THE QUANTITATIVE CHARACTERIZATION OF MIDDLE DISTILLATE FUELS
FOR REDUCED SMOKE EMISSION
AND
IMPROVED LOW TEMPERATURE OPERABILITY

A THESIS

PRESENTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE

OF

MASTER OF SCIENCE IN CHEMICAL ENGINEERING

AT

NEWARK COLLEGE OF ENGINEERING

Newark, New Jersey
1973

ABSTRACT

Forty-eight inference equations are presented to approximate the hydrocarbon composition of middle distillate fuels and of the solids separating from these fuels at temperatures below their cloud points by consideration of fuel physical inspections. The physical inspections consist of API gravity, aniline point, cloud point, and distillation curves for ten fuels from major United States and European refineries. To determine the percentage of solids separating from cooled fuels, each fuel is filtered over a temperature range from the cloud point to -40 F in 10 F increments. Aromatic, naphthenic, and paraffinic hydrocarbon contents and the n-paraffin carbon number distributions of the fuels and separated solids are determined using gas chromatography and mass spectroscopy. Hydrocarbon composition variables are correlated with physical inspection variables by stepwise, linear multiple regression analyses using the method of least squares.

Aromatic, naphthenic, and paraffinic hydrocarbon contents average 30, 32, and 38 wt.%, respectively, and are approximated successively from aniline point and volumetric average boiling point data. The n-paraffin contents average 19 wt.%, separate at approximately 0.2 wt.%/ F and constitute an average 81 wt.% of the solids separated from fuels cooled to -20 F; the median and semi-interquartile range of the carbon number distributions at this temperature average 18 and 1.2, respectively, versus values of 15 and 2.3, respectively, for the total n-paraffins in the fuels. The n-paraffin separation characteristics are approximated from cloud point and distillation data.

The relative concentrations of aromatic, naphthenic, and paraffinic hydrocarbons indicate combustion quality and subsequent smoke emission. The n-paraffins separating from cooled fuels can form immobilizing matrices. Thus, the forty-eight inference equations provide a systematic approach to the problems of smoke emission and low temperature operation.

APPROVAL OF THESIS

THE QUANTITATIVE CHARACTERIZATION OF MIDDLE DISTILLATE FUELS FOR REDUCED SMOKE EMISSION AND IMPROVED LOW TEMPERATURE OPERABILITY

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APPROVED:

NEWARK, NEW JERSEY

JUNE, 1973

To Carolyn

ACKNOWLEDGMENTS

The understanding and assistance of Dr. Avner Shilman and the other faculty members at Newark College of Engineering is gratefully acknowledged. Special thanks are also due Carolyn, a loving wife; she encouraged the effort and typed the finished product.

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INTRODUCTION

Demand Trends

Crude petroleum consists of a mixture of hydrocarbons, apparently formed by the compaction and decomposition of plant and animal remains.[1] Its use for illumination and lubrication dates from antiquity. The modern petroleum era began when the first producing well was drilled at Titusville, Pennsylvania, in 1859. Shortly after 1900, heavy fuel oil for railroads, steamships, and industry became the dominant product. With the increasing use of automobiles, gasoline exceeded fuel oil output in 1930.

The growing demand for middle distillate fuels developed after 1930, first for space heating and subsequently for diesel engines;[2] the middle distillate designation arises from the 325 to 675 F boiling range of the fuels, which is approximately the middle of the distillation temperatures encountered in crude refining. Present middle distillates are blended from virgin and catalytically or thermally cracked refinery components; the percentage of cracked components typically ranges from 0 to 70 per cent. As light virgin stocks are increasingly required to meet jet fuel demands, the percentage of cracked stocks in middle distillates is increasing.[3]

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[1] Harold Gershinowitz, "Present and Future Sources and Compositions," Kenneth A. Kobe and John J. McKetta, Jr. (eds.), Advances in Petroleum Chemistry and Refining, Vol. 1, Interscience Publishers, Inc., New York, 1958, pp. 48-77.

[2] Richard J. Gonzalez, "Petroleum Operations in the United States," ibid., pp. 1-47.

[3] J. B. Durant and Eltinge Lamont, "Fuels, Engine Conditions and Diesel Smoke," Society of Automotive Engineers, No. 3R, January 1959.

The use of middle distillate fuels for home heating and diesels increased tremendously after 1945. Heating oil demand grew with the construction of central home heating installations designed for automatic control. The diesel fuel market grew as the diesel engine broadened its field of application to the extent that diesel locomotives displaced steam locomotives for all types of railroad operations; automotive diesel engines are now being used for highway vehicles at an accelerating rate, and marine diesel applications are growing relative to other forms of power. In 1965, the world-wide demand for these fuels was two billion barrels per year; the almost four and a half billion barrel demand forecast for 1975 will at least equal gasoline demand. The growing market for middle distillate fuel, as well as for jet fuel and cracking feedstock, has placed heavy demands on the middle of the crude oil barrel.[4,5]

This increasing demand results from the energy required to fuel rising standards of living; petroleum liquid fuels are favored because of their ease of portability and their efficiency in use. In the United States, middle distillate fuel demand trends toward maintaining approximately 20 per cent of the crude oil barrel. In

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[4] National Petroleum News Factbook Issue, McGraw-Hill, Inc., New York, 1970.

[5] J. V. Hanlon, W. B. Maxwell, E. J. Forster, and P. M. Ponder, "The Development and Application of Predictive Systems for Diesel Fuel Quality," National Petroleum Refiners Association, Fuels and Lubricants, No. FL-69-67, presented at annual meeting, New York, September 1969.

Europe, however, the middle distillate fuel percentage will rise from 30 to 35 per cent between 1965 and 1975. This is largely a result of the replacement of coal burning equipment and the widespread use of the diesel engine for automotive transport.[6,7]

The popularity of the diesel engine stems from its ability to convert more fuel energy into useful work than any other power developing engine over the entire range of speed and load. This thermal efficiency is further enhanced by the economy of burning less expensive diesel fuels. The performance features of these fuels are similar although diesel engines vary widely in size, maximum speed, power output, and mechanical design.

New more powerful, economic, and durable engines are developing rapidly; this progress is inseparably connected with the development and improvement of middle distillate fuels for these engines.[8] Similarly, although heating oils are used in a variety of burner types, they must provide dependable minimum maintenance field performance. The burning performance of middle distillate fuels in both diesel engine and home heating applications is a function of hydrocarbon composition.

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[6] Harold A. Beatty and Sheeler G. Lovell, "Fuel Trends," Kenneth A. Kobe and John J. McKetta, Jr. (eds.), _op. cit._ pp.78-117.

[7] C. G. A. Rosen, "Power Plants of the Future," _ibid._, pp. 579-580.

[8] G. F. Bolshakov, "Modern and Prospective Jet and Diesel Fuels," _Khimiya i Tekhnologiya Topliv i Masel_, No. 3, March 1969, pp. 61-122.

Composition

Due to organic origins, crude oils are composed primarily of hydrocarbons, compounds of hydrogen and carbon.[9,10] Hydrocarbons are classified on the basis of structure as either aromatic or aliphatic. Aromatic hydrocarbons are unsaturated ring compounds characterized by resonating double bonds. The saturated aliphatic hydrocarbons are classified into families that include alkanes and cyclic aliphatics, which are known to the petroleum industry as paraffins and naphthenes, respectively. Paraffins are characterized by saturated open chain structures; the open chain paraffins may be either normal paraffins, straight chain, or isoparaffins, branched chain. Naphthenes are saturated closed chain five and six carbon atom ring hydrocarbons.[11,12,13,14] The paraffins and naphthenes are

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[9] H. Gershinowitz, op. cit.

[10] W. L. Nelson, Petroleum Refinery Engineering, McGraw-Hill, Inc., New York, 1958.

[11] Ibid.

[12] Robert Thornton Morrison and Robert Neilson Boyd, Organic Chemistry, Allyn Bacon, Inc., Boston, 1962.

[13] A. N. Sachanen, "Hydrocarbons in Gasolines, Kerosines, Gas Oils and Lubricating Oil," Cecil E. Boord, Benjamin T. Brooks, Stewart S. Kurtz, and Lewis Schwerling (eds.), Chemistry of Petroleum Hydrocarbons, New York, 1954, pp. 5-36.

[14] Benjamin T. Brooks, "The Chemical Character of Petroleum and Petroleum Products," A. E. Dunstan, A. W. Nash, B. T. Brooks, and H. Tizard (eds.), The Science of Petroleum, Vol. II, Oxford University Press, New York, 1938.

the most important constituents of crude oil. Paraffins are usually present in the largest proportion in the lower boiling or light gasoline fractions and decrease for successively higher boiling fractions.[15,16]

Knowledge of the compositions of crude oils in terms of their chemical constitutions is essential in optimizing refinery systems. This is because the properties of these constituents considerably govern the physical operations of refining, such as vaporization, fractionation, and cooling. Thus, the distribution of paraffins, naphthenes, and aromatics through the boiling range of the crude must be known to optimize the design of a new refinery or the processing schedule of a crude oil through an existing refinery.[17,18]

Owing to the enormous number of chemical constituents present in crude petroleum oils, resolution of refined products into individual hydrocarbons is feasible only for the low boiling fractions, such as motor gasolines. The only individual hydrocarbons in middle distillates which have been isolated and identified are n-tridecane through n-heptadecane, 5-methyltetralin, biphenyl, the two methyl

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[15] H. Gershinowitz, _op_. _cit_.

[16] W. L. Nelson, _op_. _cit_.

[17] H. Gershinowitz, _op_. _cit_.

[18] W. L. Nelson, _op_. _cit_.

naphthalenes, and 2,6 dimethylnaphthalene.[19,20,21,22,23,24] Hence, the separation and determination of hydrocarbon classes is particularly important. Further, from a practical viewpoint, the properties of middle distillates are attributed not so much to specific hydrocarbons as to hydrocarbon classes.

Performance

Combustion Quality. Good middle distillate fuel combustion performance involves ease of ignition, low deposit forming characteristics, and a low smoking tendency.[25] Aromatic hydrocarbons impair fuel combustion and cause a reduction in stable combustion limits.

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[19] A. N. Sachanen, *op. cit.*

[20] R. H. Hunt and M. J. O'Neal, Jr., "The Composition of Petroleum," John J. McKetta, Jr. (ed.), *Advances in Petroleum Chemistry and Refining*, Vol 10, John Wiley and Sons, New York, 1965, pp. 1-35.

[21] B. J. Mair and T. J. Mayer, *Analytical Chemistry*, Vol 36, 1964, p. 351.

[22] B. J. Mair and J. M. Burnewall, "Symposium on Advances in the Composition and Analysis of Petroleum," *American Chemical Society*, Vol. 8, No. 4, 1963.

[23] B. J. Mair, N. C. Kronskep and T. J. Mayer, *Journal of Chemical Engineering*, Vol. 7, 1962, p. 420.

[24] B. J. Mair and F. D. Rossini, *Procedures from the Fifth World Petroleum Congress*, Section V, New York, June 1959, p. 223.

[25] W. L. Nelson, *op. cit.*

Further, aromatics increase deposits and smoke emissions.[26,27,28]

Fuel composition is particularly important for proper diesel engine combustion performance. Diesel combustion occurs in a heterogeneous mixture of fuel and air. Although the overall fuel/air ratio is from 0.01 to 0.05, injecting the liquid fuel near the top of the compression stroke causes localized fuel to air mixtures ranging from pure fuel vapor to air. Thus, the fuel ignites spontaneously and simultaneously at numerous points throughout the combustion chamber at the optimum fuel/air ratio.[29,30]

One of the most important properties of diesel fuels is ignition quality, i.e., the ability to ignite spontaneously under the pressure and temperature conditions which exist in the engine cylinder. Good ignition quality assists in ease of starting, particularly at low temperatures, and provides low engine

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[26] I. E. Bespolov, M. S. Khaikin, B. I. Komarov, and S. P. Medvedev, *Khimiya i Tekhnologiya Topliv i Masel*, Vol. 14, No. 6, June 1969, pp. 42-45.

[27] Donel R. Olson, Nelson T. Meckel, and R. O. Quillan, Jr., "The Operation of Compression Ignition Engine on Wide Boiling Range Fuels," *Transactions of the Society of Automotive Engineers*, Vol. 70, 1962.

[28] A. L. Ward, S. S. Kurtz, Jr., and W. H. Fulweiler, "Density and Refractive Index of Crude Petroleum, Gasoline, Kerosine, Gas Oil and Fuel Oil," A. E. Dunstan, A. W. Nash, B. T. Brooks, and H. Tizard (eds.), *op. cit.*

[29] J. M. Perez and E. W. Landen, "Exhaust Emission Characteristics of Precombustion Chamber Engines," Society of Automotive Engineers, No. 680421, presented at midyear meeting, Detroit, May 1968.

[30] B. W. Millington and C. C. J. French, "Diesel Exhaust - A European Viewpoint," *Transactions of the Society of Automotive Engineers*, Vol. 75, 1967.

pressures and smooth operation. Poor ignition quality not only results in misfiring and rough operation but also promotes sludge formation, which results in engine deposits and piston varnish.[31] Increasing the content of aromatic hydrocarbons degrades the ignition quality of diesel fuels and increases ring wear.[32,33,34]

In terms of maximum power output and fuel composition, increased aromatic hydrocarbons in fuels provide at most negligible improvements.[35,36,37,38,39] The amount of heat released during combustion depends almost entirely on the volume of fuel sprayed through a nozzle. Any improvement in power or consumption is due to

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[31] W. L. Nelson, op. cit.

[32] I. E. Bespolov, et al., op. cit.

[33] D. R. Olson, et al., op. cit.

[34] B. L. Mickel and L. D. Fergeson, "Dimensions of Diesel Fuel Performance: Design, Depressants, and Response," Society of Automotive Engineers, No. 660371, presented at midyear meeting, Detroit, May 1968.

[35] J. B. Durant, et al., op. cit.

[36] A. L. Ward, et al., op. cit.

[37] R. P. Lindeman, D. K. Lawrence, and T. O. Wagner, "Diesel Power, Economy and API Gravity," American Society for Testing and Materials, Diesel Fuel Symposium, presented at annual meeting, Atlantic City, June 1966.

[38] W. C. Ainsley, "Evaluation of Diesel Fuels in Full Scale Engines," American Petroleum Institute Division of Refining, presented at midyear meeting, Tulsa, May 1941.

[39] F. C. Burk, G. H. Cloud, and W. F. Ang, "Fuel Requirements of Automotive Diesel Engines," Society of Automotive Engineers, Vol. 53, No. 3, March 1954, p. 74.

the slight heat content per volume advantage that aromatic hydrocarbons provide over the saturated paraffinic or naphthenic hydrocarbons.[40]

Exhaust Smoke Emission. By influencing the combustion process, fuel characteristics also influence exhaust emissions. The predominant characteristic of diesel exhaust is smoke; hydrocarbon, carbon monoxide, and nitrogen oxide emissions are much lower than found in gasoline exhaust.[41,42] The chemical properties of the fuel are the main controlling factors in smoke formation.[43,44]

Regulation of smoke emission has accelerated since 1939 when the California Legislature prohibited the operation of motor vehicles in a manner resulting in excessive smoke. In 1947, the Legislature further restricted the emission of air contaminants dark or darker than No. 2 on the Ringelmann Chart published by the United States

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[40] Chemical Engineers Handbook, Robert H. Perry, Cecil, H. Chilton, and Sidney D. Kirkpatrick (eds.), McGraw-Hill Book Company, New York, 1963.

[41] G. McConnell, H. E. Howells, D. W. Golothan, M. Vulliamy, J. Spiers, and C. O. Miller, "Influence of Fuel Properties and Effect of Antismoke Additives on Diesel Exhaust," Journal of the Society of Automotive Engineers, Vol. 76, No.3, March 1968, pp. 35-46.

[42] K. C. Tessier and H. E. Bachman, "Fuel Additives for the Suppression of Diesel Exhaust Odor and Smoke; Part I: Proposed Mechanisms for Smoke Suppression," American Society of Mechanical Engineers, No. 68-WA/DGP-4, presented at annual meeting, New York, December 1968.

[43] R. W. Hurn, "The Diesel Fuel Involvement in Air Pollution," National Association of Petroleum Refiners, National Fuels and Lubricants, No. FL-69-66, presented at annual meeting, New York, September 1969.

[44] N. A. Henein and J. A. Bolt, "The Effect of Some Fuel and Engine Factors on Diesel Smoke," Society of Automotive Engineers, No. 690557, presented at West Coast meeting, Seattle, August 1969.

Bureau of Mines. In 1963, the California Board of Health adopted No. 1 on the Ringelmann Chart as the standard for smoke emissions.

Since 1960, the California Highway Patrol has issued approximately 8000 citations per year for excessive smoke emission.[45] Public concern over air pollution brought passage by the 90th Congress of the Clean Air Act of 1967, which, in part, provided for conducting research directed toward fuel combustion.[46] In January 1968, the United States Department of Health, Education and Welfare proposed smoke limits for 1970 model vehicles.[47] Similarly, smoke emission limits have been legislated or proposed in West Germany, France, Belgium, Finland, Sweden, Norway, and the United Kingdom.[48,49,50,51]

Diesel smoke consits of very fine carbon particles which agglomerate into irregularly shaped bodies; it originates early in the combustion cycle in localized values of rich fuel/air ratios,

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[45] Miles L. Brubacher, "Reduction of Diesel Smoke in California," Society of Automotive Engineers, No. 660548, presented at West Coast meeting, Los Angeles, August 1966.

[46] K. C. Tessier and H. E. Bachman, op. cit.

[47] United States Public Law 90-148, "Air Pollution Prevention and Control," 90th Congress, S. 780, November 21, 1967.

[48] B. W. Millington and C. C. J. French, op. cit.

[49] N. A. Henein and J. A. Bolt, op. cit.

[50] Miles L. Brubacher, op. cit.

[51] United States Public Law 90-148, "Air Pollution, Prevention and Control," 90th Congress, S. 780, November 21, 1967.

ratios greater than 1.5 times stoichiometric.[52,53,54] The decomposition of any hydrocarbon leads eventually to the formation of acetylene and hydrogen. The simultaneous condensation and dehydrogenation of acetylene results in solid carbon.[55] This solid carbon agglomerates and is subsequently exhausted to the atmosphere as soot.

Some success at reducing smoke emission has been achieved through improved combustion chamber design.[56,57,58] Reductions in smoke can also be effected by proper engine maintenance procedures. However, even with proper design and maintenance, a diesel engine can emit objectionable amounts of smoke, particularly under conditions of overload.[59] Greater control of diesel combustion is accomplished through the use of chemicals without appreciably affecting

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[52] J. M. Perez and E. W. Landen, op. cit.

[53] S. M. Decorsen, C. E. Hussey, and M. J. Ambrose, "Smokeless Combustion in Oil Burning Gas Turbines," Combustion Institute, Central States Section, presented at spring meeting, Pittsburgh, March 1968.

[54] J. F. Alcock and W. M. Scott, "Some More Light on Diesel Combustion," Procedures of the Institute of Mechanical Engineers, No. 5, London, 1962-1963.

[55] G. Porter, "The Mechanism of Carbon Formation," Advisory Group for Aeronautical Research and Development, Netherlands Conference, No. AG13/M9, Scheveningen, May 1954.

[56] J. M. Perez and E. W. Landen, op. cit.

[57] J. S. Meuer, Transactions of the Society of Automotive Engineers, Vol. 64, 1956, p. 250.

[58] H. R. Ricardo, The High Speed Internal Combustion Engine, Blackie and Son, Ltd., London, 1923.

[59] K. C. Tessier and H. E. Bachman, op. cit.

cleanliness or performance.[60,61,62,63,64,65] Added in concentrations of several tenths per cent, these chemicals are generally colloidally dispersed barium compounds; they function either by inhibiting the formation of carbon precursors or by catalytically increasing the rate of gasification of newly formed carbon.[66,67,68]

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[60] G. McConnell, _et al._, _op. cit._

[61] D. W. Golothan, "Diesel Engine Exhaust Smoke; The Influence of Fuel Properties and the Effects of Using Barium Containing Fuel Additive," Society of Automotive Engineers, No. 670092, presented at midyear meeting, Detroit, January 1967.

[62] Ralph C. Stahman, George C. Kittredge, and Karl J. Springer, "Smoke and Odor Control for Diesel-Powered Trucks and Buses," Society of Automotive Engineers, No. 680443, presented at midyear meeting, Detroit, May 1968.

[63] C. O. Miller, "Diesel Smoke Suppression Fuel Additive Treatment," Society of Automotive Engineers, No. 670093, presented at International Engineering Congress, Detroit, January 1967.

[64] I. Glover, "The Fuel Additive Approach Towards the Alleviation of the Nuisance of Diesel Smoke," presented to Institute of Petroleum, London, April 1966.

[65] T. K. Garrett, _Automobile Engineer_, November 1966, p. 467.

[66] K. C. Tessier and H. E. Bachman, _op. cit._

[67] D. E. Wolfhorst and A. W. Carey, Jr., "A Photgraphic Study of the Influence of Barium Based Additives on Diesel Engine Combustion," Combustion Institute, Central States Section, presented at spring meeting, Pittsburgh, March 1968.

[68] C. P. Fenimore and G. W. Lones, _Journal of Physical Chemistry_, Vol. 71, No. 3, February 1967, pp. 593-597.

Exhaust smoke can also be reduced by using more volatile fuel; however, for a given engine speed, power is also reduced.[69,70,71,72] When the pump injection period is lengthened to provide equivalent power, combustion effeciency declines to produce exhaust smoke in excess of that observed with normal volatility diesel fuels.[74,75,76] Thus, the content of aromatic hydrocarbons is the most dominant fuel characteristic affecting diesel smoke emission; significant reduction in smoke is accomplished consistently by reducing the fuel aromatics.[77,78,79,80,81] It is reasonable to expect that reduction of smoke emission will effect a commensurate reduction in the emission of unburned hydrocarbons.

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[69] G. McConnell, H. E. Howells, D. W. Golothan, et al., op. cit.

[70] D. W. Golothan, op. cit.

[71] G. McConnell and H. E. Howells, "Diesel Fuel Properties in Exhaust Gas - Distant Relations?," Society of Automotive Engineers, No. 670091, presented at Automotive Engineering Congress, Detroit, January 1967.

[72] K. C. Tessier and H. E. Bachman, "Fuel Additives for the Suppression of Diesel Exhaust Odor and Smoke; Part II: Field Trials," American Society of Mechanical Engineers, No 68-WA/DGP-5, presented at annual meeting, New York, December 1968.

[73] J. D. Savage, "The Diesel Engine Exhaust Problem with Road Vehicles," Diesel Engineers and Users Association, No. 5-302, June 1965.

[74] G. McConnell, H. E. Howells, D. W. Golothan, et al., op. cit.

[75] D. W. Golothan, op. cit.

[76] G. McConnell and H. E. Howells, op. cit.

[77] J. B. Durant and Lamont Eltinge, op. cit.

[78] T. E. Bespolov, et al., op. cit.

[79] B. L. Mickel and L. D. Fergeson, op. cit.

[80] G. McConnell, M. E. Howells, D. W. Golothan, et al., op. cit.

[81] K. A. Troth, "Relationship Between Specific Gravity and Other Fuel Properties and Diesel Engine Performance," American Society for Testing and Materials, Diesel Fuel Symposium, presented at annual meeting, Atlantic City, June 1966.

Low Temperature Operation. In low temperature operations, some hydrocarbon constituents crystallize from middle distillate fuels, Although present in small concentrations, the crystals can interlock to form a three dimensional network that immobilizes the remaining liquid; also, the hydrodynamic forces generated at narrow orifices can align and compact the crystals into a solid plug.[82,83] With fuel supply interrupted, the combustion system ceases to function.

The petroleum waxes recovered from heavier distillates by dewaxing with chilled solvents are a function of the distillates from which they are derived; however, these waxes are predominantly paraffinic. The relative abundance of n-paraffin waxes increases with decreasing distillate boiling point; carbon numbers range from 18 upward. Most of the non-n-paraffins are iso-paraffins with lesser amounts of naphthenes and trace amounts of aromatics.[84,85,86,87] It is anticipated that this scheme will be observed in the hydrocarbons separating from cooling middle distillates, except that lower n-paraffin carbon numbers will be present.

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[82] B. L. Mickel and L. D. Fergeson, *op. cit.*

[83] J. Alvin McConnell, "Burner Fuel Oils Market Demand and Quality Requirements," National Petroleum Refiners Association, Fuels and Lubricants, No. FL-68-72, presented at annual meeting, New York, September 1968.

