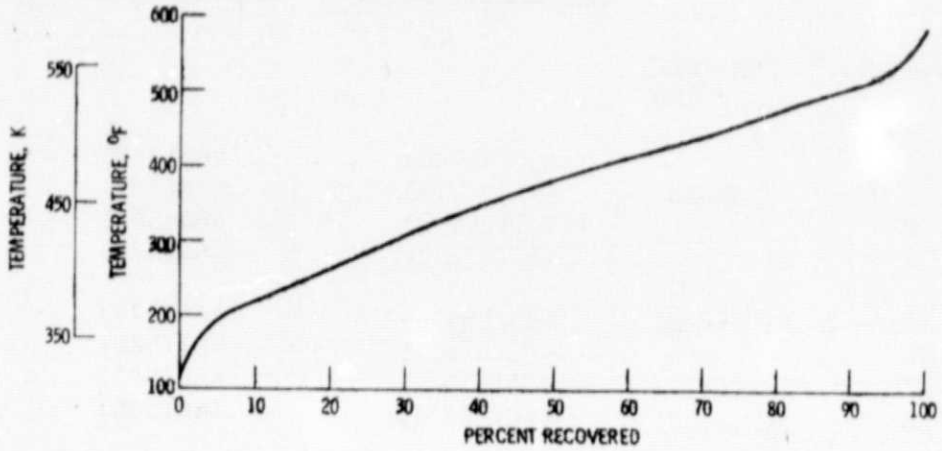

Figure 1. - Typical D2887 boiling range distribution curve for a jet fuel.

E-9034

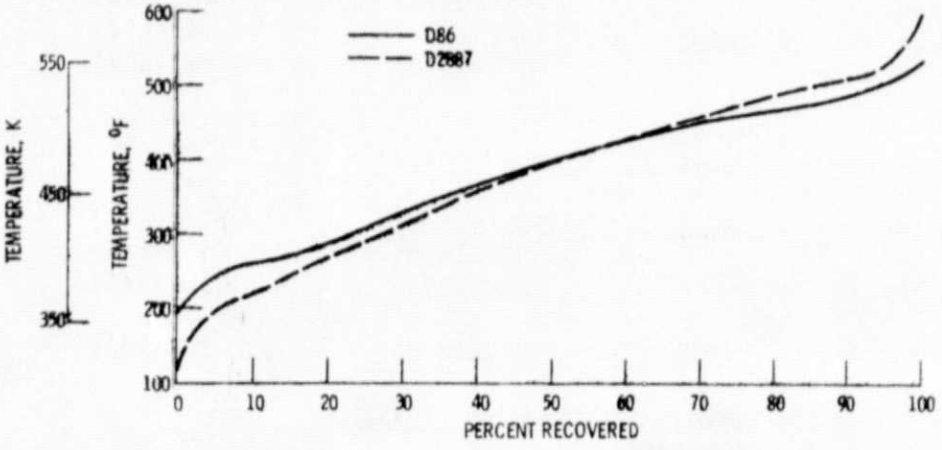

Figure 2. - Typical distillation curves by D86 and D2887 methods.

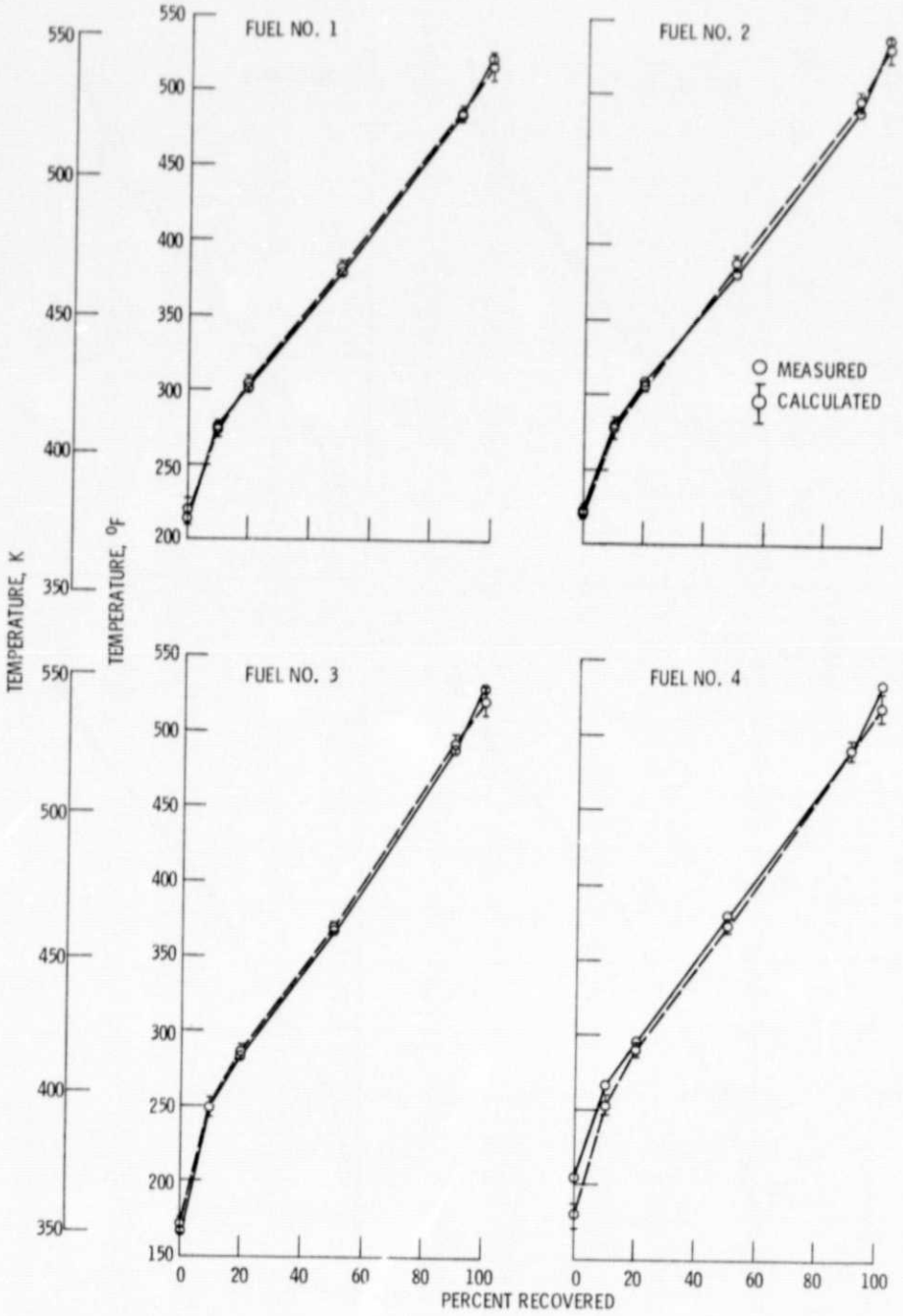

Figure 3. - Comparison of measured and calculated D86 data points shale fuels, IBP-561 K (550° F).

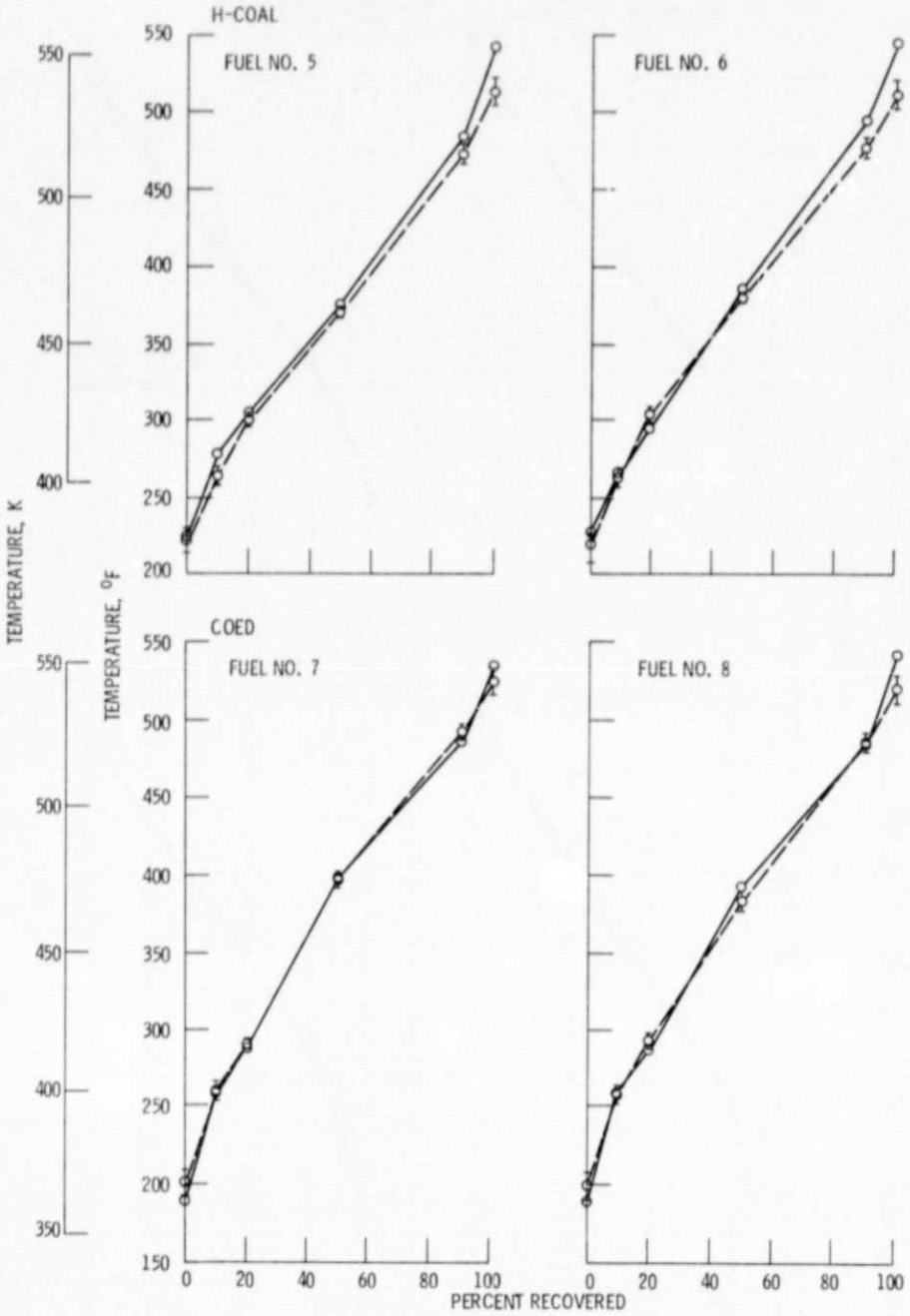

Figure 4. - Comparison of measured and calculated D86 data points. Coal fuels, IBP-561 K (550° F).