[84] R. H. Hunt, *et al.*, *op. cit.*

[85] J. V. Brunock, "Separation and Distribution of Normal Paraffins from Petroleum Heavy Distillates by Molecular Sieve Adsorption and Gas Chromatography," *Analytical Chemistry*, Vol. 38, No. 12, November 1966, pp. 1648-1652.

[86] A. Hood, R. J. Clerc, and M. J. O'Neal, *Journal of the Institute of Petroleum*, Vol. 45, 1959, p. 168.

[87] Benjamin T. Brooks, "Composition of Petroleum Waxes," C. E. Boord, B. T. Brooks, S. S. Kurtz, and L. Schwerling (eds.), *op. cit.*, pp. 37-47.

Carbon atoms in the n-paraffin hydrocarbon chain are arranged in a fully extended planar zigzag, the conformation of minimum energy. The repeat distance, the distance between successive carbon atoms on the same side of the chain axis, is approximately 2.55 Å (1 Å unit = 10^{-8} cm); the angle between successive single bonds is close to the tetrahderal angle of 109°28'.[88,89,90] These extended n-paraffin chains crystallize in a parallel alignment as the attractive van der Waals forces are stronger between parallel chains than between a chain and a plane of methyl groups.[91,92]

Crystallization starts from cruciform dendritic nuclei, from which the plane develops. The growth rate ranges from microns to millimeters per minute.[93] For both crystal formation and crystal growth, the common driving force is supersaturation of the solution. With high supersaturation, formation predominates over growth to produce small crystals; the reverse is true with low supersaturation and large

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[88] Benjamin T. Brooks, op. cit.

[89] Fred W. Billmeyer, Jr., Textbook of Polymer Science, Interscience Publishers, Inc., New York, 1966.

[90] F. Francis and S. H. Piper, "The Application of the X-Ray Method to the Study of the Paraffin Hydrocarbons," A. E. Dunstan, A. W. Nash, B. T. Brooks, and H. Tizzard (eds.), op. cit., pp. 1203-1205.

[91] M. G. Broadhurst, Journal of Research of the National Bureau of Standards, Physics and Chemistry, Vol 66A, 1962, p. 241.

[92] N. I. Chernozhukov, V. V. Vainshtok, and B. N. Kartinin, Izv Vysshikh Uchebn Zavedenii Neft i Gaz, No. 8, 1961, p. 81.

[93] Andrew Van Hook, Crystallization: Theory and Practice, Reinhold Publishing Corporation, New York, 1961.

crystals are produced.[94,95] Consequently, small crystals result from rapid cooling and large crystals result from slow cooling.[96,97]

The n-paraffins separating from cooled middle distillate fuels form a continuous series; hence, the crystals contain an equilibrium mixture of all the n-paraffins separated.[98,99,100] The differential chain lengths of the n-paraffins result in a self-perpetuating spiral growth mechanism, which facilitates growth even at very low supersaturations.[101,102,103,104,105] Hence, the crystal develops

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[94] Robert A. Findley and John A. Weedman, "Separation and Purification by Crystallization," Kenneth A. Kobe and John J. McKetta, Jr. (eds.), op. cit., pp. 118-209.

[95] Warren L. McCabe and Julian C. Smith, Unit Operations of Chemical Engineering, McGraw-Hill Book Company, New York, 1956.

[96] Edgar W. Clarke, Industrial and Engineering Chemistry, Vol. 43 No. 11, November 1951, pp. 2526-2535.

[97] S. W. Ferris and H. C. Cowles, Industrial and Engineering Chemistry, Vol. 37, No. 11, November 1945, pp. 1054-1062.

[98] Ibid.

[99] M. R. Cines, "Solid-Liquid Equilibria of Hydrocarbons," A. Farlas (ed.), Physical Chemistry of the Hydrocarbons, Vol. 1, Academic Press, New York, 1950, pp. 315-360.

[100] G. A. Holder and J. Winkler, "Wax Crystallization from Distillate Fuels," Journal of the Institute of Petroleum, Vol. 51, No. 499, July 1965, pp. 228-252.

[101] Edgar W. Clarke, op. cit.

[102] G. A. Holder and J. Winkler, op. cit.

[103] M. J. Chichakli and F. W. Jessen, "Crystal Morphology in Hydrocarbon Systems," Industrial and Engineering Chemistry, Vol. 59, No. 5, May 1967, pp. 86-98.

[104] John J. Lanriteer, Jr., Elio Passaglia, and E. A. DiMarzio, "Kinetics of Crystllization in Multicomponent Systems," Journal of Research of the National Bureau of Standards, Physical Chemistry, Vol. 71A, No. 4, July-August 1967, pp. 245-260.

[105] A. R. Verma, Crystal Growth and Dislocations, Academic Press, New York, 1953.

by monomolecular steps into a pyramidal structure.[106,107]

Crystals of solid hydrocarbons are mainly of the same shape: scalariform pyramids from parallel rhombic planes.[108,109,110,111,112] Normal and iso-paraffinic crystals are the largest and have the greatest number of rhombic planes. Aromatic crystals are the smallest; solid naphthenes are intermediate.[113] Hence, crystals from the predominantly paraffin solids of middle distillate fuels develop into large rhombic plane pyramids, with slow cooling promoting even larger structures.

Presently, there are two approaches to the problems of paraffin crystallization in middle distillate fuels. The first involves dilution of the problem paraffins through the use of low-boiling kerosine stocks in blending. The second involves the addition of several hundredths

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[106] N. I. Chernozhukov, *et al.*, *op. cit.*

[107] M. J. Chichakli and F. W. Jessen, *op. cit.*

[108] *Ibid.*

[109] N. I. Chernozhkov, *Khimiya i Tekhnologiya Topliv i Masel*, Vol. 1I, No. 2, February 1966, p. 168.

[110] N. I. Chernozhukov, V. V. Vainshtok, B. N. Kartinin, and V Ya, Zezekalo, "The Crystallization of Solid Petroleum Hydrocarbons," *Khimiya i Tekhnologiya Topliv i Masel*, Vol. 14, No. 3, March 1969, pp. 15-18.

[111] J. Katz, *Journal of the Institute of Petroleum Technology*, Vol. 18, 1932, p. 37.

[112] H. Rhodes, C. W. Mason, and W. R. Sutton, *Industrial and Engineering Chemistry*, Vol. 19, 1927, p. 935.

[113] N. I. Chernozhukov, *Khimiya i Tekhnologiya Topliv i Masel*, Vol. 11, No. 2, February 1966, p. 168.

weight per cent of a chemical. The chemical modifies the size and shape of the crystallizing paraffin; it does not affect either the amount of crystallizing paraffin or the temperature at which crystallization occurs.[114,115,116,117,118]

Most of the paraffin modifying chemicals are polymers containing paraffinic groups.[119,120] The paraffinic portion allows incorporation of the chemical by adsorption and/or cocrystallization into the growing paraffin crystal; the nonparaffinic portion hinders further growth and agglomeration.[121,122,123,124,125,126] However, in order

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[114] G. A. Holder and J. Winkler, *op. cit.*

[115] G. A. Holder, "Effect of Polymers in the Crystal Growth of n-$C_{20}H_{42}$, n-$C_{22}H_{46}$, n-$C_{20}H_{50}$, n-$C_{28}H_{50}$, and Some of Their Binary Mixtures," American Chemical Society, presented at winter meeting, Phoenix, January 1966.

[116] J. L. Tiedje, "The Use of Pour Depressants in Middle Distillates," *Procedures from the Sixth World Petroleum Congress*, Section VI, Frankfurt, June 1963.

[117] B. F. Bridwell, "Effects of Various Additives on Crystal Habit and Other Properties of Petroleum Wax Solutions," Ph.D. dissertation, The University of Texas, Austin, September 1963.

[118] L. E. Lorenson, *American Chemical Society, Division of Petroleum Chemistry Preprints*, Vol. 7, No. 413, September 1962, P. 61.

[119] G. A. Holder and J. Winkler, *op. cit.*

[120] L. E. Lorenson, *op. cit.*

[121] L. E. Lorenson and W. A. Meritt, *American Chemical Society, Division of Petroleum Chemistry Preprints*, Vol. 7, No. 413, September 1962, p. 71.

[122] A. Bondi, *Petroleum Refiner*, Vol. 22, 1943, p. 287.

[123] G. Gavlin, E. A. Swire, and S. P. Jones, *Industrial and Engineering Chemistry*, Vol. 45, No. 10, October 1953, p. 2327.

[124] E. Koch, *Erdoel Kohle*, Vol. 8, 1955, p. 793.

[125] R. A. Ruehrwein, *Procedures from the Third World Petroleum Congress*, Section VII, June 1951, p. 423.

[126] G. R. Schultz, J. Moos, G. H. Goettner, and M. Acanal, *Erdoel Kohle*, Vol. 17, 1964, p. 2.

for chemicals to provide low temperature performance benefits in automotive diesels, fuel systems may require winterization by removing suction filters and relocating pressure filters depending on cold weather severity.[127,128,129,130,131,132,133,134,135]

In summary, middle distillate fuels constitute the middle 325 to 675 F boiling range of the crude oil barrel; and as they are consumed

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[127] B. L. Mickel and L. D. Fergeson, _op. cit._

[128] Thomas J. Fallon, "Flow Improver Additives are Effective for Winterizing Diesel Fuel," Society of Automotive Engineers, No. 680537, presented at West Coast meeting, San Francisco, August 1968.

[129] Raymond A. Filippini, "High Cloud Flow Improved Diesel Fuels Operate in Severe Winter Climates," National Petroleum Refiners Association, Fuels and Lubricants, No. FL-68-60, presented at annual meeting, New York, September 1968.

[130] K. A. Beyreis, V. P. Catto, and E. S. Swanson, Jr., "The Role of Flow Improvers in Solving Winter Fuel Problems," Society of Automotive Engineers, No. 660372, presented at summer meeting, Detroit, June 1966.

[131] D. L. Allen, "Flow Improved Diesel Fuels are a Success in Severe Winter Trials," National Association of Petroleum Refiners, Fuels and Lubricants, No. 65-35F, presented at annual meeting, New York, September 1965.

[132] H. E. Deen, E. S. Swanson, Jr., and W. M. Peltola, "Designing Diesel Fuels and Fuel Systems for Low Temperatures," Society of Automotive Engineers, No. 939A, presented at National Transportation, Powerplant, and Fuels and Lubricants Meeting, Baltimore, October 1964.

[133] "Fuel Waxing in Cold Weather," _Diesel Engine Superintendant_, July 1964.

[134] Harold E. Deen and Edward H. Johnson, "Pour Depressed Fuels are a Field Success," National Petroleum Refiners Association, No. FL-63-29, presented at National Fuels and Lubricants Meeting, Cleveland, September 1963.

[135] H. R. Osborne, "Effect of Fuel Quality on Diesel Engine Performance at Low Temperatures," presented to Netherlands Royal Society of Engineers, February 1963.

primarily for space heating or diesel engines, they are commonly referred to as heating oils or diesel fuels, respectively. Originating from the decomposition of organic remains, middle distillate fuels consist of unsaturated aromatic and saturated paraffinic and naphthenic hydrocarbons. Their relative concentrations determine combustion quality and subsequent smoke emission, the predominant characteristic of diesel exhaust. At low temperatures, some hydrocarbon constituents crystallize to form immobilizing matrices. A systematic approach to the problems of smoke emission and low temperature operation requires the quantitative characterization of middle distillate fuels.

METHODS

Testing Techniques

The inspection techniques on petroleum products are simplified procedures which are readily adaptable to routine operation. In general, they have been adopted because they can be 1) performed quickly, 2) easily duplicated by laboratory technicians and 3) interpreted as a function of the performance of the product while in use.[1] Common tests performed on middle distillates are gravity, distillation, aniline point and cloud point. Test methods have been standardized by the American Society for Testing and Materials (ASTM). To broaden the thesis as much as possible, tests are conducted on eight United States and two European middle distillate fuels from major refiners.

Gravity. Almost all liquid petroleum products are handled and sold on a volume basis, usually barrels or gallons. However, product weight is often required to calculate such items as freight rates, aircraft and ship fuel loads, and combustion efficiencies. Gravity is an expression of the weight to volume relationship of a product. It is reported at a standard 60 F temperature due to expansion.

There are two scales in use in the petroleum industry. The specific gravity is defined as the ratio of the weight of a given volume of the product at 60 F to the weight of an equal volume of

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[1] W. L. Nelson, op. cit.

water at the same temperature. In the United States petroleum industry, however, the American Petroleum Institute (API) gravity scale is more widely used. This is an arbitrary scale calibrated in degrees and related to specific gravity by the formula

$$\text{API Gravity, API} = \frac{141.5}{\text{specific gravity @ 60/60 F}} - 131.5$$

As a result of this relationship, the higher the specific gravity, the lower the API gravity. Thus, with pure water at 10 API, liquids lighter than water have values greater than 10 and liquids heavier than water have values less than 10.

In ASTM D 287, gravity is determined by floating a hydrometer in a cylinder containing the liquid. The plane at which the liquid surface intersects the hydrometer scale is read as the observed gravity. A thermometer is lowered into the sample to determine the test temperature. If the test temperature differs from 60 F, the observed gravity is corrected to the gravity at 60 F by use of petroleum measurement tables.

Distillation. A chemically pure hydrocarbon, like any other pure liquid compound, boils at a certain temperature when atmospheric pressure is constant. However, middle distillate fuels contain many different hydrocarbons, each boiling at a different temperature. By gradually increasing the temperature, successively higher boiling constituents are vaporized. Thus, boiling occurs over a range of temperatures. These boiling characteristics are important as middle distillate fuels are converted to the vapor state prior to combustion.

In ASTM D 86, often referred to an an ASTM or Engler distillation, one hundred cubic centimeters of fuel is distilled from a flask containing a thermometer and connected to a condenser, which consists of a brass tube surrounded by cracked ice. Heat is supplied to the flask such that the first drop of condensate drips into a graduate in not less than five or more than ten minutes; the vapor temperature is simultaneously recorded as the initial boiling point (IBP). By regulating the heat source, distillation is controlled at a uniform rate of five cubic centimeters per minute; the vapor temperature is recorded as each successive ten per cent is collected. The maximum temperature observed as the last drop of liquid vaporizes is recorded as the final boiling point (FBP).

As there is no attempt to fractionate, the vapor temperature does not represent the actual boiling point of the material situated at that percentage in the fuel; hence, this procedure is referred to as an ASTM distillation. To correct for cracking at temperatures above 475 F, the following equation is used:

$$\log C = -1.587 + 0.00473\ T'$$

where C is the correction to be added to T', the observed temperature in degrees Fahrenheit. Ideally, an average boiling point should be independent of width of boiling range when other average properties such as specific gravity, average molecular weight and chemical type are constant.[2] Although either a weight

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[2] W. L. Nelson, op. cit.

average or a volume average increases with increases in the boiling range, a volume average varies less and is preferable for this reason.

The volumetric average boiling point (VABP) is the weighted average of the distillation temperatures after 10, 30, 50, 70, and 90 volume per cents have distilled:

$$\text{VABP} = \frac{T_{10} + T_{30} + T_{50} + T_{70} + T_{90}}{5}$$

A slope, in degrees Fahrenheit per per cent distilled, is calculated by assuming a linear distillation curve for the temperatures between the 10 and 90 per cent points:

$$\text{Slope} = \frac{T_{90} - T_{10}}{90 - 10}$$

Thus, distillation characteristics are described by the line defined from the VABP and the slope near that point.

Aniline Point. The degree of solvent power also varies with hydrocarbon type. As a group, the aliphatics are lower in solvent power than the aromatics. The naphthenes are intermediate in solvency between the paraffins and the aromatics but are more similar to the paraffins in their properties.

Aniline, an aromatic substance, is at least partially soluble in almost all hydrocarbons; and, of course, its degree of solubility in any particular hydrocarbon increases with increasing temperature. The aniline point, defined by ASTM D 611, is the minimum temperature at which 10 ml. of dry aniline and 10 ml. of dry middle distillate are miscible. Low aniline points indicate high solubility and, thus, high aromatic content.

Cloud Point. It is often necessary to know what temperatures a particular middle distillate fuel can be subjected to before it begins to lose its fluid characteristics. Most fuels are mixtures of hydrocarbon types and there is a tendency for those containing paraffins to form firm crystals at low temperatures. The paraffin crystals impart a cloudy appearance to the fuel.

In the determination of cloud points by ASTM D 2500, the fuel sample is cooled from a temperature at least 25 F above the anticipated cloud point in a jacketed glass jar containing a prescribed thermometer. At intervals of even Fahrenheit degrees, the sample is inspected, without disturbance, for cloudiness. The temperature at which a distinct opaque layer appears in the very bottom of the jar is recorded as the cloud point.

Paraffin Separation. The cloud point indicates the temperature at which the paraffins present in a middle distillate fuel first begin to crystallize. However, it does not indicate the amount of paraffins that will crystallize at lower temperatures. The only means of determining the quantity of crystals formed at any given temperature is through a separation technique.

To effect a separation, a weighed sample of middle distillate fuel is cooled in a standard cold chest to a given temperature below the cloud point and maintained at this temperature for at least sixteen hours. The solid phase that forms is vacuum filtered at temperature through Whatman No. 1 filter paper and washed with chilled acetone. Occlusion of mother liquor impurities in the crystal mass can be severe.[3,4] Hence, 0.05 wt.% Paradyne,[5] a commerical paraffin crystal modifier, is added to the fuel before cooling to minimize occlusion and, thus, aid filterability. After stripping on a steam bath to constant weight, the solids are weighed and a percentage is calculated for a particular temperature.

Temperature effects are summarized by calculating the slope of the line for cumulative n-paraffins separated versus temperature. The quantity of n-paraffins separated at the cloud point is considered zero. Hence, the line is determined by the slope and a point.

Composition Characterization. The development of the methods of gas chromatography and mass spectroscopy enables their application to group type analyses of middle distillate fuels.[6,7] Gas chromatography functions by a continuous process of selective adsorption; separation depends on the relative solubility of the components between stationary liquid and mobile gas phases. In mass spectroscopy, ion streams are altered in direct proportion to their masses by continuously

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[3] R. A. Findley and J. A. Weedman, op. cit.

[4] Warren L. McCabe and Julian A. Smith, op. cit.

[5] Paradyne is a registered trademark of the Exxon Chemical Company.

[6] W. S. Young, "Mass Spectroscopy of Hydrocarbons," C. E. Boord, B. T. Brooks, S. S. Kurtz, and L. Schwerling (eds.), op. cit., pp. 405-434.

[7] M. Kuras and S. Hala, Journal of Chromatography, Vol. 51, 1970, pp. 45-57.

varying a magnetic field; a spectrum of mass numbers versus current is obtained from which group types can be identified.

The relative lack of resolution combined with the small concentrations involved complicates measurement of the n-paraffin carbon number distributions.[8] Hence, the descriptive statistics are based on measures of central tendency and dispersion using the median and semi-interquartile range. The median is the midpoint of the distribution, which eliminates the effect of any extreme values; the semi-interquartile range is one half the range between the third and first quartile and is normally used when the median is the measure of central tendency.[9,10]

To summarize the temperature effects on n-paraffin carbon number distributions, the medians and semi-interquartile ranges are determined at 10 F intervals from +10 F to -40 F. Thus, carbon number distributions are described from approximately 10 F below the fuel cloud point, as measurable n-paraffin quantities do not separate at the cloud point, to the lowest winter temperature observed in most regions of the United States. By plotting the medians and semi-interquartile ranges versus temperature, their rates of change

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[8] J. V. Brunnock, op. cit.

[9] Mary Gibbons Natrella, Experimental Statistics, National Bureau of Standards Handbook, No. 91, United States Government Printing Office, Washington, D. C., October 1966.

[10] Irwin Miller and John E. Freund, Probability and Statistics for Engineers, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1965.

with temperature are calculated from the slope of the line. Extrapolation to the cloud point yields a convenient value.

Unsaturated aromatics are separated from the saturated paraffins and naphthenes by gas chromatography. Mass spectroscopy is subsequently used to determine the paraffins and naphthenes in the saturates fraction. The content and carbon number distribution of n-paraffins is determined directly by gas chromatography.

Of course, the methods and required equipment for gas chromatography and mass spectroscopy are specialized and prohibitively expensive for characterizing middle distillate fuels in most routine refinery and terminalling operations.[11] Further, the hydrocarbon constituents that crystallize below the fuel cloud points have not previously been characterized; yet these constituents dominate useage patterns at low temperatures. Hence, it is desired to characterize middle distillate fuels at temperatures both above and below the cloud point using readily performed, common petroleum inspection tests.

Present Indexes

Crude oils have long been classified as paraffin, intermediate, or naphthene base; in addition, the few oils containing significant amounts of aromatic hydrocarbons are called aromatic or benzenoid base.[12] The U. S. Bureau of Mines designates eight bases of crude oil; the first and second words of the designation apply to key

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[11] J. V. Hanlon, W. B. Maxwell, E. J. Forster, and P. M. Ponder, op. cit.

[12] W. L. Nelson, "Aromatic Base Crude Oil," Oil and Gas Journal, December 1, 1944, p. 91.

fraction No. 1, the gasoline or low boiling fraction, and to key fraction No. 2, the lubricant or high boiling fraction, respectively. Key fraction No. 1, which boils from 482 to 527 F at atmospheric pressure, has a minimum 40 API gravity for paraffin base crude oils and maximum 33 API for naphthene base crude oils. Likewise, key fraction No. 2, which boils from 527 to 572 F at 40 mm pressure (approximately 733 to 779 F at 760 mm), has a minimum 30 API and maximum 20 API for paraffin and naphthene base crude oils, respectively. In addition, key fraction No. 2 is augmented by the statement "wax free" if the cloud point is below +5 F, which means little wax.[13] The U. S Bureau of Mines uses the Hempel distillation, which achieves a mild degree of fractionation by incorporating a section of packed column between the flask and the condenser.

Most methods of classification apply best for close-cut hydrocarbon fractions which boil without decomposition; none of them are truly successful in indicating chemical composition. Even aniline point, which has a long established reputation as a means of indicating the presence of aromatic hydrocarbons, is limited unless the relative paraffinic and naphthenic proportions are also known.[14,15] Typical aniline points with a 550 F midboiling point are 185 F for paraffin,

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[13] A. Lane and C. Garton, "Base of a Crude Oil," U.S. Bureau of Mines Rept. Invest., No. 3279, September 1935.

[14] W. L. Nelson, Petroleum Refinery Engineering, op. cit.

[15] S. S. Kurtz, Jr., "Physical Properties and Hydrocarbon Structure," C. E. Boord, B. T. Brooks, S. S. Kurtz, and L. Schwerling (eds.), op. cit, pp. 275-331.

160 F for intermediate and 120 F for naphthene base fuels. Because of regularities in the relation between boiling point, gravity, and hydrocarbon type, various indexes have been proposed based on boiling point or gravity and one other property.

The most widely used index in the Watson Characterization Factor, which relates boiling point and gravity by the equation:

$$K = \frac{\sqrt[3]{T_b}}{S}$$

where T_b is the absolute average molal boiling point in degrees Rankine (F + 460) and S is specific gravity at 60/60 F. The molal average boiling point is converted from the volumetric average boiling point obtained in an ASTM D 86 distillation. This ratio was derived as the empirical equation of a curve relating average boiling point to specific gravity for a series of cuts taken from several types of petroleum stock considered to be fairly uniform in character throughout their boiling ranges. The Watson Characterization Factor has been related to aniline point, viscosity, molecular weight, critical temperature, and hydrocarbon percentages; in fact, almost any laboratory data can estimate this factor, which has been used to characterize crude oils, petroleum products, and hydrocarbons. Paraffin, intermediate, and naphthene crude bases are indicated by values from 12.90 to 12.15, from 12.10 to 11.50, and from 11.45 to 10.50, respectively. For aromatics with few side chains, the values are below 10.[16,17,18,19,20]

The correlation index, like the Characterization Factor, relates boiling point and gravity. The equation is:

$$\text{C. I.} = \frac{48,640}{T_k} + 473.75 - 456.8$$

where T_k is absolute average boiling point in degrees Kelvin (C + 273) and S is specific gravity at 60/60 F. With a 400 F midboiling point, fuels exhibit 18.5 for paraffin base and 59.0 for naphthene base; aromatics with few side chains have index values above 70.[21]

The viscosity-gravity constant is used primarily for lubricating oils and is defined by the equation:

$$\text{V.G.C.} = \frac{10S - 1.0752 \log(V - 38)}{10 - \log(V - 38)}$$

where S is the specific gravity at 60/60 F and V is viscosity at

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[16] W. L. Nelson, Petroleum Refinery Engineering, op. cit.