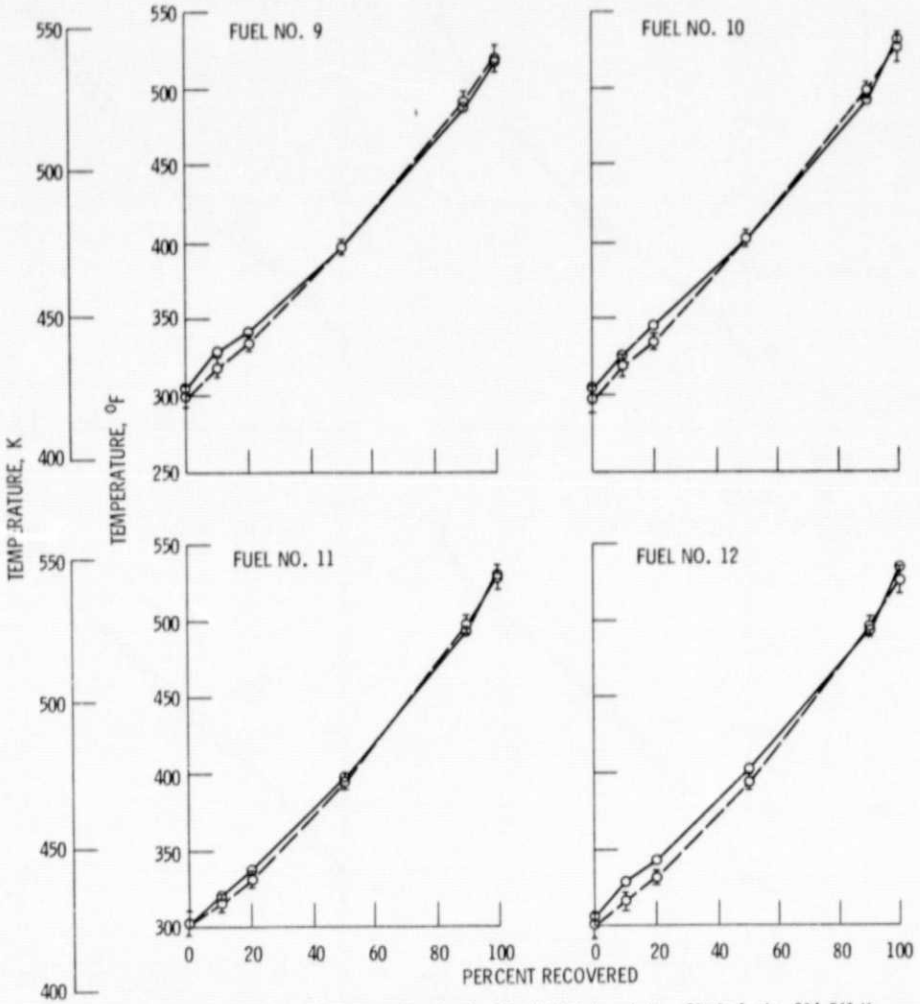

Figure 5. - Comparison of measured and calculated D86 data points. Shale fuels, 394-561 K (250°-550° F).

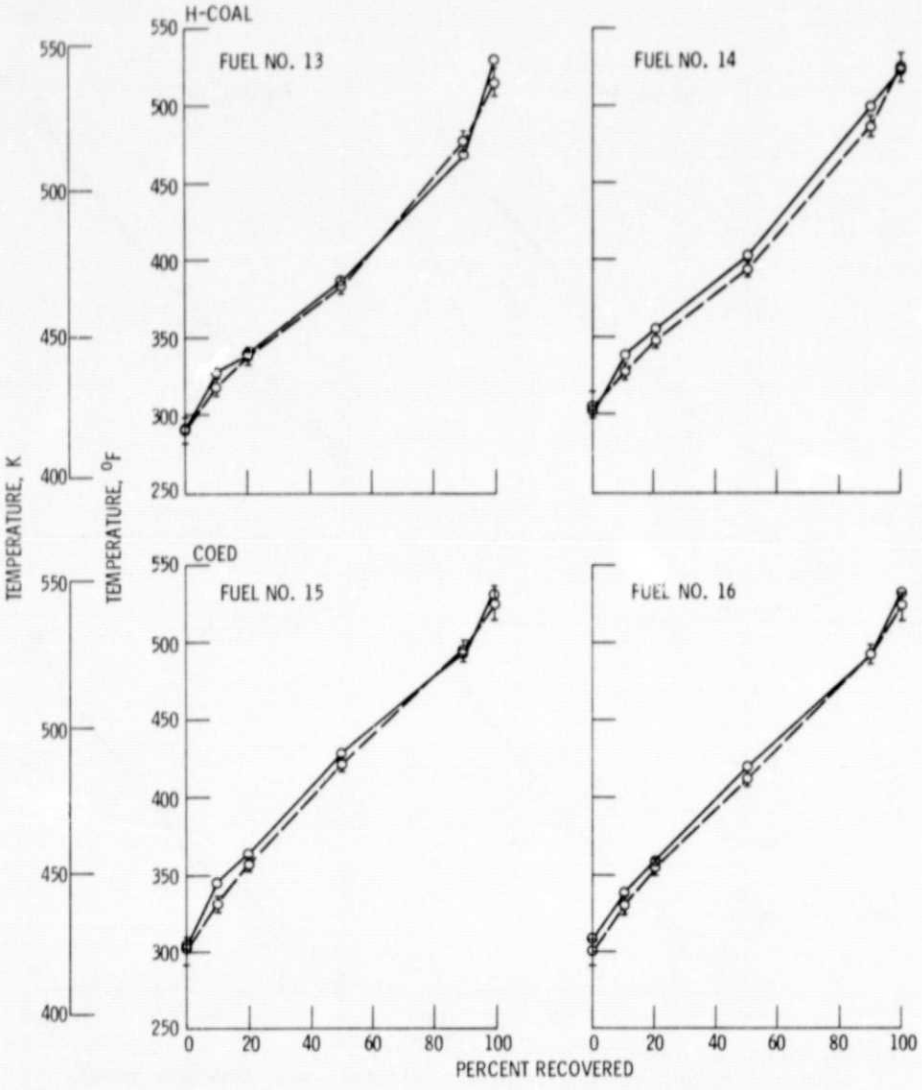

Figure 6. - Comparison of measured and calculated D86 data points. Coal fuels, 394-561 K (250°-550° F).

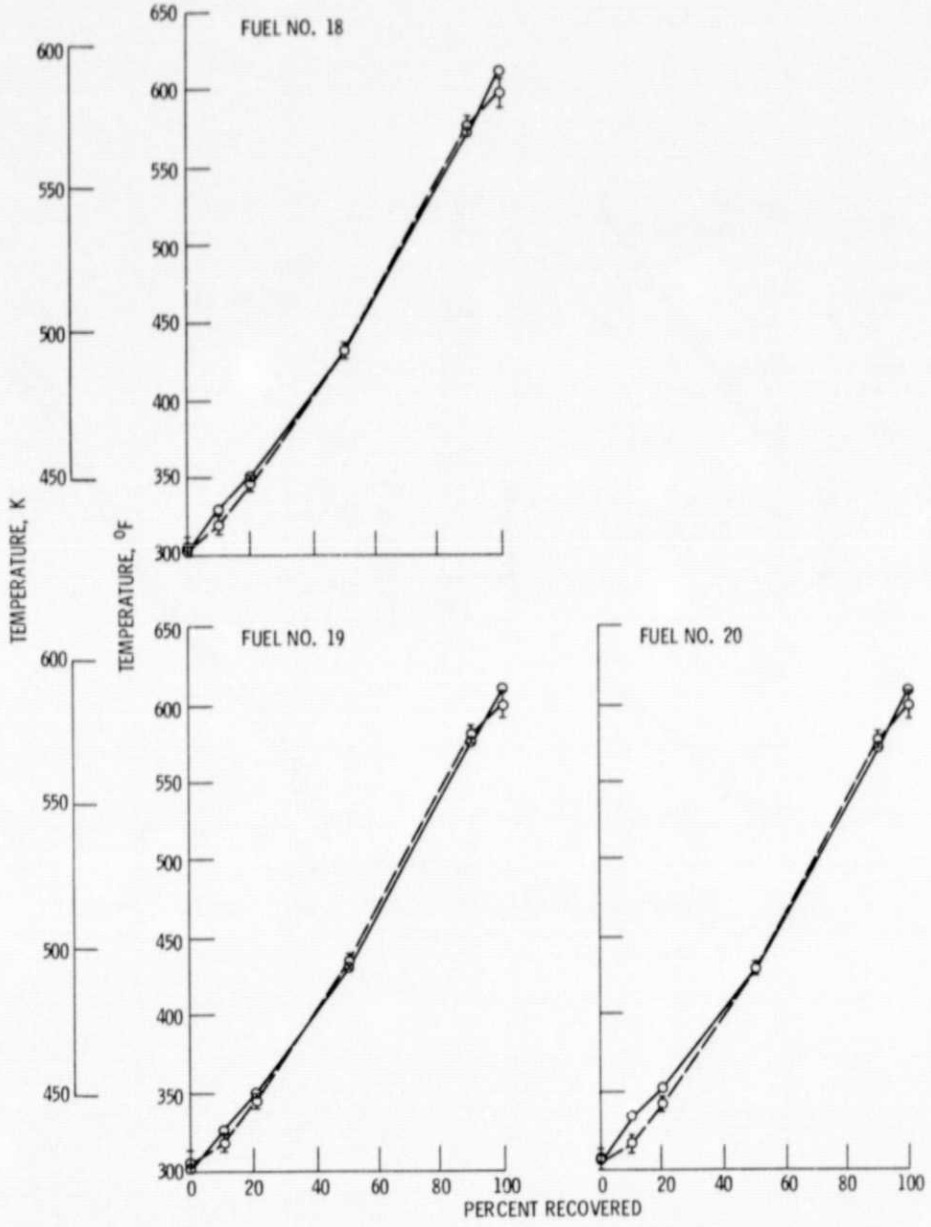

Figure 7. - Comparison of measured and calculated D86 data points. Shale fuels, 394-616 K (250^0-650^0 F).

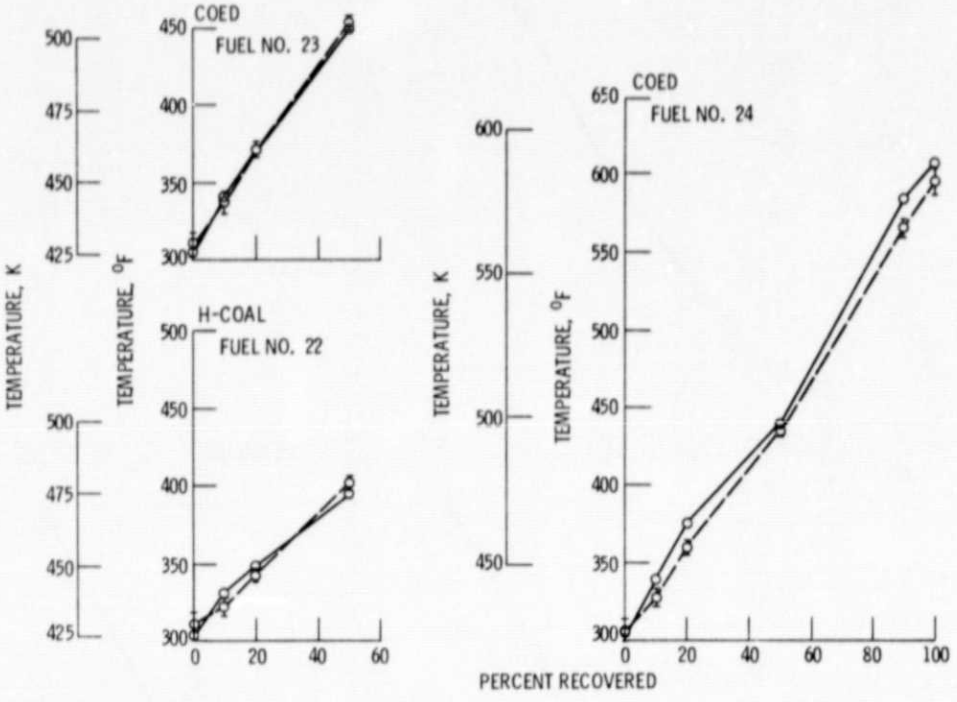

Figure 8. - Comparison of measured and calculated D86 data points. Coal fuels, 394-616 K (250° -650° F).