[17] S. S. Kurtz, Jr., op. cit.

[18] K. Van Nes and H. A. Van Weston, Aspects of the Constitution of Mineral Oil, Elsevere, New York, 1951.

[19] K. M. Watson, E. F. Nelson, and George B. Murphy, "Characterization of Petroleum Fractions," Industrial and Engineering Chemistry, Vol. 29, No. 12, December 1935, pp. 1460-1464.

[20] K. M. Watson and E. F. Nelson, Industrial and Engineering Chemistry, Vol 27, 1933, pp. 880-887.

[21] H. M. Smith, U. S. Bureau of Mines, Technical Paper, No. 610, 1940.

100 F in Saybolt Universal Seconds. Paraffinic and intermediate base lubricating oils have constants of 0.802 and 0.872, respectively.[21,22]

The rate of change of lubricating oil viscosity with temperature depends on hydrocarbon composition; this is indicated by viscosity index, ASTM D 567, which is calculated by:

$$\text{V. I.} = \frac{L - U}{L - H}\ (100)$$

where U is viscosity at 100 F of the oil and L and H are viscosities at 100 F of oils having the same viscosity at 210 F as the sample oil but with viscosity indexes of 0 and 100, respectively. Typical paraffin base lube oils exhibit a desirable 100 V.I., which indicates that the oil does not tend to thicken at low temperatures or thin at elevated temperatures; naphthene base oils exhibit about a 40 V.I.[23,24] However, viscosity index is meaningful only for lubricating oils. Numerous other constants more limited in usefulness include Diesel Index, which involves gravity and aniline point; Parachor, which involves gravity and surface tension; boiling point/gravity constant; characterization gravity; and carbon/hydrogen ratio.[25]

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[21] S. S. Kurtz, Jr., _et al._, "Relationship Between Carbon Type Composition, Viscosity-Gravity," _Analytical Chemistry_, Vol. 28, 1928.

[22] J. B. Hill and H. B. Coates, _Industrial and Engineering Chemistry_, Vol. 20, 1928, p. 641.

[23] Dean and Davis, "Viscosity Variations of Oils with Temperature," _Chemical and Metallurgical Engineering_, Vol. 36, 1928, p. 168.

[24] "Applying Viscosity Index to the Solution of Lubricating Oil Problems," _Oil and Gas Journal_, March 31, 1932, p. 92.

[25] W. L. Nelson, _Petroleum Refinery Engineering_, _op. cit._

Inference Techniques

If measures of one characteristic accompany measures of another characteristic, they covary and can be correlated by a rank-order correlation coefficient; coefficients of +1 and -1 indicate high positive and high negative correlation, respectively. If there is a correlation between measurements, one measurement can be inferred from the other measurement. Hence, rather than pursue the development of a series of indexes, empirical equations are developed to infer selected characteristics. As predictive variables are unknown initially, all inspection data obtained on the fuels are tested for inclusion in the equations. The best equation forms are selected statistically; rejected equation forms are not reported. The final empirical equations are a balance between good precision, simplicity, and consistency.

Physical situations can be described by linear multivariable relationships of the form:

$$\underline{y} = b_0 + b_1\underline{x}_1 + b_2\underline{x}_2$$

between a dependent variable $\underline{y}$ and one or two independent variables $\underline{x}_1$ and $\underline{x}_2$. As the choice of which are $\underline{x}_1$ and $\underline{x}_2$ variables and which is the $\underline{y}$ variable is arbitrary, the variables which are easiest to measure are called $\underline{x}_1$ and $\underline{x}_2$. The equations are limited to a three term maximum as the data is collected from a ten fuel population.

For each multiple regression, the problem is that of fitting a plane to a set of $\underline{n}$ points with coordinates $(x_{1_i}, x_{2_i}, x_{3_i})$.

As the relationship is linear, the method of least squares is applied to obtain estimates of the coefficients b_0, b_1, and b_2; the method minimizes the sum of the squares of the vertical distances from the points to the plane.[26,27]

$$\sum_{i=1}^{n} \left[y_i - (\beta_0 + \beta_1 x1_i + \beta_2 x2_i) \right]^2$$

This approximation is considered justified on the basis that the exact expression is unknown and that the domain of dependent variables is fairly limited.

Frequency distributions are used to reduce some of the data to more suitable forms. Although some of the information contained in the set of data is sacrificed, important features in the data emerge and correlation is facilitated. All of the distributions are unimodal and nearly symmetrical bell-shaped curves; hence, the distributions follow closely the pattern of normal distributions. The median, a location parameter, is the most frequently occurring value and divides the area under the distribution curve in half. The range, a dispersion parameter, measures the data spread.

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[26] M. G. Natrella, *op. cit.*

[27] Miller and Freund, *op. cit.*

RESULTS

Empirical equations are presented for the quantitative characterization of middle distillate fuels in terms of the hydrocarbon composition of the fuels, the composition of the solids separating from cooling fuels, and the interrelationships among fuel physical inspections. For inclusion in the results, an inference equation with two independent variables must have a minimum 0.79 fraction of explained variance; with a single independent variable, a minimum 0.69 fraction of explained variance is sufficient. Included in the appendix are inference equations with two and one independent variables having 0.69 and 0.59 minimum fractions of explained variance, respectively.

Hydrocarbon Composition of Fuels

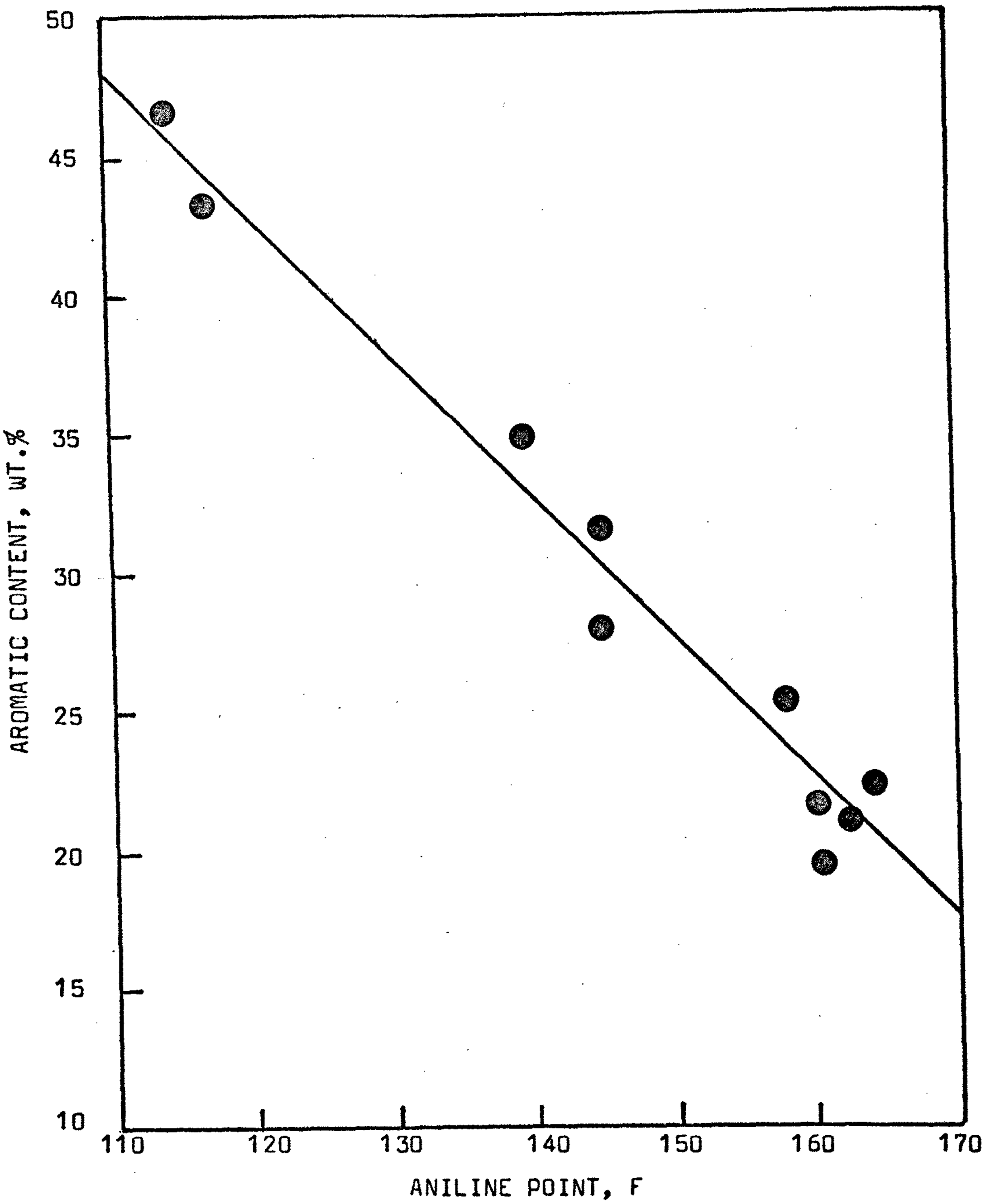
The starting point for approximating hydrocarbon composition is aromatic content as the empirical equation for this characteristic yields a higher fraction explained than for either naphthenic or paraffinic content. Aromatic content covaries negatively with aniline point according to:

$$\text{Aromatics (wt\%)} = 104 - 0.510\ \text{Aniline(F)}$$

for a 0.96 fraction of explained variance (Figure 1). The correlation coefficient is -0.98; other correlation coefficients include those with the Watson Characterization Factor at -0.96, API gravity at -0.79, and volumetric average boiling point at +0.85. Aromatic contents of the sample fuels average 30 wt.% and vary from

FIGURE 1

AROMATICS = 104.36 - 0.5103 ANILINE



19 to 47 wt.%. Thus, aliphatic hydrocarbons, the naphthenes and paraffins, are the predominant constituents of the middle distillate fuels averaging 70 wt.% and varying from 53 to 81 wt.% (Tables X, XI, XXXIX)

The naphthenic hydrocarbon content covaries with volumetric average boiling point and aromatic content or aniline point. To achieve a 0.87 fraction of explained variance, the equation has the form

$$\text{Naphthenes (wt\%)} = -57.4 + 0.191 \text{ Dist. VABP(F)} - 0.374 \text{ Aromatics (wt\%)}$$

(Figure 2). Alternatively,

$$\text{Naphthenes (wt\%)} = -94.0 + 0.188 \text{ Dist. VABP(F)} + 0.184 \text{ Aniline(F)}$$

for a lower 0.84 fraction of explained variance and a lower determinant of the correlation matrix. The equation relating naphthenic content solely to volumetric average boiling point yields a 0.72 fraction of explained variance. Naphthenic contents for the sample fuels average 32 wt.% and vary from 20 to 47 wt.% (Tables X, XII, XXXIX).

Paraffinic hydrocarbon content is best determined by difference after calculating the aromatic and naphthenic hydrocarbon contents.

$$\text{Paraffins (wt\%)} = 100 - \text{Aromatics (wt\%)} - \text{Naphthenes (wt\%)}$$

Alternatively, paraffinic content is determined from

$$\text{Paraffins (wt\%)} = -8.0 + 1.60 \text{ Gravity (API)} - 0.312 \text{ Naphthenes (wt\%)}$$

which has a 0.82 fraction of explained variance (Figure 3). The correlation coefficient for paraffinic content and API gravity

FIGURE 2

NAPHTHENES = -57.38 + 0.1910 DIST. VABP - 0.3744 AROMATICS

▲ NAPHTHENES = -106.34 + 0.2632 DIST. VABP

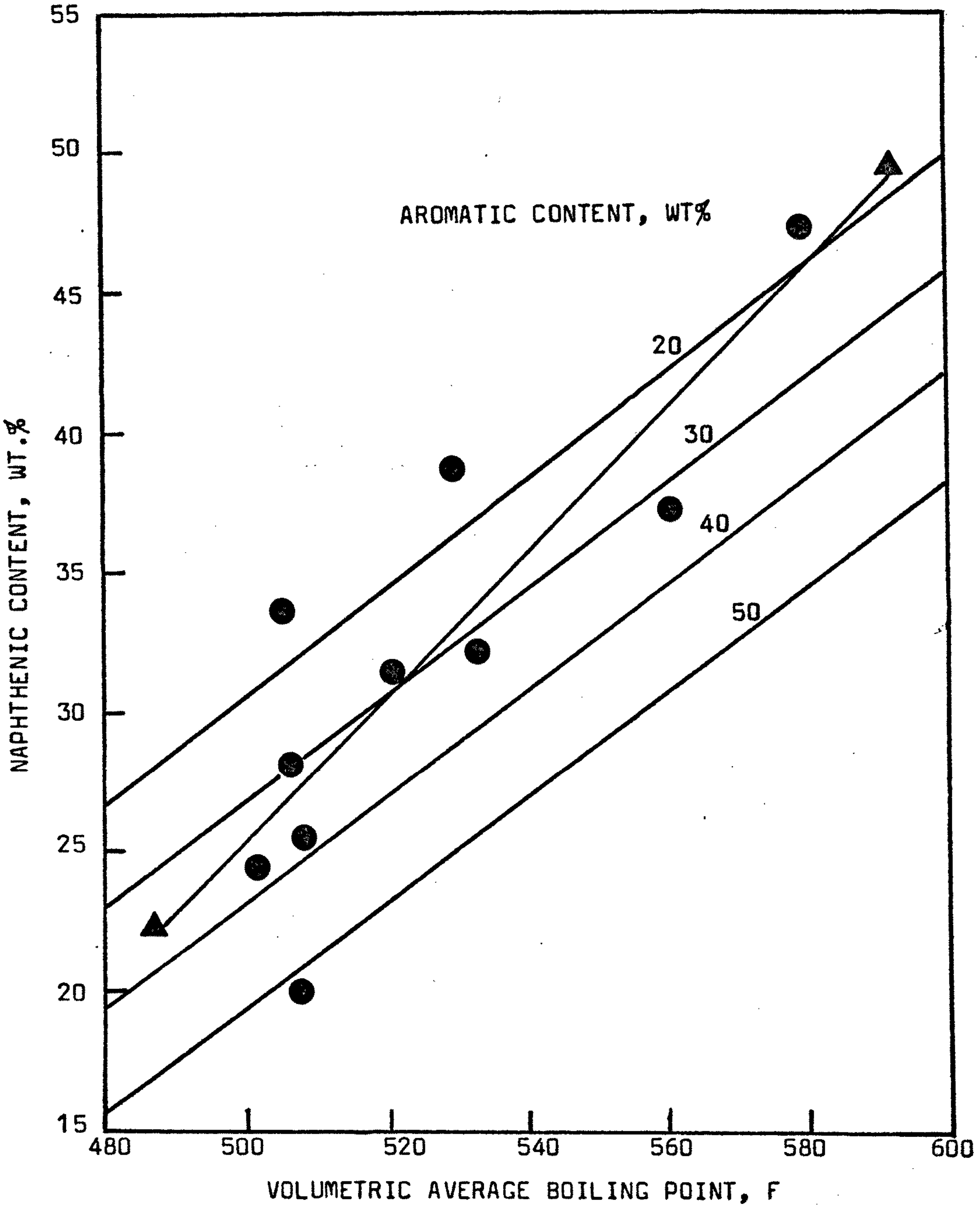
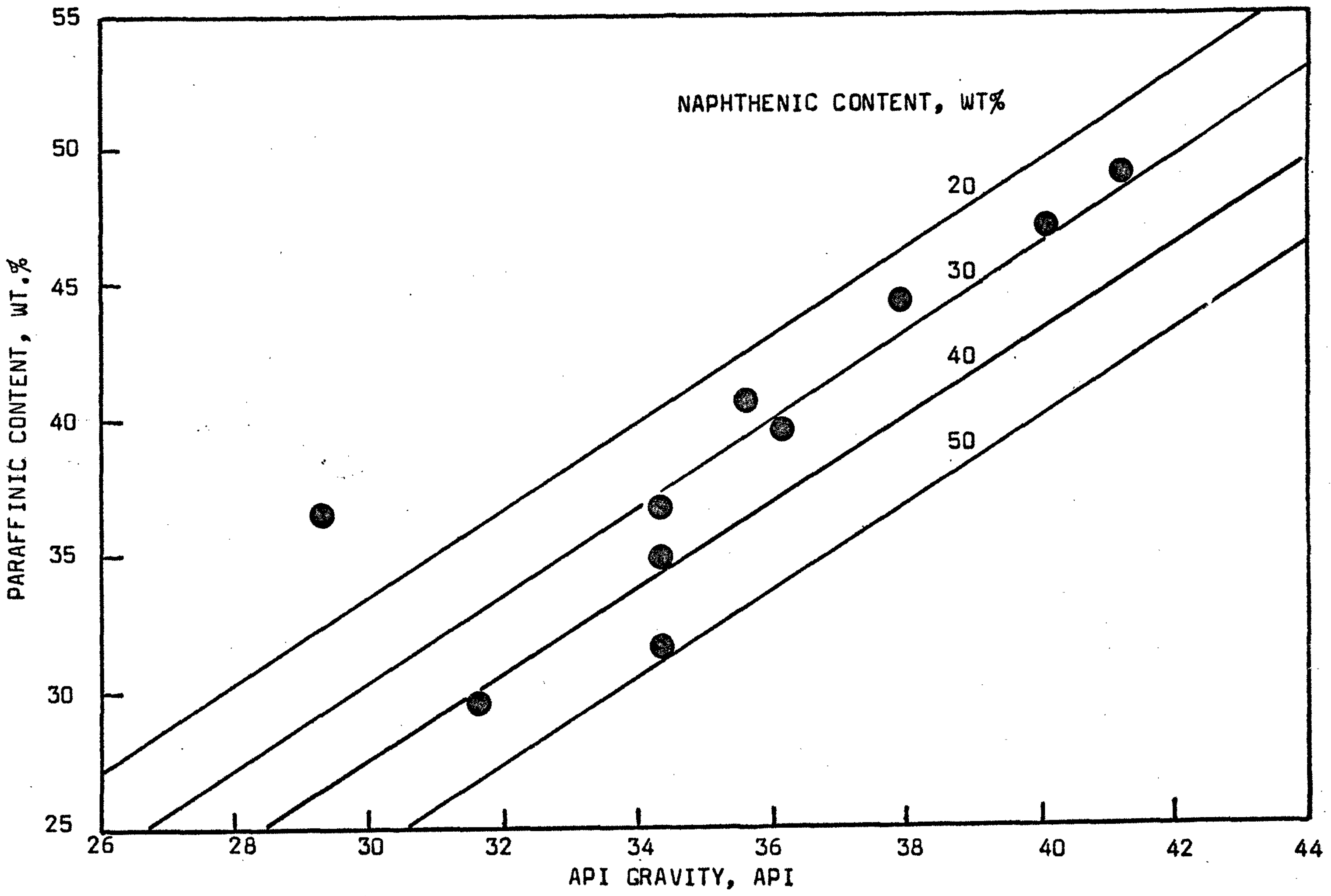


FIGURE 3

PARAFFINS = -7.986 + 1,594 GRAVITY - 0.3121 NAPHTHENES



is also +0.82; however, the equation incorporating only API gravity has a reduced 0.67 fraction of explained variance. Paraffinic contents for the sample fuels average 39 wt.% and vary from 30 to 49 wt.% (Tables X, XII, XXXIX).

The paraffinic hydrocarbon content is composed of n-paraffins and iso-paraffins. In the sample fuels, n-paraffins average 19 wt.% and vary from 11 to 24 wt.%; conversely, iso-paraffins average 20 wt.% and vary from 13 to 26 wt.%. Thus, in the majority of the sample fuels, the n- and iso-paraffins are present in approximately equal concentrations, the difference averaging 1 wt.% (Table X).

The content of n-paraffins has a +0.79 correlation coefficient with total paraffinic hydrocarbon content. The inference equation is

$$\text{n-Paraffins (wt\%)} = 54.2 + 0.770\ \text{Paraffins (wt\%)} - 0.104\ \text{Dist. 90\% (F)}$$

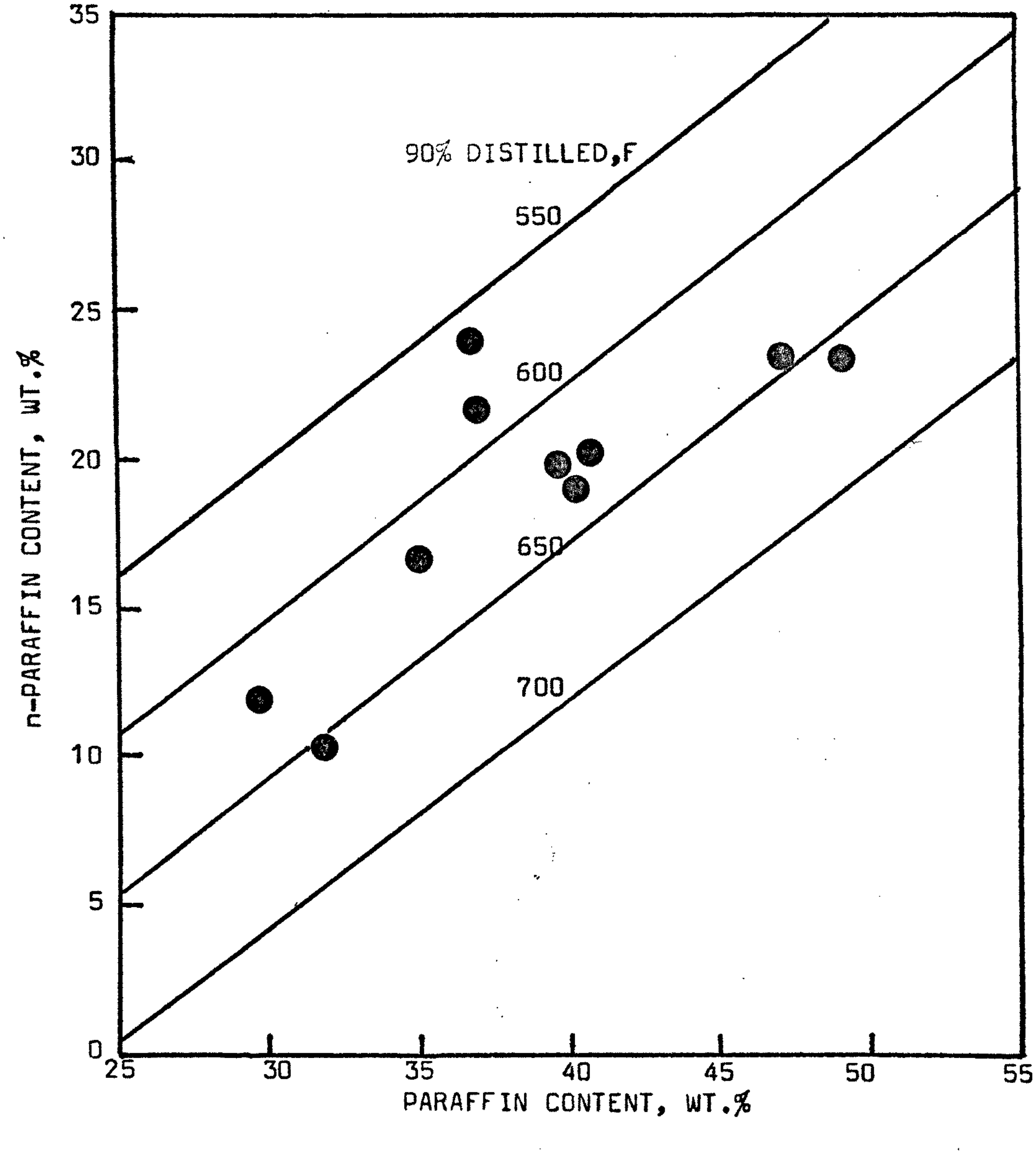
for a fraction of explained variance of 0.85 (Figure 4). Additionally, n-paraffins are approximated using naphthenes, aromatics, or cloud point as the second independent variable; the fraction of explained variance averages 0.77. With paraffinic content the sole independent variable, the fraction of explained variance reduces to 0.62 (Tables XIV, XXXIX).