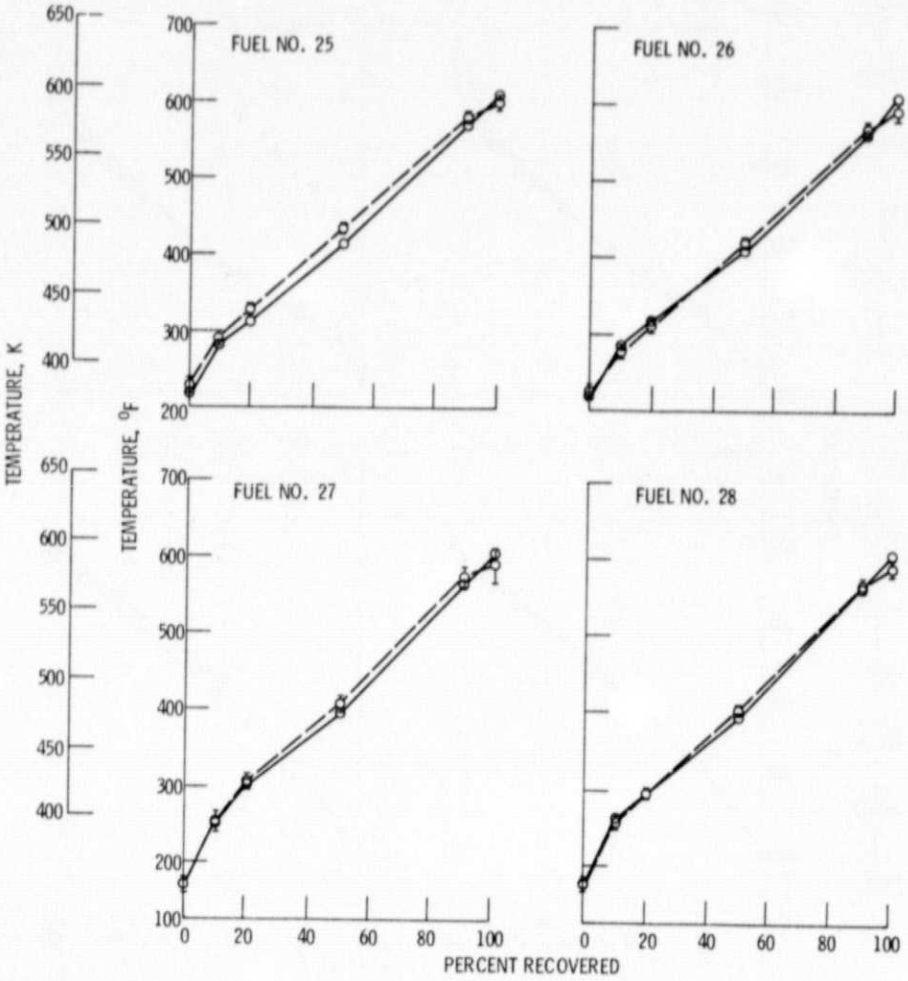

Figure 9. - Comparison of measured and calculated D86 data points. Shale fuels, IBP-616 K (650° F).