Chain lengths detected for the n-paraffins span 8 to 28 carbon numbers. The median number averages 15 and varies from 13 to 16; it is approximated with the equation

$$\text{n-P Median} = 9.32 - 0.0967\ \text{Paraffins (wt\%)} + 0.0178\ \text{Dist. VABP (F)}$$

FIGURE 4

n-PARAFFINS = 54.16 + 0.7702 PARAFFINS - 0.1040 DIST. 90%



at a 0.89 fraction of explained variance (Figure 5). The correlation coefficient is -0.81; however, with paraffinic content the sole independent variable, the fraction of explained variance is 0.65. Alternatively, the median n-paraffin carbon number is approximated by the equation

$$\text{n-P Median} = 18.8 - 0.020 \text{ n-Paraffins (wt.\%)} - 0.658 \text{ Dist. Slope (F/\%)}$$

for a lower 0.84 fraction of explained variance. With n-paraffins the sole independent variable, the fraction of explained variance reduces to 0.58 (Tables X, XV, XXI-XXX, XXXIX).

The semi-interquartile range associated with the median n-paraffin carbon number averages 2.3 and varies from 1.5 to 3.0. The range has correlation coefficients with distillation slope and 10% point of +0.98 and -0.88, respectively; the inference equation using the distillation slope is

$$\text{n-P Range} = 0.389 + 0.704 \text{ Dist. Slope (F/\%)}$$

for a 0.96 fraction of explained variance (Figure 6). The 25 and 75% quartiles are approximated at lower 0.87 and 0.83 fractions of explained variance, respectively (Tables X, XVI, XXXIX).

The equation for the n-paraffin 25% carbon number is

$$\text{n-P } 25\% = 17.9 - 1.37 \text{ Dist. Slope (F/\%)} - 0.0880 \text{ n-Paraffins (wt\%)}$$

(Figure 7). The correlation coefficient with distillation slope is -0.88, and the inference equation incorporating only that variable yields a 0.77 fraction of explained variance; a +0.87

FIGURE 9

n-P MEDIAN = 9.324 - 0.09665 PARAFFINS + 0.01783 DIST. VABP

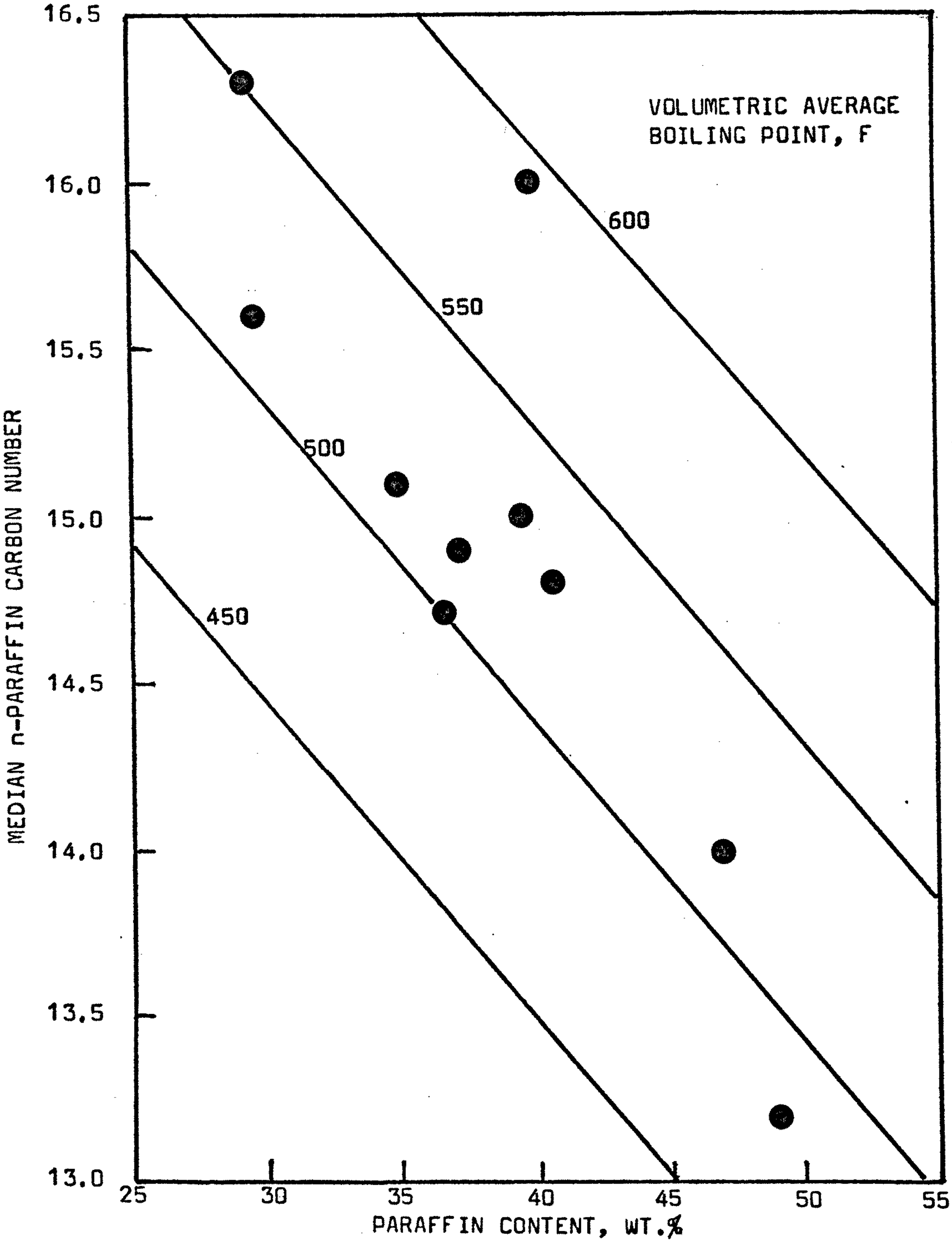


FIGURE 6

n-P RANGE = 0.389 + 0.704 DIST. SLOPE

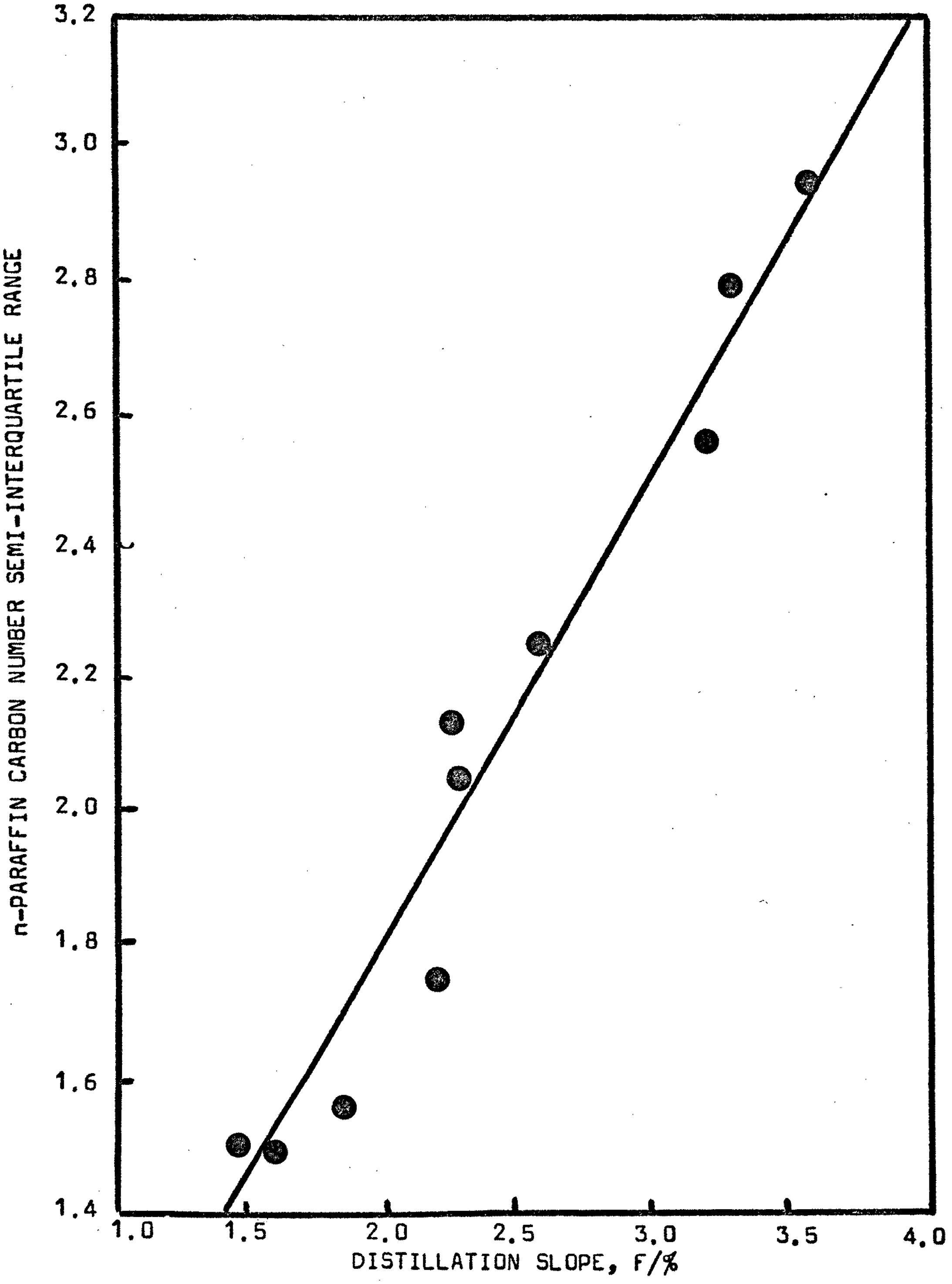
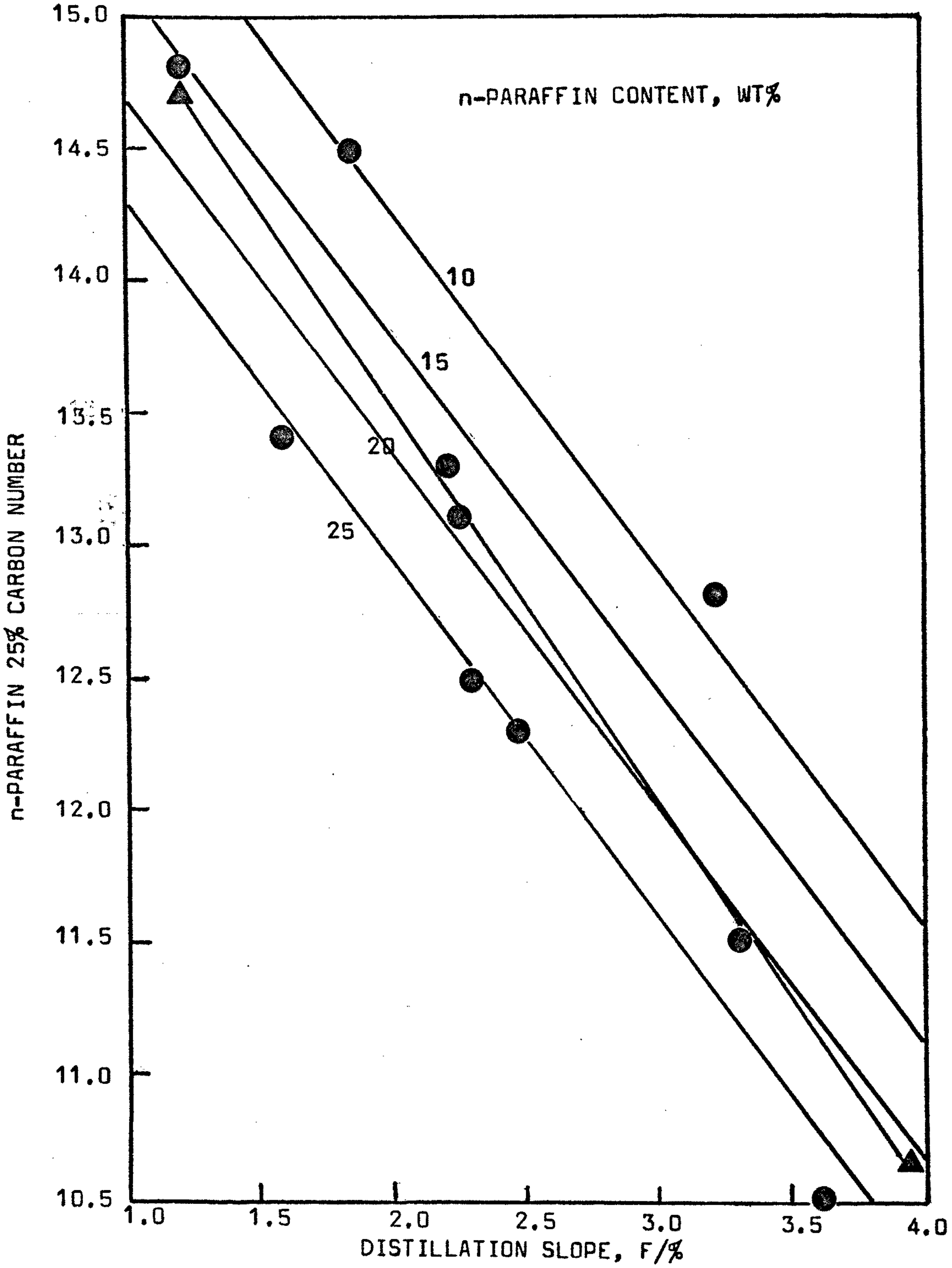


FIGURE 7

n-P 25% = 17.87 - 1.366 DIST. SLOPE - 0.08795 n-PARAFFINS

▲ n-P 25% = 16.57 - 1.520 DIST. SLOPE



correlation exists with the distillation 10% point. The n-paraffin 75% carbon number is approximated by

$$\text{n-P } 75\% = 18.6 - 0.116 \text{ n-Paraffins (wt\%)} + 0.142 \text{ n-P @-20F (wt\%)}$$

(Figure 8). The correlation coefficient with n-paraffins is -0.81, and the inference equation incorporating only that variable yields a 0.65 fraction of explained variance. In the sample fuels, the n-paraffin 25% carbon number averages 13 and varies from 11 to 15; the 75% carbon number averages 17 and varies from 16 to 18 (Tables X, XVII, XVIII, XXXIX)

The n-paraffin carbon number distribution variables are interrelated by the equation

$$\text{n-P Median} = -0.876 + 0.543 \text{ n-P } 25\% + 0.524 \text{ n-P } 75\%$$

for a 0.92 fraction of explained variance. The median and 25% n-paraffin carbon numbers have a+0.92 correlation coefficient. The equation relating solely these variables is

$$\text{n-P Median} = 6.49 + 0.658 \text{ n-P } 25\%$$

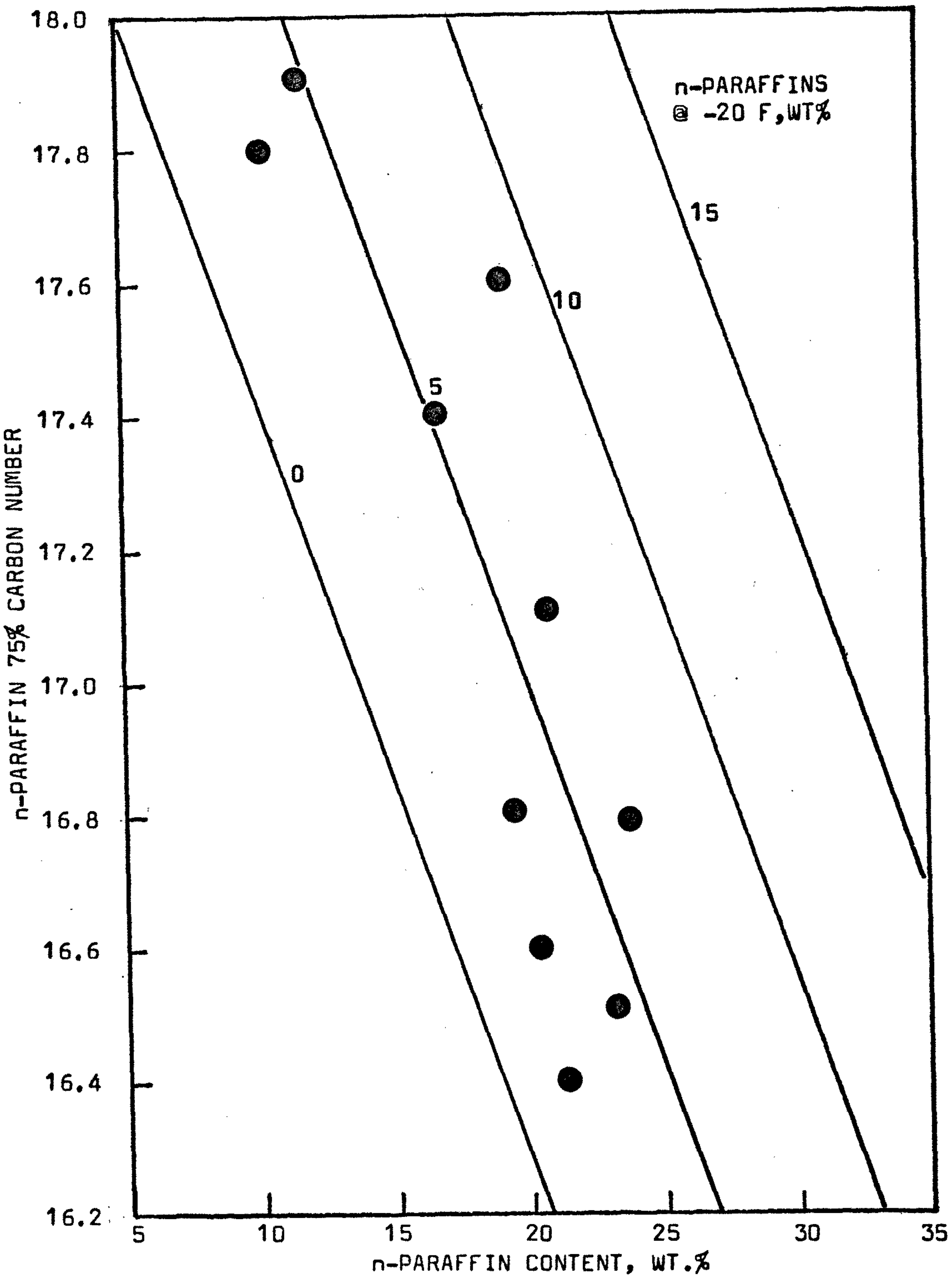
which has a 0.84 fraction of explained variance (Tables XV, XXXIX).

Composition of Separating Solids

The separation of solids from cooling middle distillate fuels initiates at the fuel cloud point. Cloud points of the sample fuels average +11 F and vary from -8 to +22 F. At -20 F, solids separated from the fuels average 6 wt.%, varying from 3 to 12 wt.%. The

FIGURE 8

n-P 75% = 18.61 - 0.1158 n-PARAFFINS + 0.1425 n-P @ 20 F



n-paraffins in these solids comprise an average 81%; on a fuel basis, the n-paraffins average 5 wt.% and vary from 3 to 9 wt.% (Tables XIX, XXI-XXX).

At -40 F, solids separated from the fuels increase to average 12 wt.% and vary from 5 to 23 wt.%. The paraffinic hydrocarbons average 80 wt%, comprised of 70/10 n-paraffins/iso-paraffins. Naphthenic and aromatic hydrocarbons average 15 and 5 wt.%, respectively. On a fuel basis, the paraffins average 9 wt.%, comprised of 8/1 n-paraffins/iso-paraffins; paraffins vary from 5 to 17 wt.%, comprised of wt.% from 5 to 14 and from 0 to 3 n-paraffins and iso-paraffins, respectively. Naphthenic hydrocarbons average 2 wt.% and vary from 0 to 5 wt.%; aromatic hydrocarbons average 1 wt.% and vary from 0 to 2 wt.% (Tables XIX, XXI-XXX)

Over the temperature span from the fuel cloud points to -40 F, the highest carbon number n-paraffin separating from a given fuel averages 26 and varies from 21 to 28; the lowest averages 11 and varies from 11 to 14. At the cloud point, the median n-paraffin carbon number averages 20 and varies from 17 to 22; the semi-interquartile range associated with this median averages 1.0 and varies from 0.8 to 1.3. At -20 F, the median n-paraffin carbon number decreases to average 18 and varies from 17 to 20; the associated semi-interquartile range increases to average 1.2 and varies from 0.9 to 1.6. At -40 F, the median n-paraffin carbon number further decreases to average 17 and varies from 16 to 18; the associated semi-interquartile range further increases to average 1.4 and varies from 0.9 to 1.9 (Figures 9-18)

FIGURE 9

CUMULATIVE n-PARAFFIN CARBON NUMBER DISTRIBUTION FOR FUEL NO. 1
CLOUD POINT: +12 F

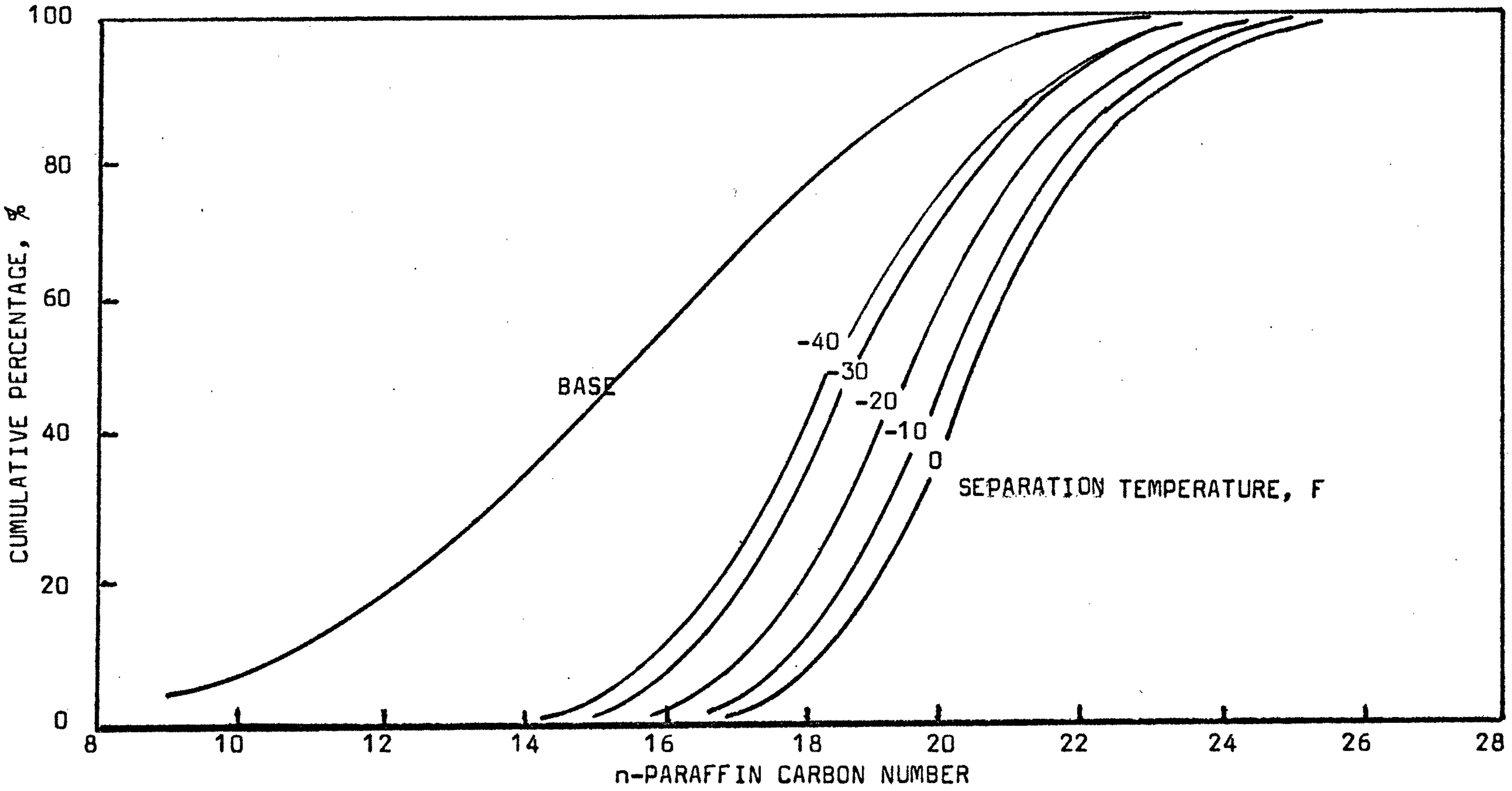


FIGURE 10

CUMULATIVE n-PARAFFIN CARBON NUMBER DISTRIBUTION FOR FUEL NO. 2
CLOUD POINT: +14 F

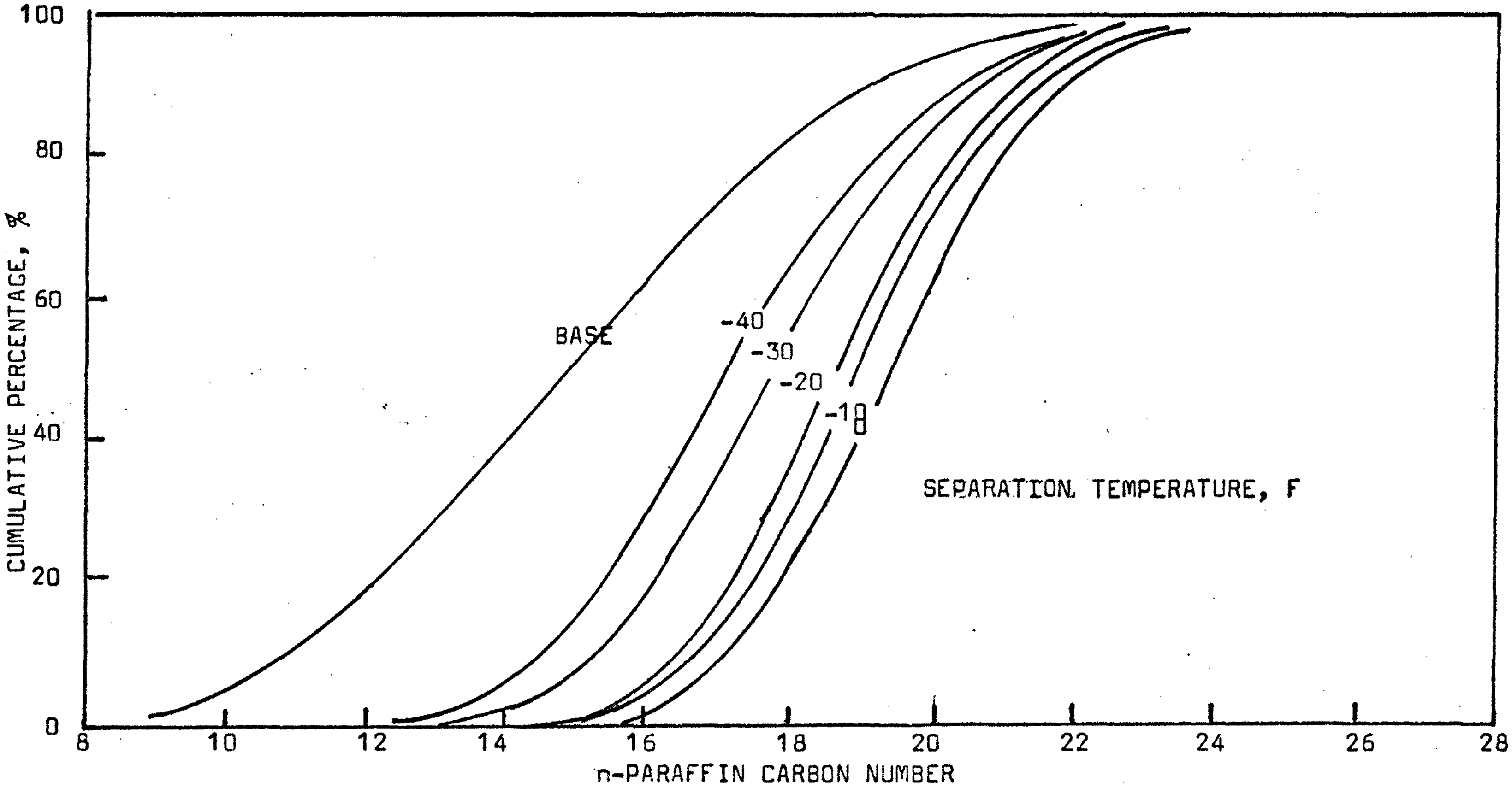


FIGURE 11

CUMULATIVE n-PARAFFIN CARBON NUMBER DISTRIBUTION FOR FUEL NO. 3
CLOUD POINT: +10 F

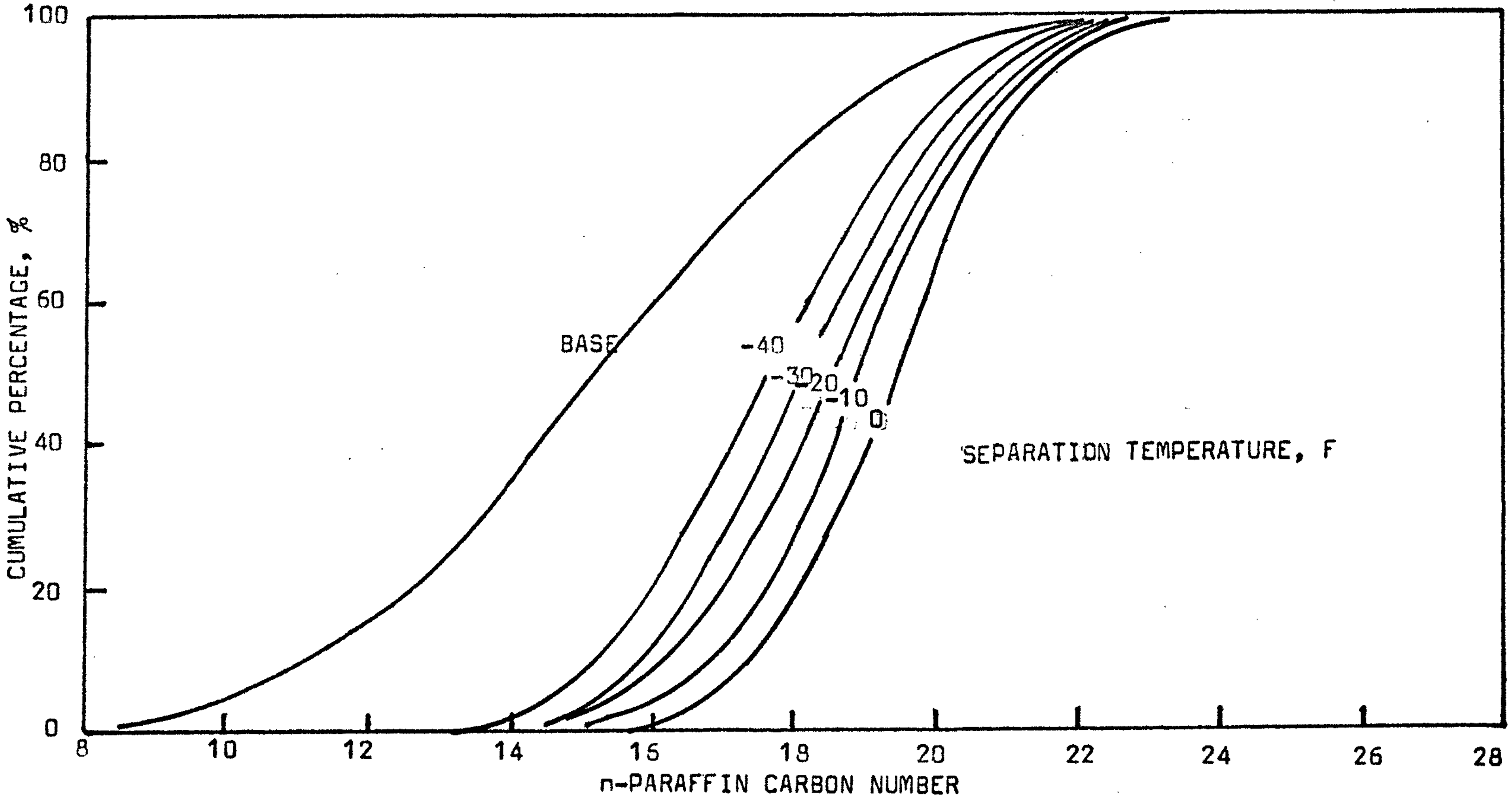


FIGURE 12

CUMULATIVE n-PARAFFIN CARBON NUMBER DISTRIBUTION FOR FUEL NO. 4
CLOUD POINT: +4 F

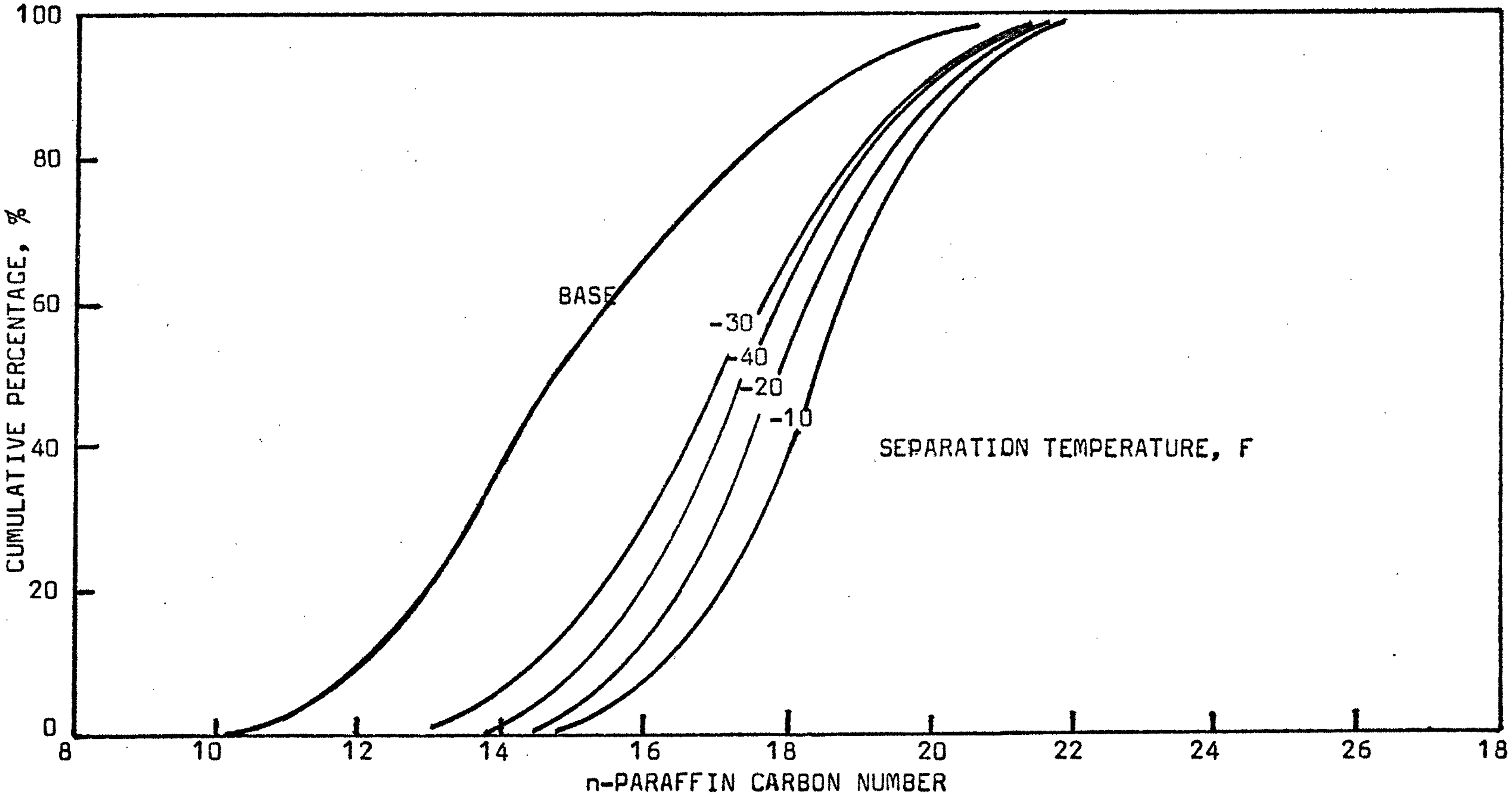


FIGURE 13

CUMULATIVE n-PARAFFIN CARBON NUMBER DISTRIBUTION FOR FUEL NO. 5
CLOUD POINT: -8 F

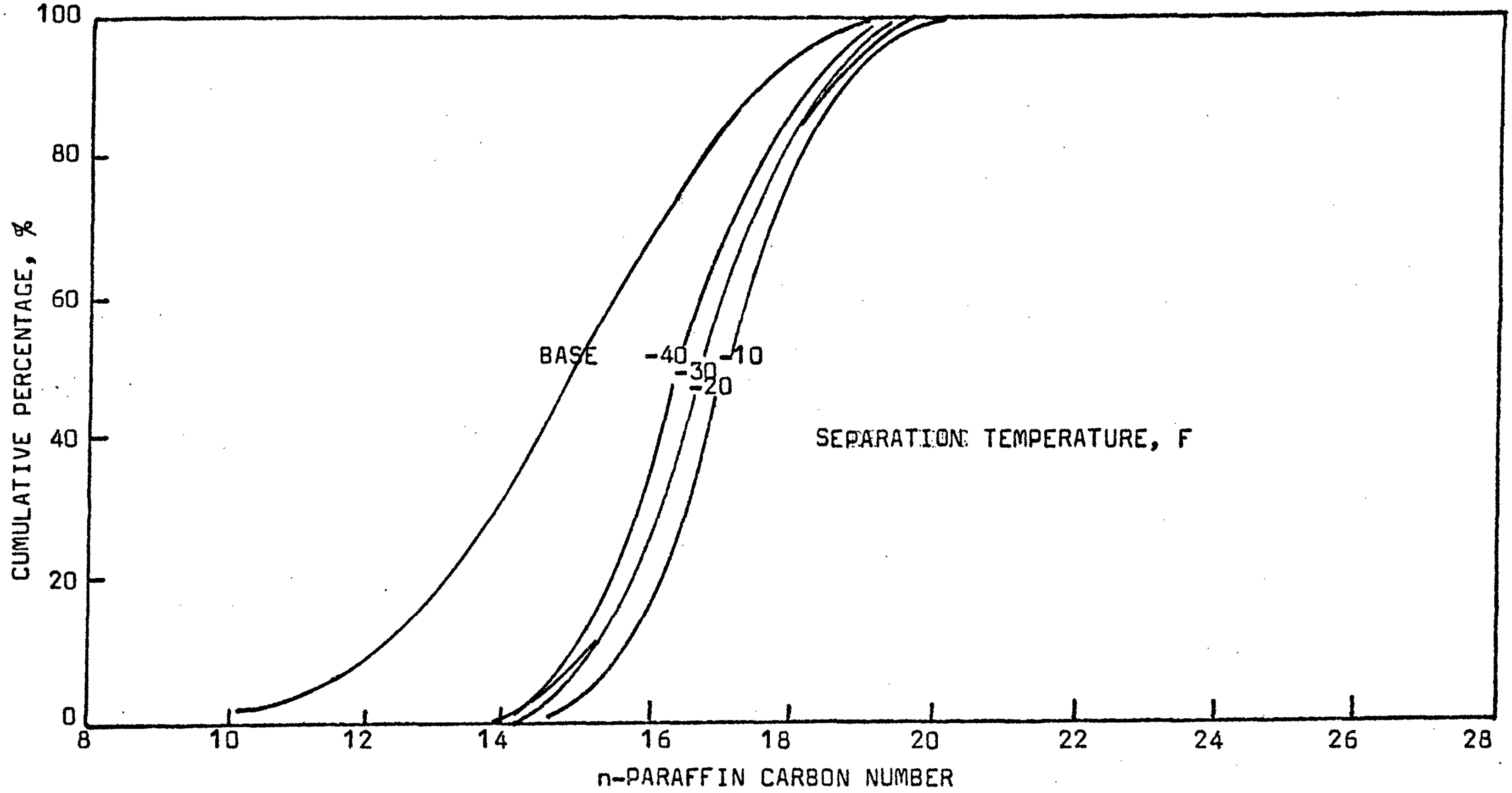


FIGURE 14

CUMULATIVE n-PARAFFIN CARBON NUMBER DISTRIBUTION FOR FUEL NO. 6
CLOUD POINT: +22 F

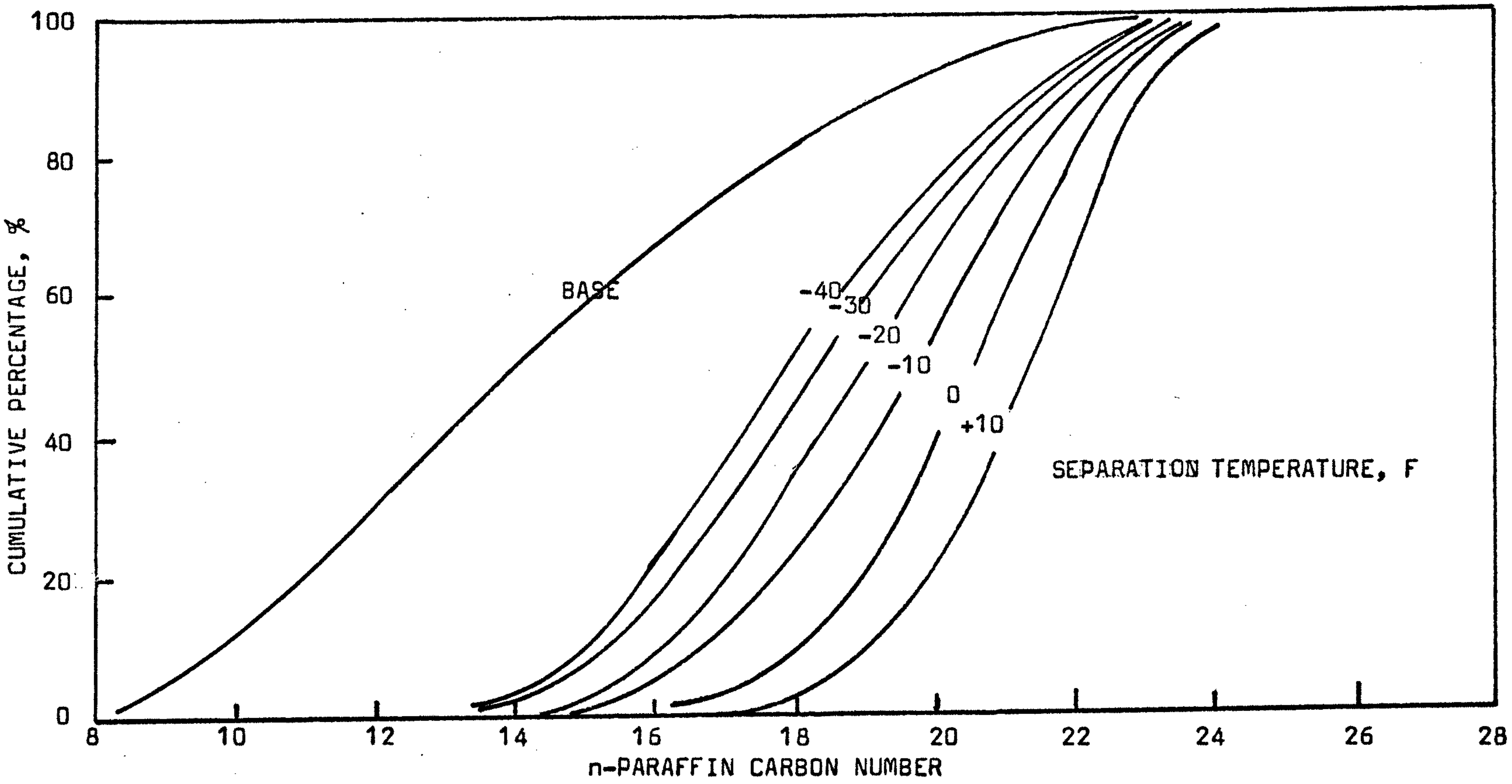


FIGURE 15

CUMULATIVE n-PARAFFIN CARBON NUMBER DISTRIBUTION FOR FUEL NO. 7
CLOUD POINT: +18 F

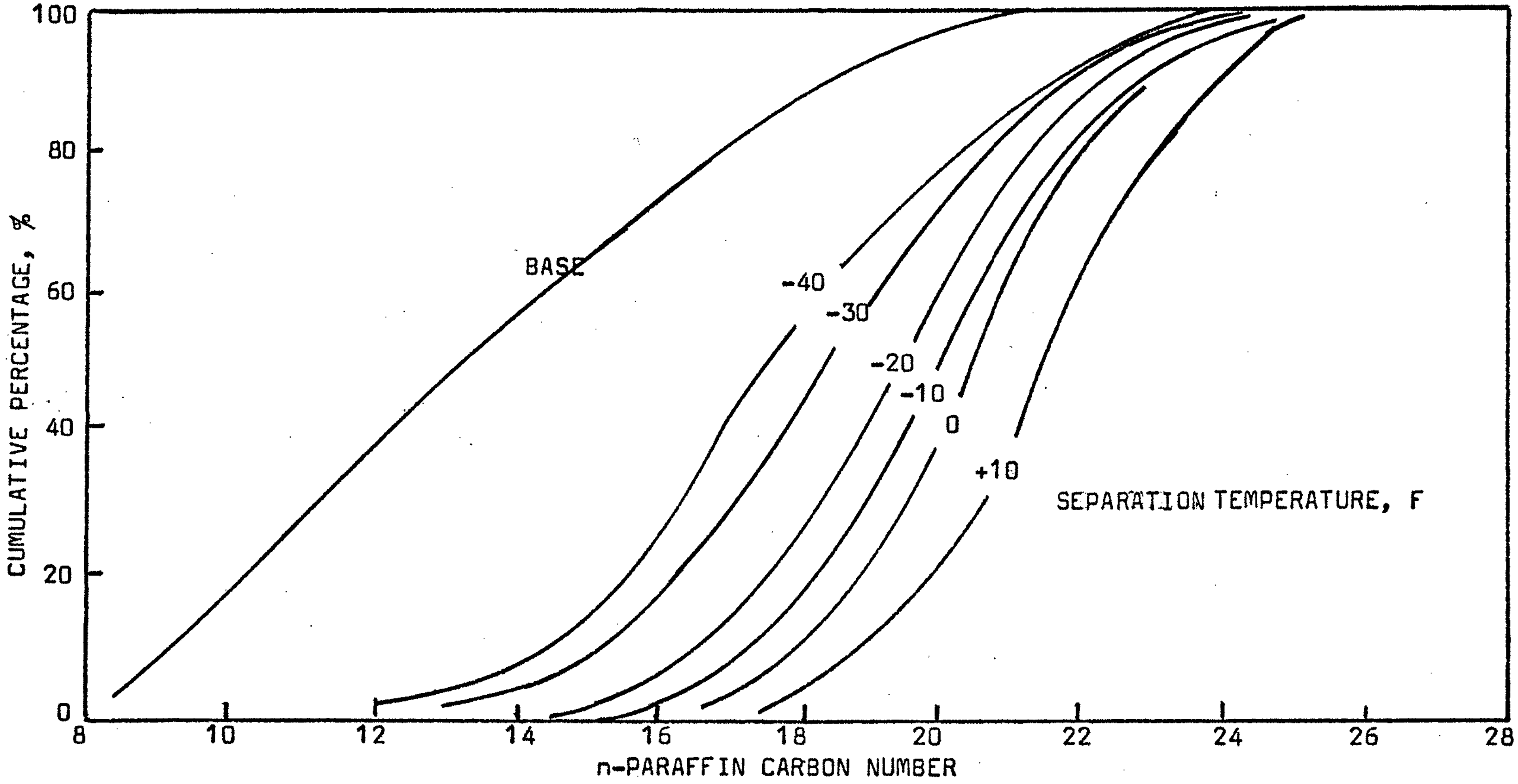


FIGURE 16

CUMULATIVE n-PARAFFIN CARBON NUMBER DISTRIBUTION FOR FUEL NO. 8
CLOUD POINT: +12 F

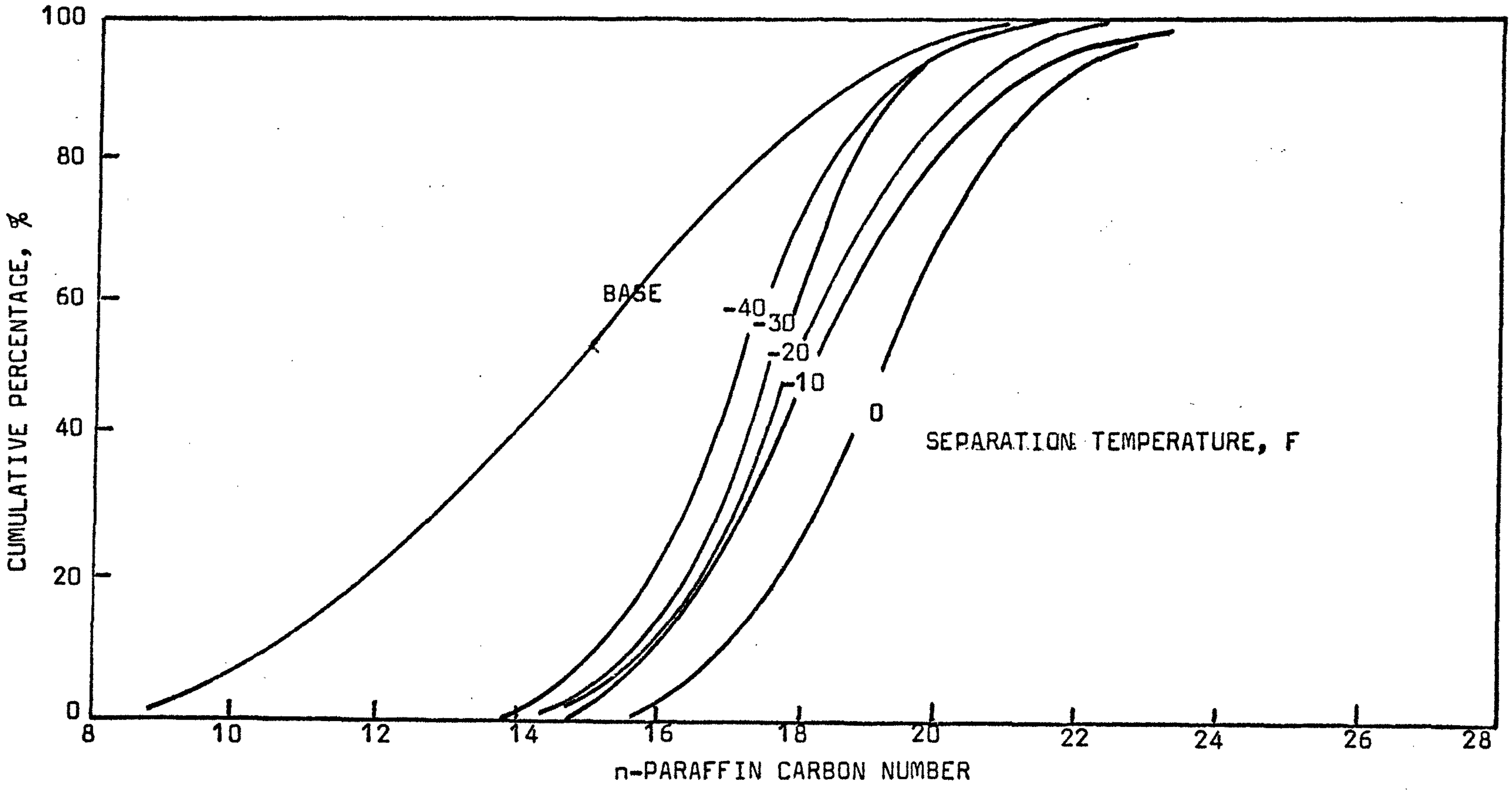


FIGURE 17

CUMULATIVE n-PARAFFIN CARBON NUMBER DISTRIBUTION FOR FUEL NO. 9
CLOUD POINT: +8 F

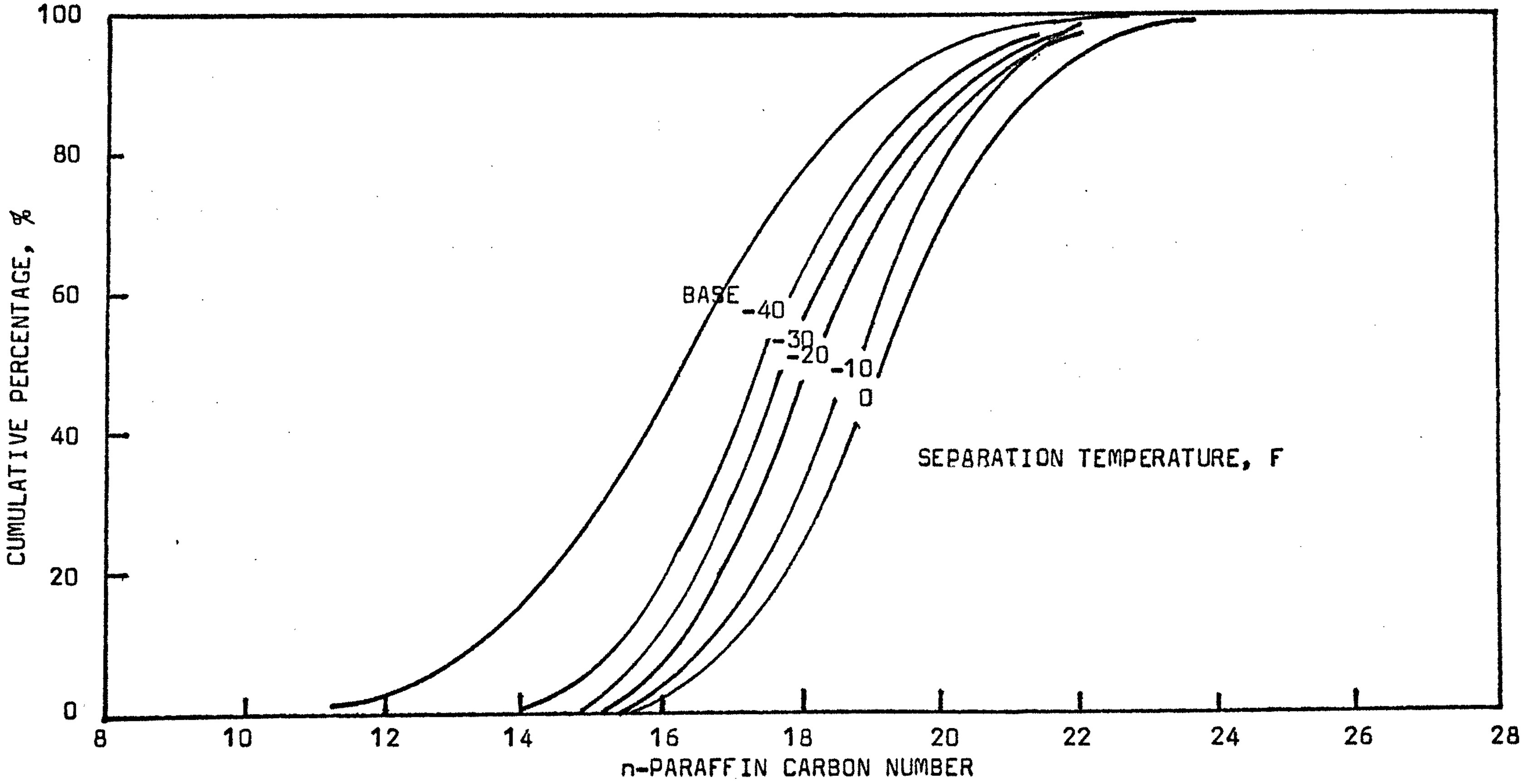
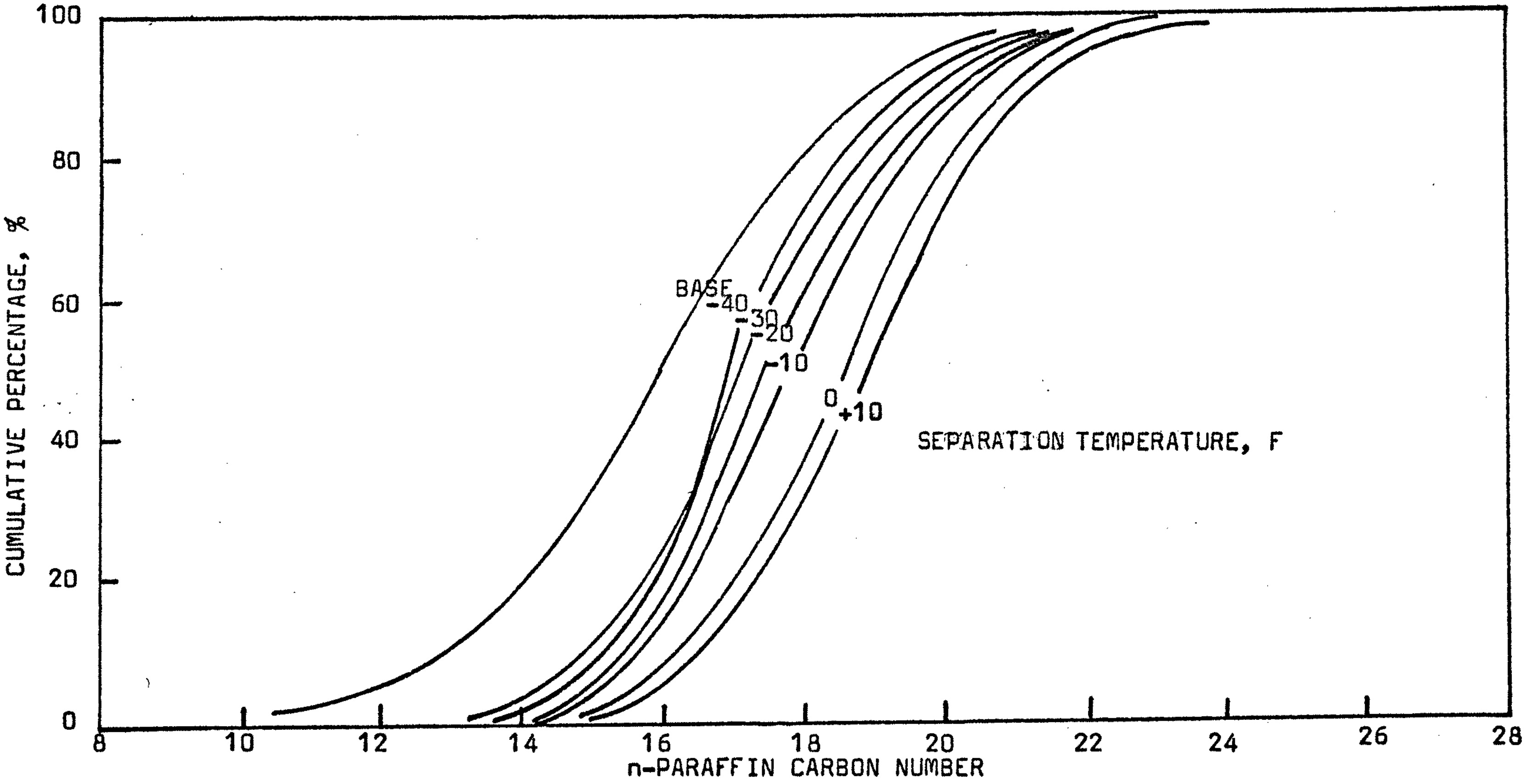


FIGURE 18

CUMULATIVE n-PARAFFIN CARBON NUMBER DISTRIBUTION FOR FUEL NO. 10
CLOUD POINT: +18 F



(Tables XIX-XXX). The following equations approximate the change in these values as fuels cool to lower temperatures; additionally, the change in median n-paraffin carbon number can be utilized to approximate the total n-paraffin separation rate.

The median n-paraffin carbon number has a correlation coefficient with the cloud point of +0.83. Including the 10% distillation point or the volumetric average boiling point with the cloud point yields the inference equations

C Med. Init. = 23.8 + 0.127 Cloud (F) - 0.0121 Dist. 10% (F)

C Med. Init. = 28.7 + 0.154 Cloud (F) - 0.0197 Dist. VABP (F)

for 0.82 and 0.79 fractions of explained variance, respectively. (Figure 19). A +0.84 correlation coefficient exists between this median carbon number and distillation slope. Inference equations incorporating this variable are