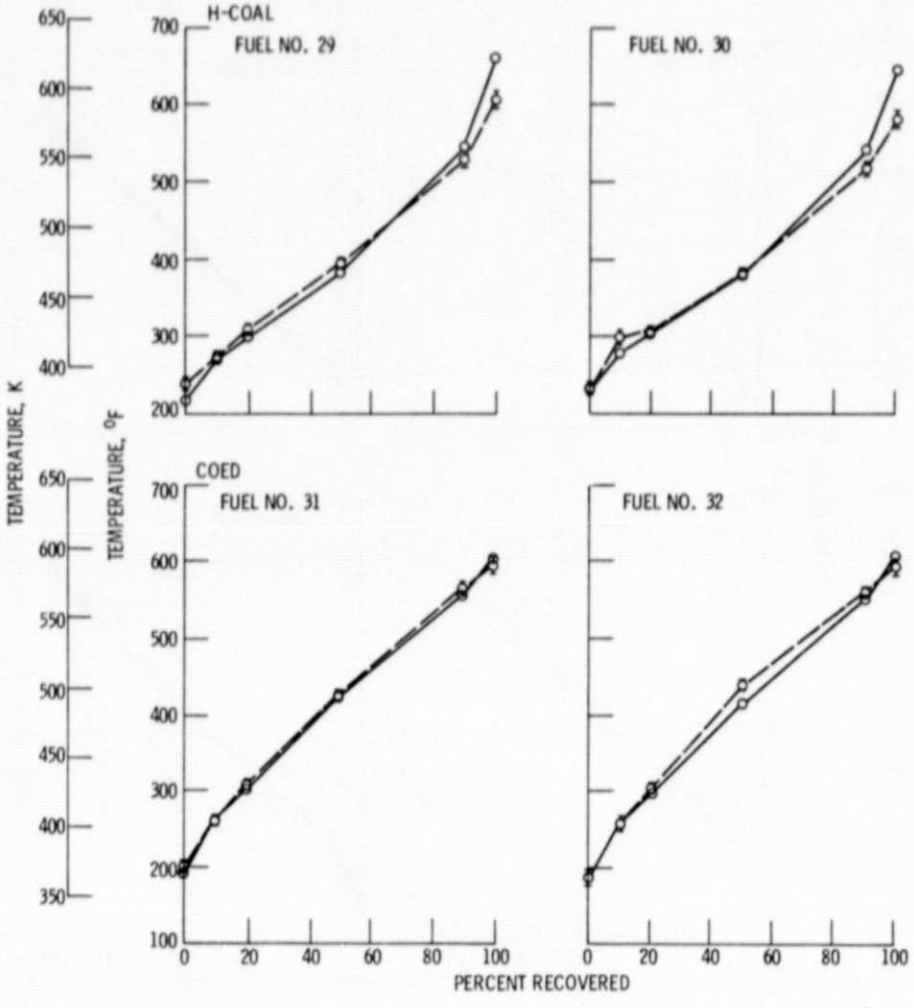

Figure 10. - Comparison of measured and calculated D86 data points. Coal fuels, IBP-616 K (650° F).

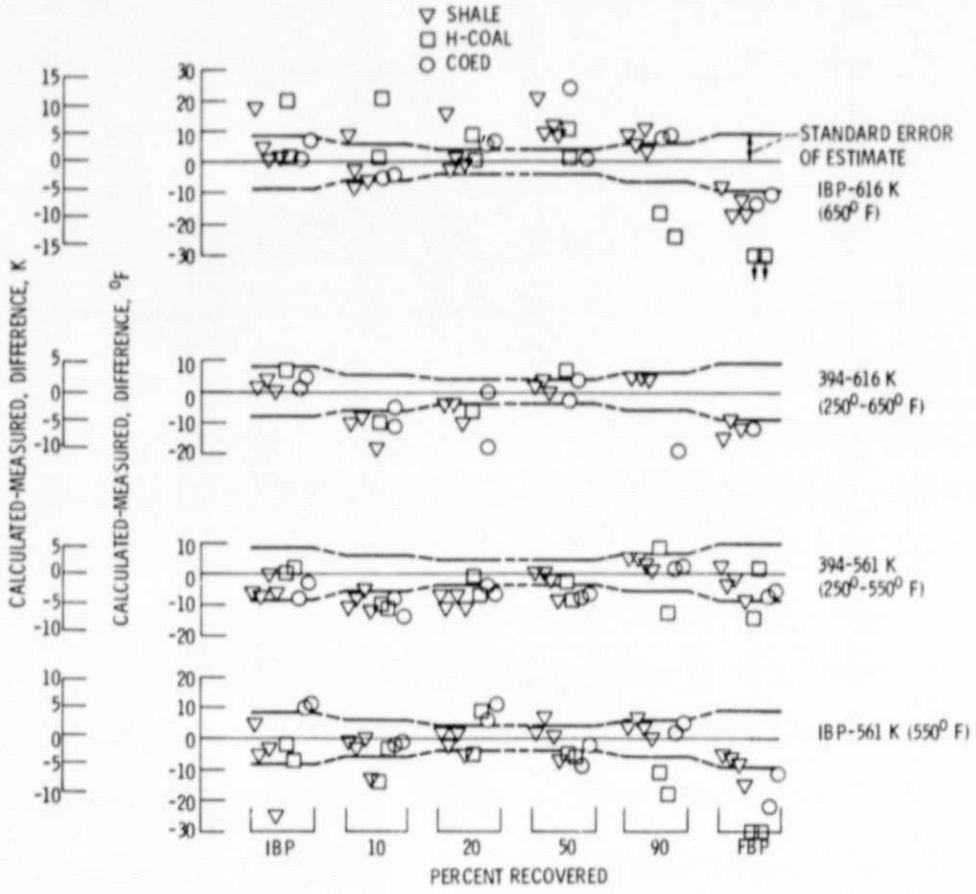

Figure 11. - Difference between measured D86 data points and data points calculated from D2887.

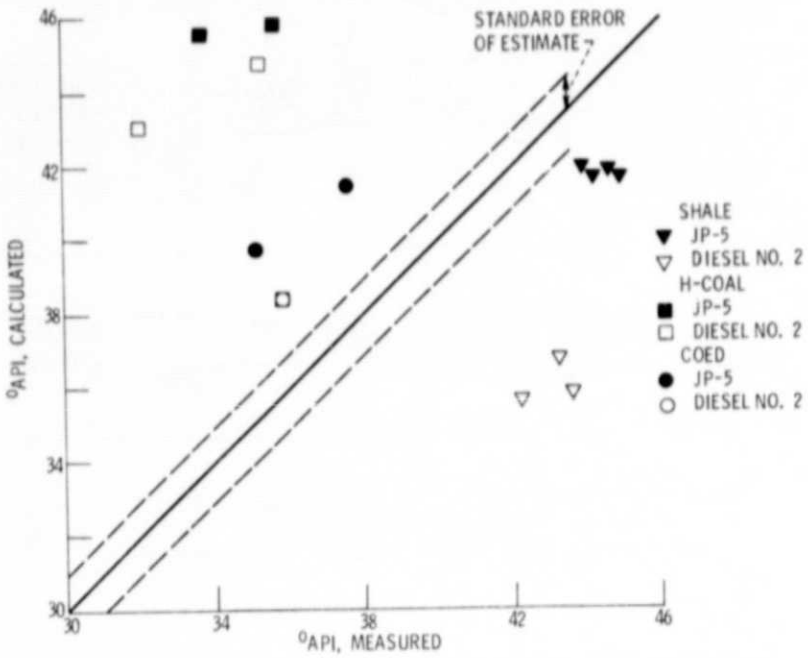

Figure 12. - Comparison of calculated and measured °API for JP-5 and diesel no. 2 type fuels.

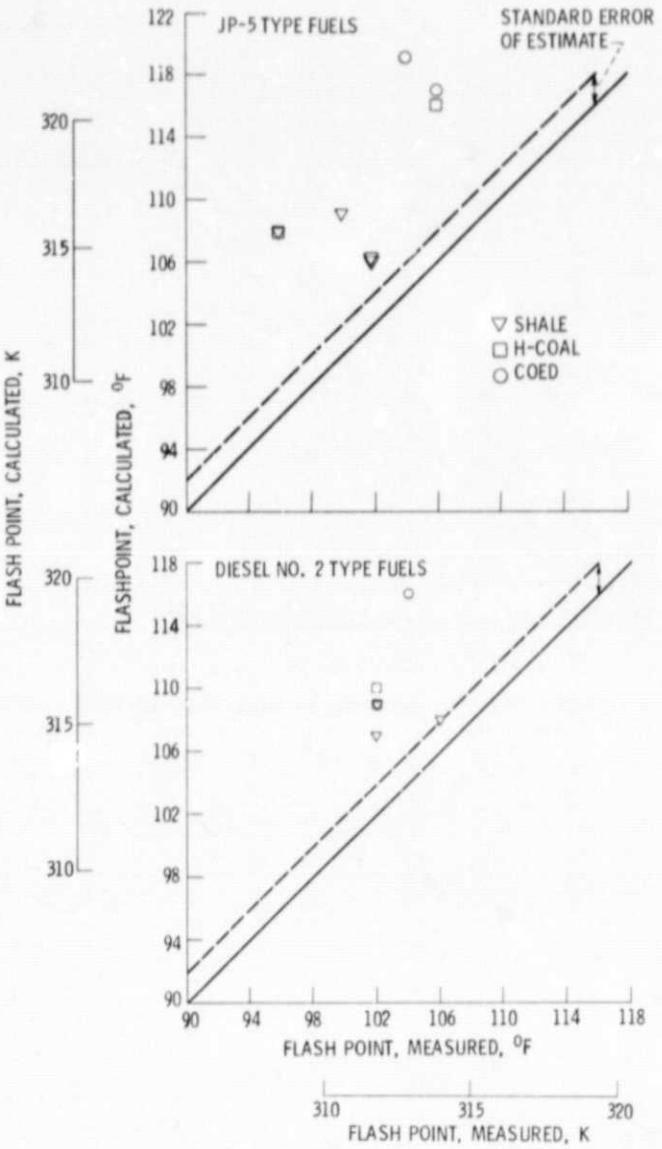

Figure 13. - Comparison of calculated and measured flash points.

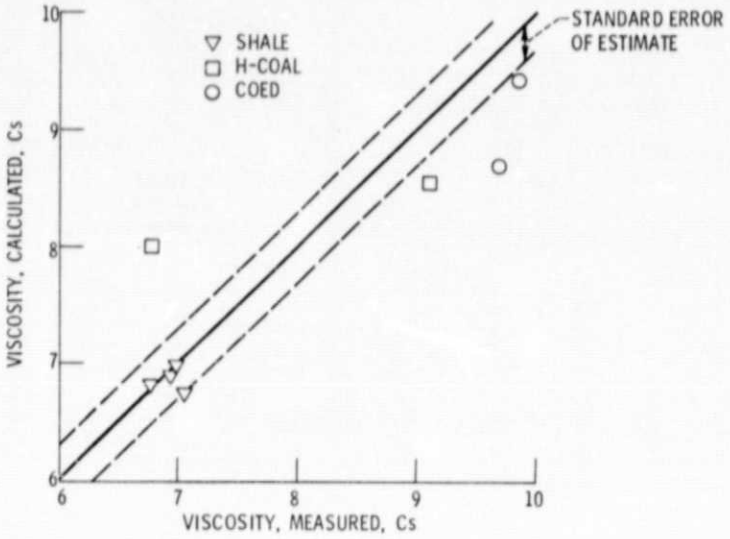

Figure 14. - Comparison of calculated and measured viscosity at 239 K (-30° F) for JP-5 type fuels.