C Med. Init.= -1.86 + 1.24 Dist. Slope(F/%) + 0.0302 Dist. 90% (F)

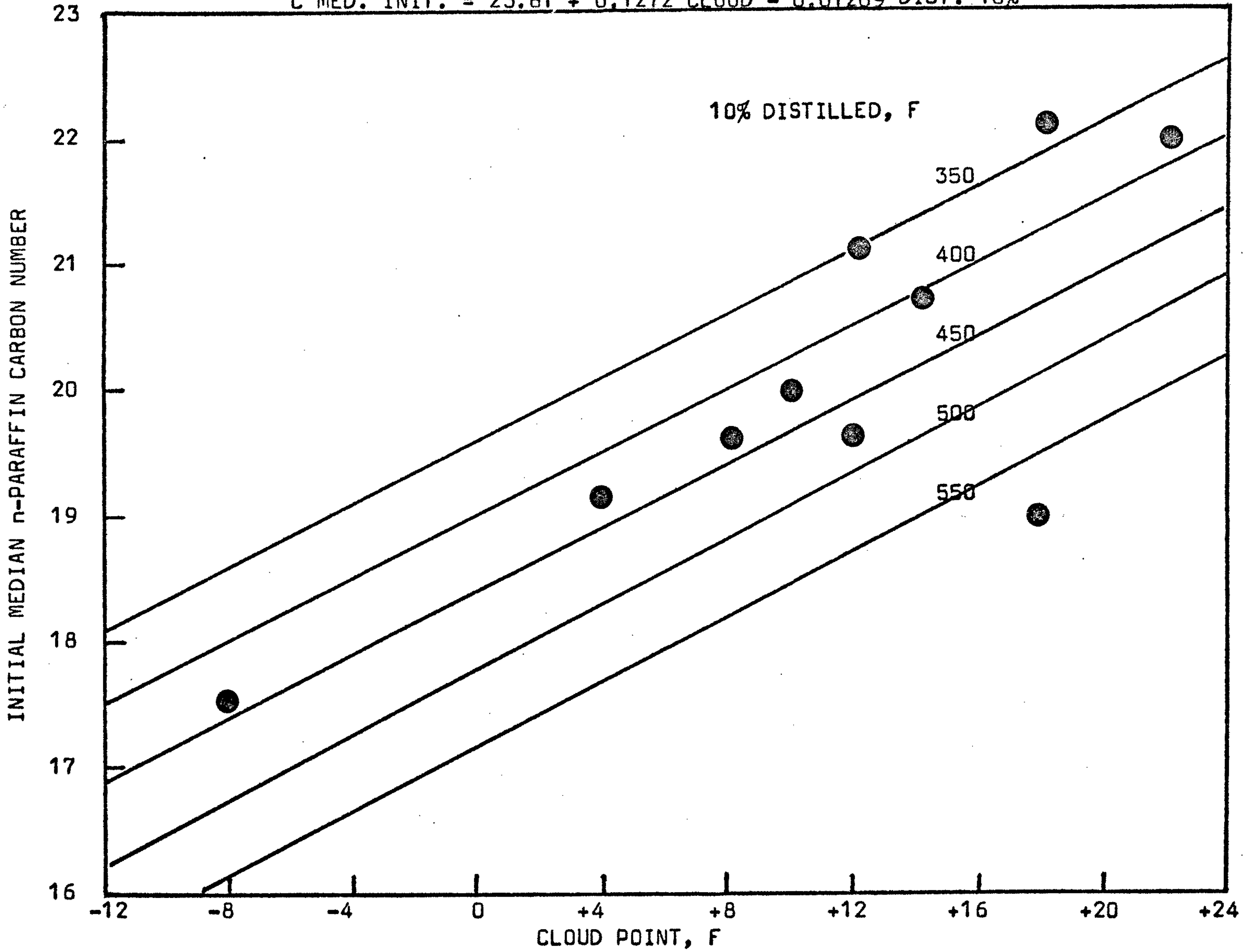
C Med. Init.= 16.3 + 1.145 Dist. Slope(F/%) + 0.0883 Cloud (F)

C Med. Init.= -0.357 + 2.40 Dist. Slope(F/%) + 0.0276 Dist. VABP (F)

Although the average fraction of explained variance is 0.86, the determinate of the correlation matrix is lower with each equation than with the previous two equations. Using only distillation slope as the independent variable yields a 0.72 fraction of explained variance. Finally, a +0.80 correlation also exists with the distillation 90% point (Tables XX, XL).

FIGURE 19

C MED. INIT. = 23.81 + 0.1272 CLOUD - 0.01209 DIST. 10%



When the fuel cools, the median carbon number of the accumulated separating n-paraffins is reduced. The absolute rate of change of median n-paraffin carbon number with temperature averages 0.05 C/ F and varies from 0.02 to 0.08 C/ F, expressing the temperature change as the number of degrees below the fuel cloud points. The inference equation is

$$|\text{C Med. Rate}|\ (|\text{C/ F}|) = 0.138 + 0.00152\ \text{Cloud (F)} - 0.000196\ \text{Dist. VABP (F)}$$

for a 0.69 fraction of explained variance (Figure 20). Without the volumetric average boiling point, the fraction of explained variance is 0.59 (Tables XX, XXXIII).

The initial and absolute rates of change of the median n-paraffin carbon number are interrelated by

$$\text{C Med. Init.} = 5.01 + 91.8\,|\text{C Med. Rate}|\,(|\text{C/ F}|) = 0.601\ \text{n-P}\ 75\%$$

for a fraction of explained variance of 0.95 (Figure 21). With the rate of change as the single independent variable,

$$\text{C Med. Init.} = 15.4 + 89.9\,|\text{C Med. Rate}|\,(|\text{C/ F}|)$$

for a 0.90 fraction of explained variance. Additionally, the initial median carbon number is approximated by

$$\text{C Med. Init.} = 3.43 - 1.29\ \text{n-P}\ 25\% + 1.95\ \text{n-P}\ 75\%$$

for a 0.82 fraction of explained variance (Tables XXXII, XXXIII, XXXVI, XXXVII).

FIGURE 20

|C MED. RATE| = 0.1376 + 0.001524 CLOUD − 0.0001960 DIST. VABP

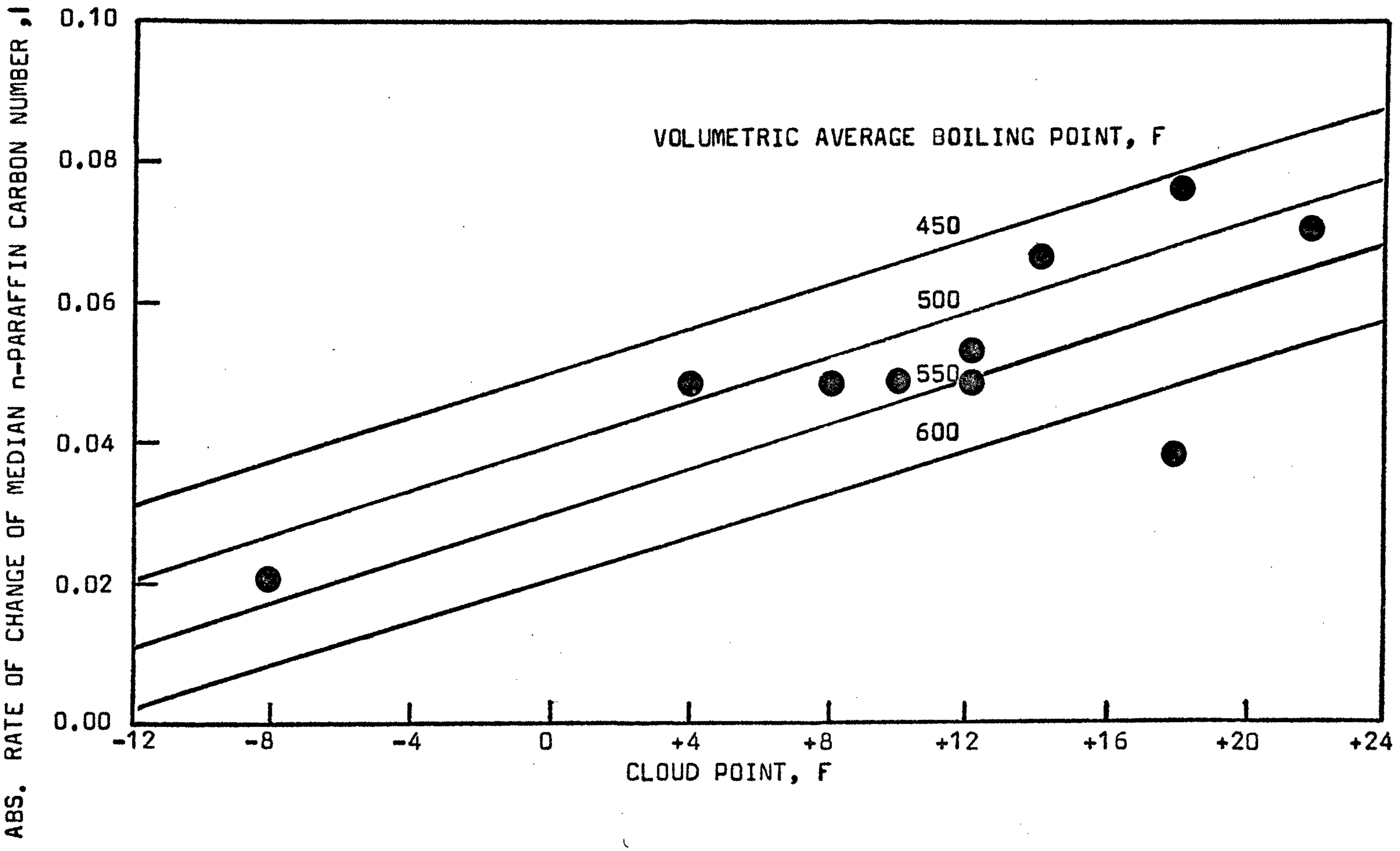
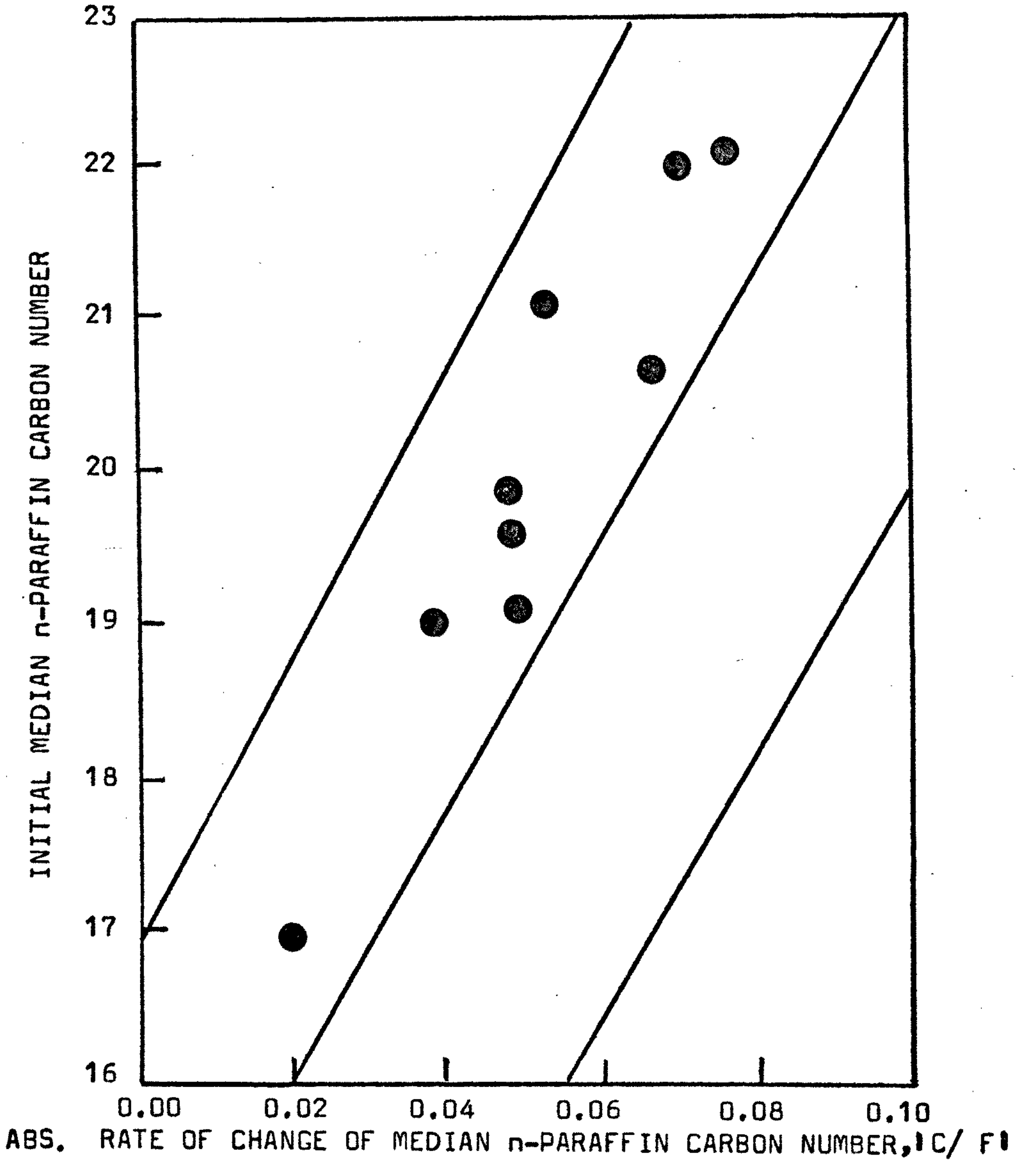


FIGURE 21

C MED. INIT. = 5.012 + 91.77|C MED. RATE|+ 0.6016 n-P 75%



Most significantly, decreasing the fuel temperature below the cloud point also brings increasing concentrations of n-paraffins separating from the fuel. The concentration of n-paraffins is approximated using the fuel cloud point as the initial point, at which separation equals zero, and the inference equation for separation rate

n-P Sep.(wt%/F) = 0.195 - 3.33|C Med. Rate|(|C/F|) + 0.00767 n-Paraffins(wt%)

for a 0.84 fraction of explained variance (Figure 22). With paraffin concentration as the second independent variable, the fraction of explained variance remains almost the same at 0.85, but the determinant of the correlation matrix is lowered.

n-P Sep.(wt%/F) = 0.122 - 4.44|C Med. Rate|(|C/F|) + 0.00715 Paraffins(wt%)

Alternatively, with the initial median carbon number as the first independent variable

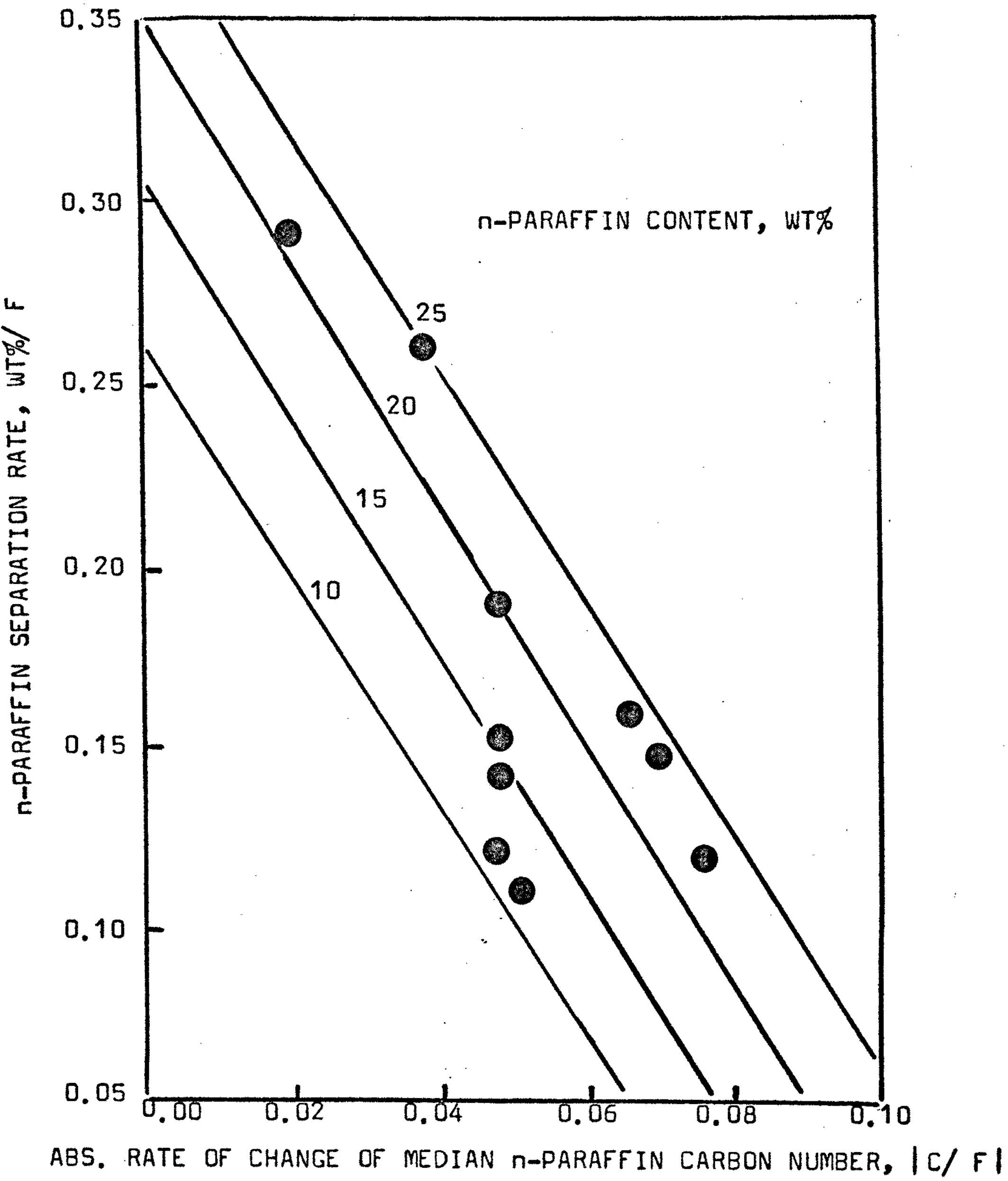
n-P Sep.(wt%/F) = 0.726 - 0.0332 C Med. Init. + 0.00570 n-Paraffins(wt%)
n-P Sep.(wt%/F) = 0.814 - 0.0422 C Med. Init. + 0.00522 Paraffins(wt%)

for an average 0.80 fraction of explained variance. With the initial median carbon number as the sole independent variable, the fraction of explained variance is reduced to 0.62. The n-paraffin separation rate from cooling fuels averages 0.2 wt.%/F and varies from 0.1 to 0.3 wt.%/F (Tables XIX, XXXI).

As the concentration of n-paraffins increases in the cooling fuels, the n-paraffin carbon number semi-interquartile range increases at an

FIGURE 22

n-P SEP. = 0.1950 - 3.328 |C MED. RATE| + 0.007669 n-PARAFFINS



average rate of 0.008 C/ F; it varies from nil to 0.018 C/ F. The inference equation

$$\text{C Range Rate (C/F)} = 0.0182 + 0.304\,|\text{C Med Rate}|\,(|\text{C/ F}|) - 0.0259\ \text{C Range Init.}$$

has a fraction of explained variance of 0.92 (Figure 23); as before, the temperature change is expressed as the number of degrees below fuel cloud points. This equation requires simultaneous solution with the equation for the initial median n-paraffin carbon number,

$$\text{C Range Init.} = 1.02 - 22.0\ \text{C Range Rate (C/ F)} + 0.0140\ \text{Cloud (F)}$$

which has a 0.84 fraction of explained variance (Figure 24) (Tables XX, XXXIV, XXXV).

Interrelationships Among Inspections

In addition to inference equations for the hydrocarbon composition of and the n-paraffin separation from middle distillate fuels, inference equations can approximate interrelationships among the fuel physical inspections. The API gravity and aniline point have a 0.79 correlation coefficient and the inference equation

$$\text{Gravity(API)} = 26.4 + 0.198\ \text{Aniline (F)} - 0.0462\ \text{Dist. 10\% (F)}$$

has a 0.97 fraction of explained variance (Figure 25). With aniline point as the sole independent variable, the fraction of explained variance is reduced to 0.62. The gravities of the sample fuels average 35.5 and vary from 29.2 to 41.2 API; aniline points average 146.5 F and vary from 114.0 to 164.0 F (Tables I, III, IV, XXXVIII).

FIGURE 23

C RANGE RATE = 0.01815 + 0.3042|C MED. RATE| - 0.02593 C RANGE INIT.

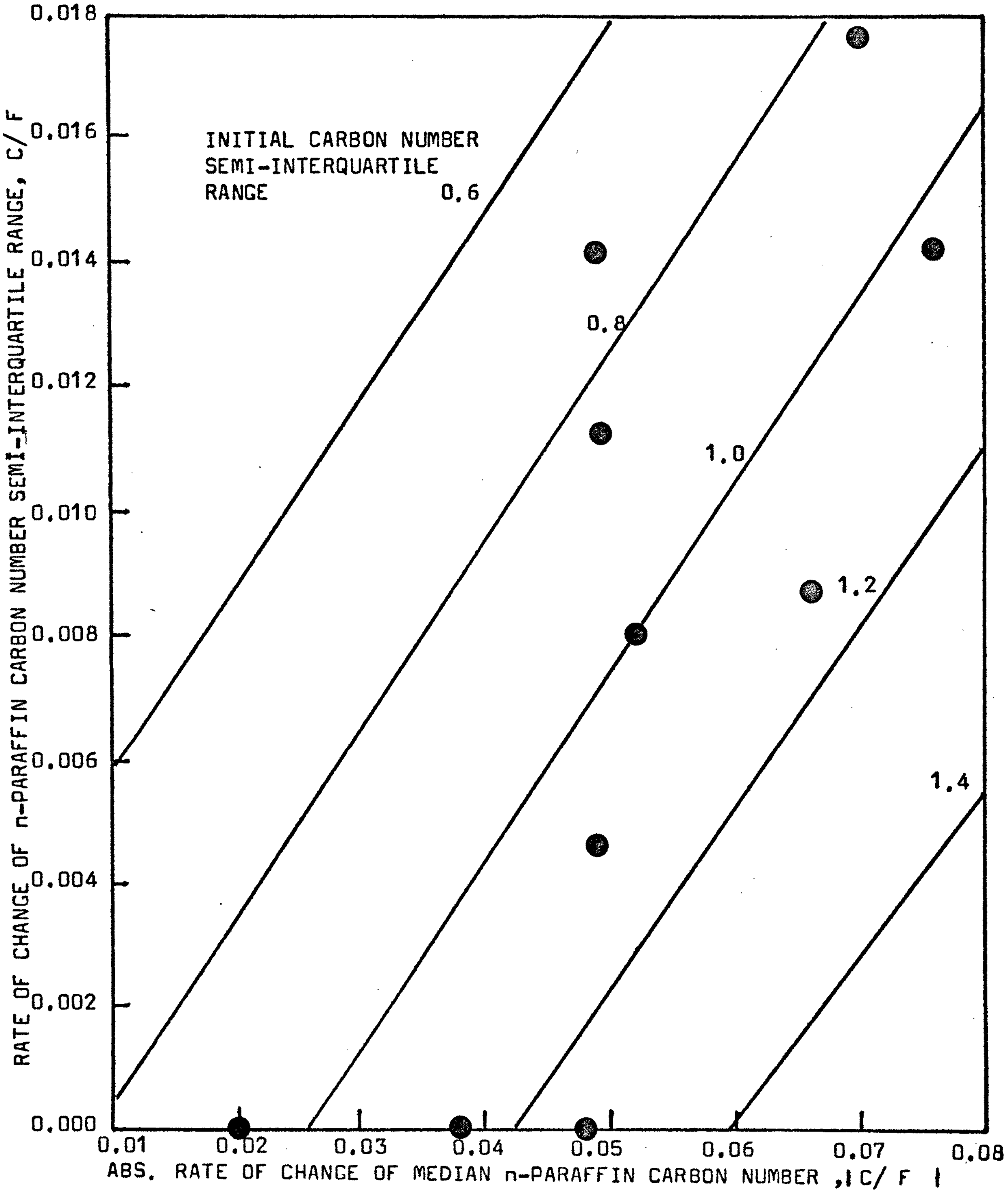


FIGURE 24

C RANGE INIT. = 1.019 - 21.96 C RANGE RATE + 0.01400 CLOUD

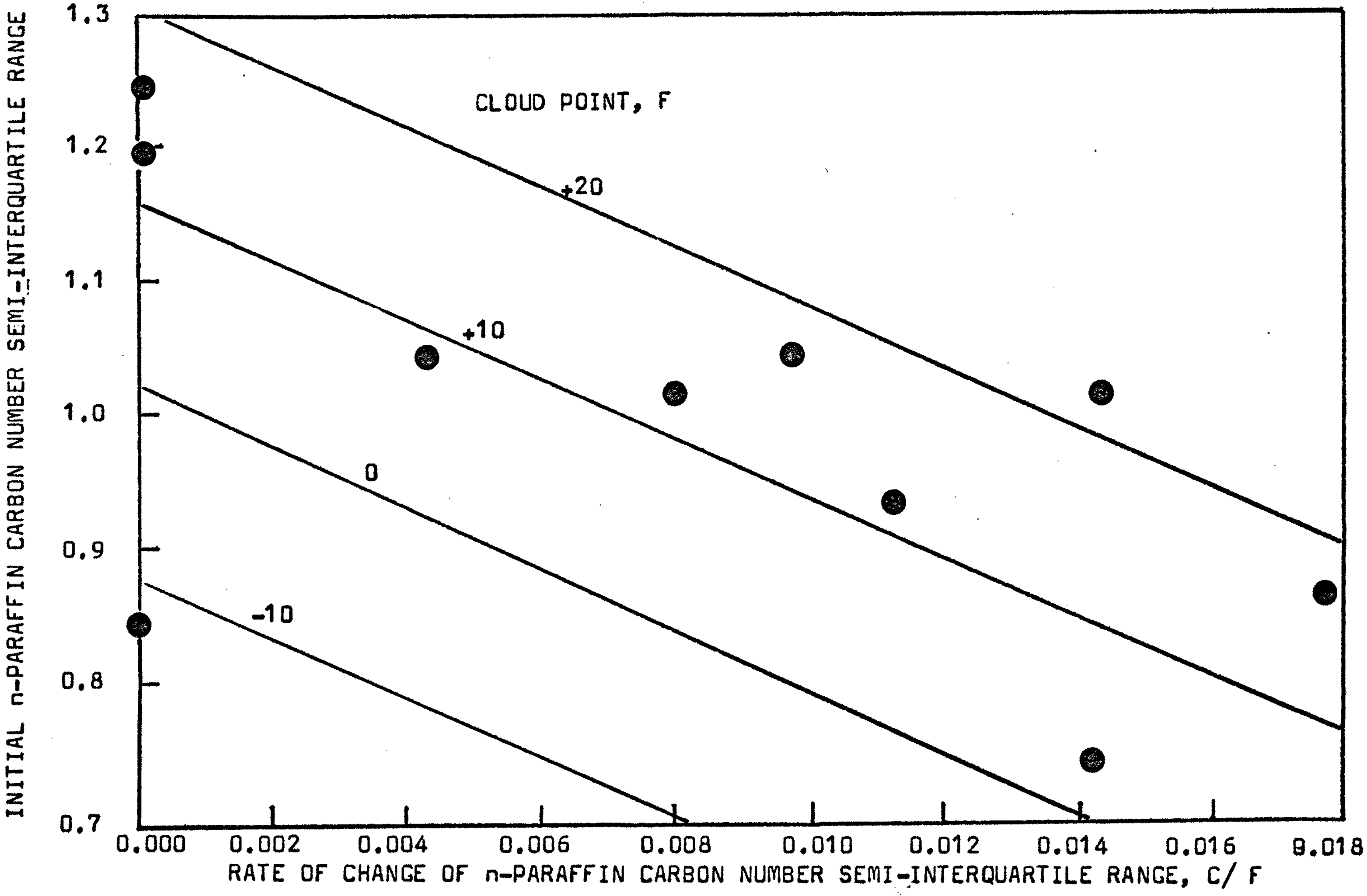
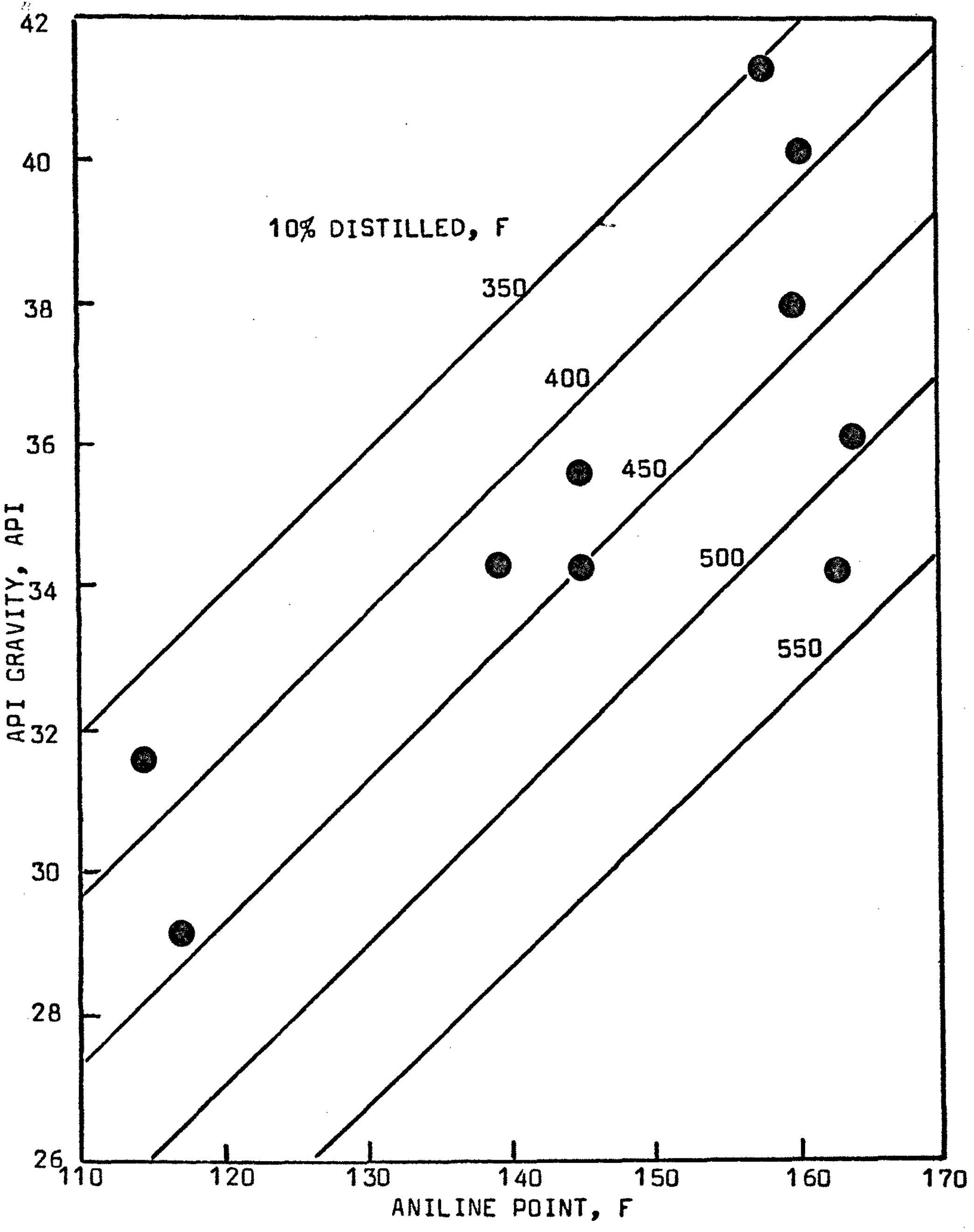


FIGURE 25

GRAVITY = 26.38 + 0.1975 ANILINE - 0.04624 DIST. 10%



Cloud points of the sample fuels average +11 F and vary from -8 to +22 F; they have a +0.86 correlation coefficient with the distillation 90% point. The inference equation is

$$\text{Cloud (F)} = -177 + 0.302\ \text{Dist. } 90\%$$

which has a 0.73 fraction of explained variance (Figure 26). The distillation 90% points average 624 F and vary from 569 to 659 F (Tables I, II, V, IX, XXXVIII).

Other distillation measurements evaluated included the slope, which can be approximated using only the distillation 10% and 90% point.

$$\text{Slope (F/\%)} = 5.21 - 0.0125\ \text{Dist. } 10\%\ \text{(F)} + 0.0124\ \text{Dist. } 90\%\ \text{(F)}$$

which has a 1.00 fraction of explained variance. Including only the 10% point,

$$\text{Slope (F/\%)} = 8.21 - 0.0134\ \text{Dist. } 10\%\ \text{(F)}$$

for a 0.84 fraction of explained variance (Figure 27). The slope and 10% point have a +0.88 correlation coefficient. In the sample fuels, distillation 10% points average 430 F and vary from 368 to 524 F (Tables I, II, VII, XXXVIII).

Finally, the distillation 10% point also has a +0.88 correlation coefficient with the volumetric average boiling point. The inference equation for this latter variable is