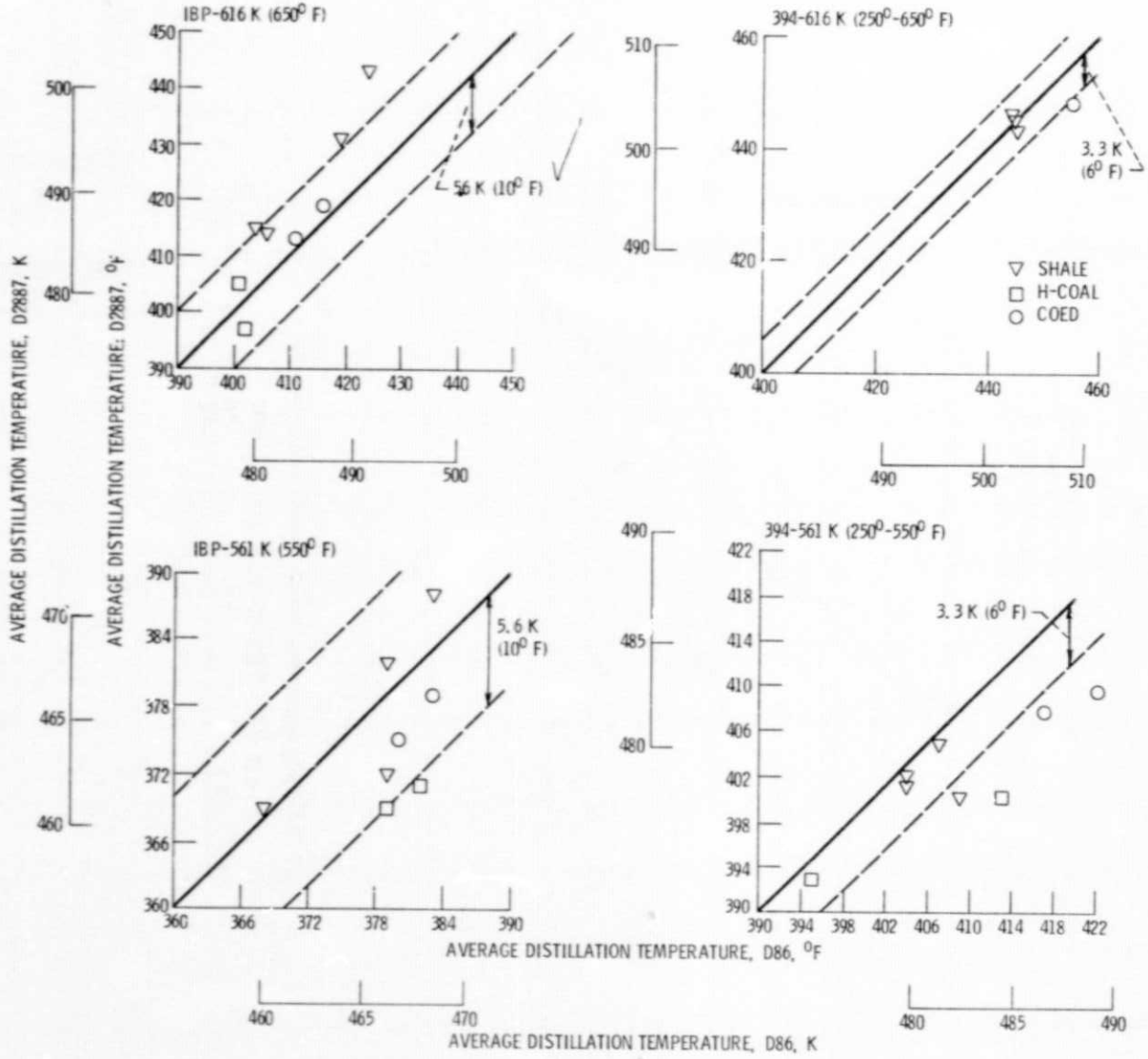

Figure 15. - Comparison of D2887 and D86 average distillation temperatures.

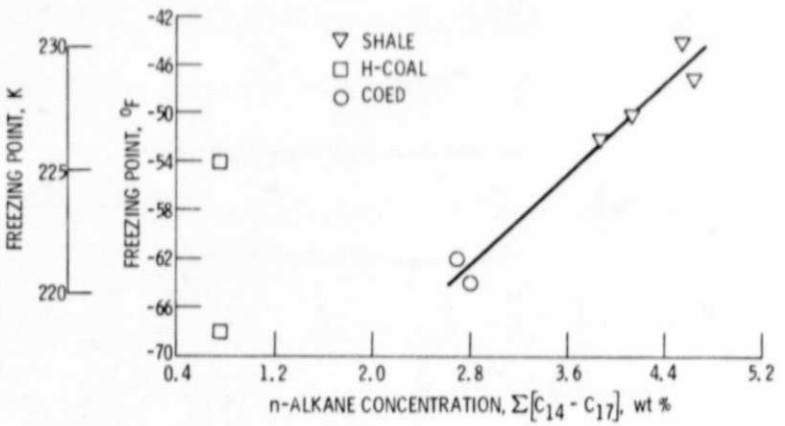

Figure 16. - Plot of freezing point against n-alkane concentration ($\Sigma$of C_{14} to C_{17}) of JP-5 type fuels.

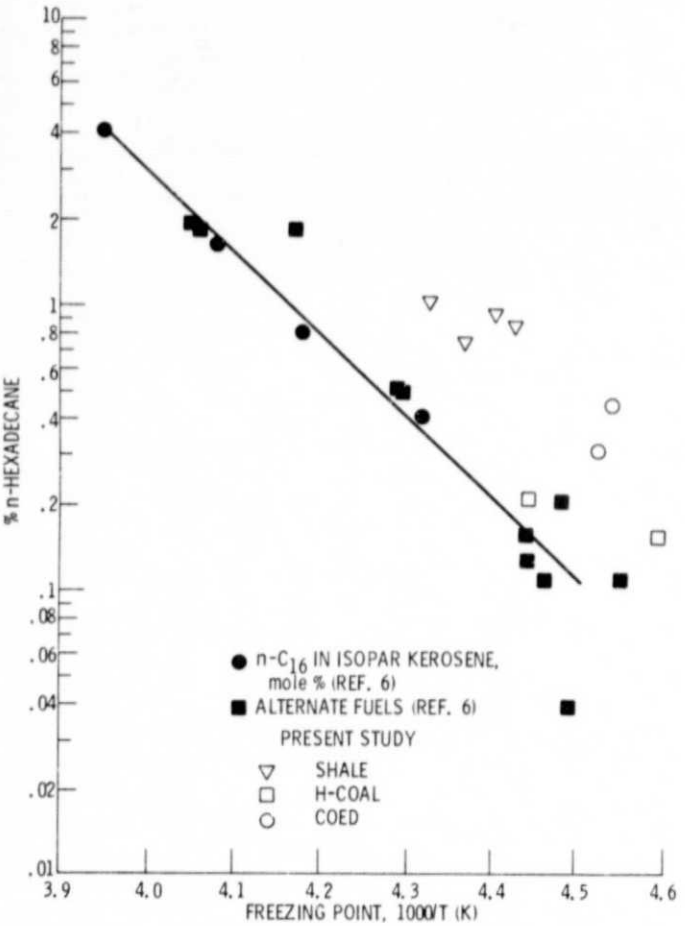

Figure 17. - Freezing point of jet fuels as function of n-C_{16} concentration, wt %.