$$\text{Dist. VABP (F)} = 328 + 0.460\ \text{Dist. } 10\%\ \text{(F)}$$

FIGURE 26

CLOUD = -177.1 + 0.3017 DIST. 90%

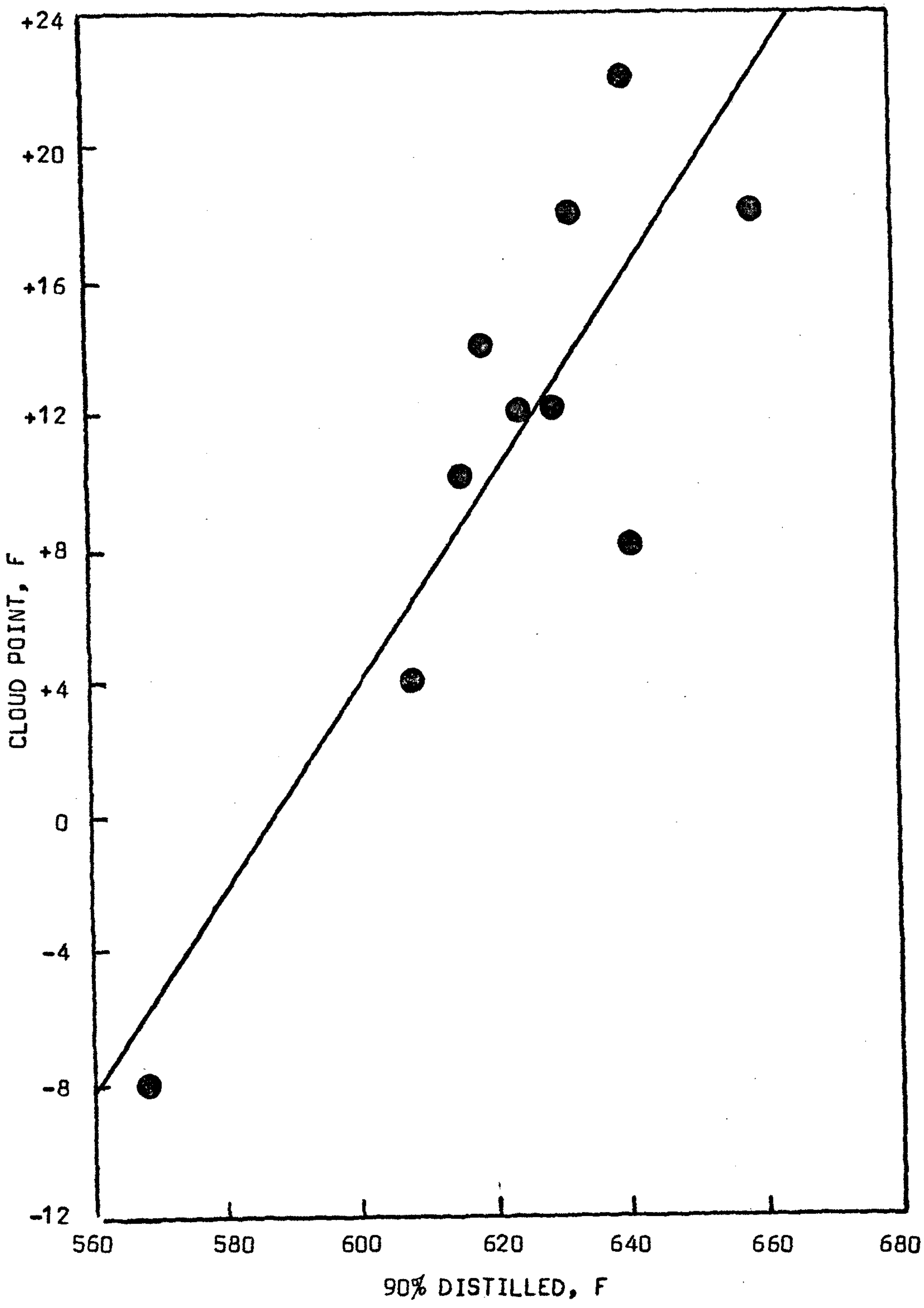
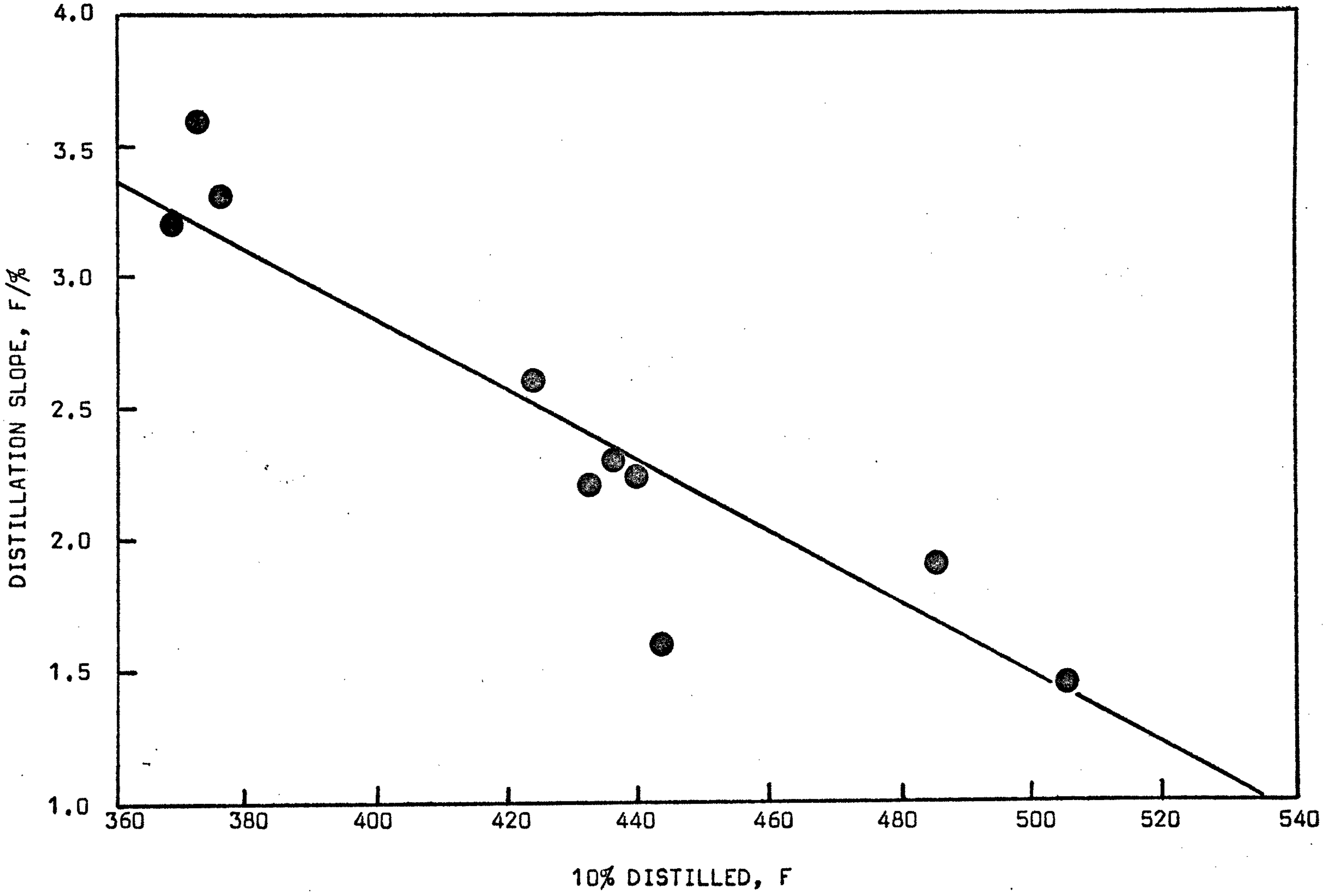


FIGURE 27

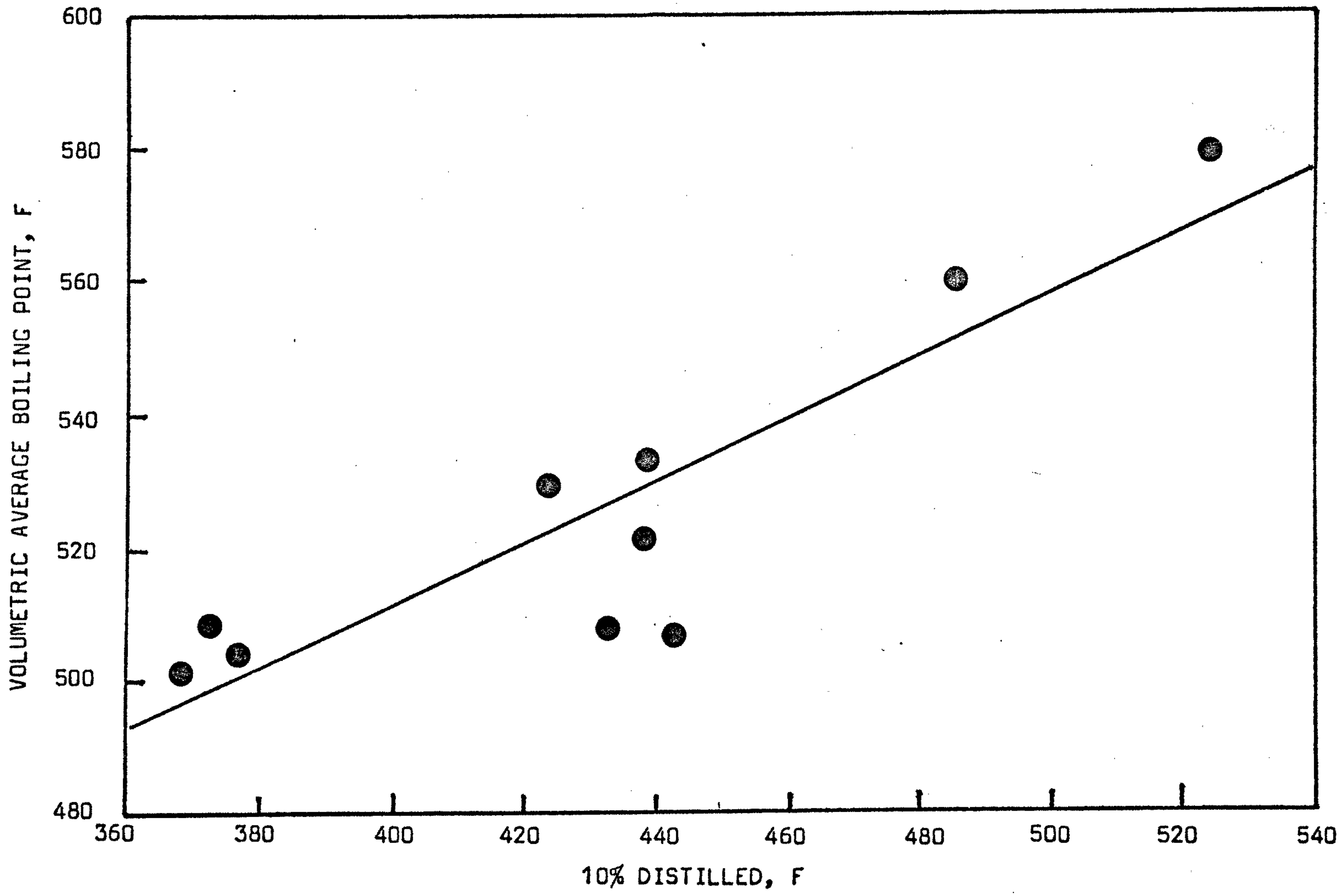
DIST. SLOPE = 8.206 - 0.01344 DIST. 10%



which has a 0.78 fraction of explained variance (Figure 28). The volumetric average boiling points in the sample fuels average 525 F and vary from 502 to 579 F (Tables I, II, VI, XXXVIII).

FIGURE 28

DIST. VABP = 327.8 + 0.4596 DIST. 10%



CONCLUSIONS

Aliphatic hydrocarbons are the predominant constituents of middle distillate fuels averaging 70 wt.%, which is comprised of paraffins and naphthenes at concentrations of 38 and 32 wt.%, respectively. The paraffinic hydrocarbon content is composed of almost equal proportions of n- and iso-paraffins. The remaining 30 wt.% is composed of aromatic hydrocarbons.

When fuels cool below the cloud point, some hydrocarbon constituents crystallize at an approximately constant rate to yield concentrations of 6 and 12 wt.% at -20 and -40 F, respectively. The majority of the crystallized hydrocarbons are n-paraffins, although the proportion decreases with decreasing temperature; at -20 and -40 F, the n-paraffin concentrations in the separated solids average 81 and 70 wt.%, respectively. At -40 F, the balance is comprised of 15 wt.% naphthenic, 10 wt.% iso-paraffinic, and 5 wt.% aromatic hydrocarbons. Thus, the hydrocarbons separating from fuels cooled below cloud points are almost exclusively aliphatic and predominantly n-paraffinic.

However, at the low 0.2 wt.%/F average separation rate, an average of only 9 wt.% n-paraffins have crystallized at temperatures as much as 50 F below fuel cloud points; this represents slightly less than half the total n-paraffins present in the fuel. Consequently, significant differences exist in the n-paraffin carbon number distributions of the total present in the fuel and of those crystallizing from the fuels at temperatures that are below the cloud point. The distributions of the total n-paraffins have an average median of 15 and an average semi-interquartile range of 2.3; the semi-interquartile range represents 25 and 75% quartiles averaging 13 and 17, respectively, or a total range of from approximately 8 to 28 carbon numbers. The median carbon number of the crystallized n-paraffins averages 20 at the cloud point and decreases at a rate of approximately one carbon number per 20 F to average 18 at -20 F and 17 at -40 F; the associated semi-interquartile range increases at approximately 0.2 carbon numbers per 20 F from 1.0 at the cloud point to 1.2 and 1.4 at -20 and -40 F, respectively.

Inference Equations

A total of forty-eight inference equations are available to approximate the quantitative characteristics of middle distillate fuels. Aromatic, naphthenic, and paraffinic hydrocarbon composition is approximated by twenty-four equations; the separation of n-paraffins from cooling middle distillates is approximated by eighteen equations. Finally, six equations approximate interrelationships among the fuel physical inspections (Table XLI). Of course, dependent and independent variables can be interchanged; some of these alternatives are provided in the appendix.

Middle distillate hydrocarbon composition is approximated from aniline point and distillation data. The aromatic, naphthenic, and paraffinic hydrocarbon contents are evaluated successively from aniline point and volumetric average boiling point determinations.

TABLE XLI

THE QUANTITATIVE CHARACTERISTICS OF MIDDLE DISTILLATE FUELS

DEPENDENT VARIABLE	INFERENCE EQUATION	FRACTION EXPLAINED	CORRELATION DETERMINANT
Aromatics (wt%)	104.4 - 0.510 Aniline (F)	0.96	1.00
Naphthenes (wt%)	-57.4 + 0.191 Dist. VABP (F) - 0.374 Aromatics (wt%)	0.87	0.73
	-94.0 + 0.188 Dist. VABP (F) + 0.184 Aniline (F)	0.84	0.67
	-106.3 + 0.263 Dist. VABP (F)	0.72	1.00
Paraffins (wt%)	100 - Aromatics (wt%) - Naphthenes (wt%)	-	-
	-7.99 + 1.59 Gravity(API) - 0.312 Naphthenes (wt%)	0.82	0.90
	-10.3 + 1.38 Gravity(API)	0.67	1.00
n-Paraffins (wt%)	54.2 + 0.770 Paraffins (wt%) - 0.104 Dist. 90% (F)	0.85	0.83
	4.48 + 0.567 Paraffins (wt%) - 0.230 Naphthenes (wt%)	0.77	0.99
	-18.3 + 0.796 Paraffins (wt%) + 0.226 Aromatics (wt%)	0.77	0.70
	-8.61 + 0.792 Paraffins (wt%) - 0.262 Cloud (F)	0.78	0.73
	-4.18 + 0.602 Paraffins (wt%)	0.62	1.00
n-P Median	9.32 - 0.0966 Paraffins (wt%) - 0.0178 Dist. VABP (F)	0.89	0.91
	19.6 - 0.120 Paraffins (wt%)	0.65	1.00
	18.8 - 0.120 n-Paraffins (wt%) - 0.658 Dist Slope (F/%)	0.84	0.93
	17.8 - 0.147 n-Paraffins (wt%)	0.58	1.00
	-0.876 + 0.534 n-P 25% + 0.524 n-P 25%	0.91	0.71
	6.48 + 0.658 n-P 25%	0.84	1.00
n-P Range	0.389 + 0.704 Dist. Slope (F/%)	0.96	1.00
	1.64 + 0.0559 Cloud (F)	0.69	1.00
n-P 25%	17.9 - 1.37 Dist. Slope (F/%) - 0.0880 n-Paraffins (wt%)	0.87	0.93
	16.6 - 1.52 Dist. Slope (F/%)	0.77	1.00
n-P 75%	18.6 - 0.116 n-Paraffins (wt%) + 0.142 n-P@-20F (wt%)	0.83	0.85
	18.9 - 0.0946 n-Paraffins (wt%)	0.65	1.00

TABLE XLI (continued)

THE QUANTITATIVE CHARACTERISTICS OF MIDDLE DISTILLATE FUELS

DEPENDENT VARIABLE	INFERENCE EQUATION	FRACTION EXPLAINED	CORRELATION DETERMINANT
n-P Sep. (wt%/F)	0.195 - 3.33|C Med. Rate|(|C/F|) + 0.00767 n-Paraffins(wt%)	0.84	0.95
	0.122 - 4.44|C Med. Rate|(|C/F|) + 0.00715 Paraffins (wt%)	0.85	0.67
	0.726 - 0.0332 C Med. Init. + 0.00570 n-Paraffins (wt%)	0.79	1.00
	0.814 - 0.0422 C Med. Init. + 0.00522 Paraffins (wt%)	0.81	0.79
	0.824 - 0.0327 C Med. Init.	0.62	1.00
C Med. Init.	23.8 + 0.127 Cloud (F) - 0.0121 Dist. 10% (F)	0.82	0.90
	28.7 + 0.154 Cloud (F) - 0.0197 Dist. VABP (F)	0.79	0.99
	-1.86 + 1.24 Dist. Slope (F/%) + 0.0302 Dist. 90% (F)	0.83	0.71
	16.3 + 1.14 Dist. Slope (F/%) + 0.0883 Cloud (F)	0.87	0.62
	-0.357 + 2.40 Dist. Slope (F/%) + 0.0276 Dist. VABP (F)	0.85	0.59
	15.7 + 1.78 Dist. Slope (F/%)	0.72	1.00
	3.43 - 1.29 n-P 25% + 1.94 n-P 75%	0.82	0.71
|C Med. Rate|(|C/F|)	0.138 + 0.00152 Cloud (F) - 0.000196 Dist. VABP (F)	0.69	0.99
	0.0352 + 0.00147 Cloud (F)	0.59	1.00
	0.0466 - 0.0103 C Med. Init. + 0.00636 n-P 75%	0.95	0.98
	-0.150 + 0.0100 C Med. Init.	0.90	1.00
C Range Init.	1.02 - 22.0 C range Rate (C/F) + 0.0140 Cloud (F)	0.83	0.80
C Range Rate (C/F)	0.0182 + 0.304 | C Med. Rate | (|C/F|) - 0.0259 C Range Init.	0.92	1.00
Aniline	-127.0 + 4.92 Gravity(API) + 0.231 Dist. 10% (F)	0.97	0.92
	4.61 + 4.00 Gravity(API)	0.62	1.00
Cloud (F)	-177 + 0.302 Dist. 90% (F)	0.73	1.00
Dist. VABP (F)	328 + 0.460 Dist. 10% (F)	0.78	1.00
Dist. Slope (F/%)	5.21 - 0.125Dist. 10% (F) + 0.0124 Dist. 90% (F)	1.00	0.98
	8.21 - 0.0134 Dist. 10% (F)	0.84	1.00

Including paraffin content with the distillation 90% point or volumetric average boiling point enables calculation of n-paraffinic content or median n-paraffin carbon number, respectively. A large paraffin content indicates a large n-paraffin content having a low median carbon number. The n-paraffin carbon number semi-interquartile range is calculated from distillation slope; a large slope indicates a large range.

The n-paraffin separation characteristics are approximated primarily from cloud point and distillation data. The median carbon number at initial separation or its absolute rate of change with decreasing temperature are calculated by including cloud point with the distillation 10% point or volumetric average boiling point, respectively; a high cloud point indicates both a high initial median carbon number crystallizing at the cloud point and a high absolute rate of change with decreasing temperature. The rate of change of median carbon number is further related to the total n-paraffin separation rate and the rate of change of carbon number semi-interquartile range. A high absolute rate of change of median carbon number indicates a low total separation rate; conversely, if the n-paraffins crystallize rapidly from a cooling middle distillate, the median carbon number over the temperature range changes little from the value at initial separation. A high absolute rate of change in the median also indicates a high rate of change in the semi-interquartile range, which further indicates a high initial semi-interquartile range at the cloud point..

Thus, for both the n-paraffin carbon number median and semi-interquartile range, initial values and rates of change with temperature are related. However, for the median, a high initial value indicates a high absolute rate of change; for the semi-interquartile range, a high initial value indicates a low rate of change.

Interrelationships also exist among middle distillate physical inspections. Aniline point has a positive correlation with API gravity and the 10% distillation point. Additionally, the 10% distillation point can approximate the volumetric average boiling point and the distillation slope. Finally, a high 90% distillation point indicates a high cloud point.

Exhaust Smoke Emission

with the inference equations for hydrocarbon composition, it is possible to indicate the smoking tendency of middle distillate fuels. High paraffinic hydrocarbon contents are desirable to reduce exhaust smoke emission; the inference equations enable approximation of fuel paraffinicity from physical inspections. In general, high paraffinicity is indicated by high aniline points, high API gravities, and low volumetric average boiling points.

It is reasonable to expect that reduction of smoke emission will effect a commensurate reduction in the emission of unburned hydrocarbons. The further benefits of high paraffinicity are better ignition quality; for ease of starting, smooth operation, and reduced sludge formation; and less ring wear. Further reduction in exhaust smoke emission can be achieved by the addition of barium compounds.

Low Temperature Operation

Low temperature plugging problems encountered with middle distillate fuels result from the separation of n-paraffins. Although n-paraffins increase with an increase in total paraffinic hydrocarbon content, n-paraffin separation is reduced by increasing the cloud point and distillation slope, which can be accomplished by increasing the 90% distillation point. The distillation slope can also be increased by lowering the 10% distillation point. The use of crystal modifiers can prevent the small concentrations of crystallizing n-paraffins from interlocking and immobilizing an entire body of fuel.

Increasing paraffinic hydrocarbon content and decreasing separation rate effects changes in n-paraffin carbon number distribution. The n-paraffins present in a highly paraffinic middle distillate fuel have a low median, which is reflected in low 25 and 75% quartiles, but a high semi-interquartile range. Further, when the total n-paraffin separation rate decreases, the median n-paraffin carbon number at the cloud point and its absolute rate of change with decreasing temperature both increase; the rate of change of the semi-interquartile range with decreasing temperature also increases although the range at the cloud point decreases. Consideration of the carbon number distributions of separating n-paraffins could improve the association and, thus, the effectiveness of polymeric crystal modifiers in given fuels.

Thus, as the demand for middle distillate fuel energy increases, it is possible to quantitatively approximate the impact of changes in fuel physical inspections on smoke emission and low temperature operation. The relative concentrations of unsaturated aromatic and saturated paraffinic and naphthenic hydrocarbons are approximated to indicate combustion quality and subsequent smoke emission; also, approximated are the n-paraffins that crystallize at low temperatures to form immobilizing matrices. The forty-eight inference equations provide a systematic approach to the problems of smoke emission and low temperature operation.

RECOMMENDATIONS

The exhaust smoke emission of middle distillate fuels is related to the content of paraffinic hydrocarbons. As paraffins can be approximated from fuel physical inspections, a measure of fuel smoking tendency is readily calculated. Therefore, it is recommended that fuel smoke emission ratings be established using calculated paraffinic hydrocarbon content. As smoke emission can be reduced by the addition of barium compounds, it is further recommended that an additional rating reflect the pressure of such compounds and the effect on emissions that can be expected. Smoke emission ratings would enable fuel distribution for improved air quality in areas of high vehicular density.

The low temperature plugging problem of middle distillate fuels is related to the rate of separation of n-paraffins. As the rate of separation can be approximated from fuel physical inspections, a measure of fuel plugging tendency is readily calculated. Therefore, it is recommended that fuel low temperature plugging ratings be established using calculated n-paraffin separation. rate. As fuel low temperature operability can be enhanced by the addition of polymeric crystal modifiers, it is further recommended that an additional rating reflect the presence of such modifiers and the extended low temperature performance that can be expected. Low temperature ratings would enable optimum energy utilization in winter climates.

The carbon number distributions of n-paraffins separating from middle distillate fuels is related to the fuel characteristics and temperature. As polymeric crystal modifiers function by associating with the n-paraffins, their effectiveness for a given fuel and temperature could possibly be determined by considering the carbon number distributions of the seprating n-paraffins. Therefore, it is recommended that inference equations relating polymeric crystal modifiers and n-paraffin carbon number distributions be developed. It is anticipated that such equations will enable the introduction of more effective polymeric crystal modifiers.

The forty-eight inference equations that approximate quantitative characteristics of middle distillate fuels each have a minimum 0.7 fraction of explained variance and determinant of the correlation matrix. However, they were developed from a sample of eight United States and two European fuels. If further enhancement of the inference capability of the equations is desired, it is recommended that a larger sample of fuels be evaluated on the basis of the presented relationships.

APPENDIX

TABLE I

DESCRIPTIVE STATISTICS FOR THE TEN MIDDLE DISTILLATE TEST FUELS

PHYSICAL INSPECTION VARIABLES

				DISTILLATION SUMMARY				
				% OFF, F				
FUEL NO.	API GRAVITY API	ANILINE POINT F	CLOUD POINT F	10%	VABP	90%	SLOPE F/%	WATSON CHARACTERIZATION FACTOR
1	31.6	114.0	+12	368	502	624	3.20	11.24
2	35.6	145.0	+14	437	521	619	2.28	11.60
3	34.3	145.0	+10	438	533	615	2.25	11.57
4	29.2	117.0	+4	432	508	608	2.20	11.20
5	34.3	139.0	-8	442	507	569	1.59	11.52
6	40.1	160.5	+22	376	505	640	3.30	11.90
7	41.2	158.0	+18	372	508	659	3.59	11.90
8	37.9	160.0	+12	423	530	629	2.58	11.82
9	34.3	163.0	+8	524	579	641	1.46	11.78
10	36.1	164.0	+18	485	560	632	1.84	11.84
SUM	354.6	1465.5	110	4297	5253	6236	24.29	116.37
AVERAGE	35.46	146.55	11.0	429.7	525.3	623.6	2.429	11.637
STANDARD DEVIATION	3.45	17.54	8.1	47.2	24.6	22.9	6.943	2.453
RANGE: MAXIMUM	41.2	164.0	22	524	579	659	3.59	11.90
MINIMUM	29.2	114.0	-8	368	502	569	1.46	11.20

TABLE II

COMPLETE DISTILLATION DATA FOR THE TEN MIDDLE DISTILLATE TEST FUELS

ASTM D 86 DISTILLATION, F

			% OFF, F							
			IBP	5%	10%		20%	30%		40%
FUEL NO.	VABP F	SLOPE F/%	READ	READ	READ	CORR.	READ	READ.	CORR.	READ
1	502	3.20	297	334	368	-	408	446	-	476
2	521	2.28	376	402	437	-	460	471	-	494
3	533	2.25	352	400	438	-	471	492	498	570
4	508	2.20	372	411	432	-	454	468	-	488
5	507	1.59	396	426	442	-	462	478	479	491
6	505	3.30	278	352	376	-	404	433	-	468
7	508	3.59	325	360	372	-	399	427	-	461
8	530	2.58	375	403	423	-	460	486	491	505
9	579	1.46	470	502	517	524	533	543	553	551
10	560	1.84	338	457	490	485	512	528	536	538
SUM	5253	24.29				4297				
AVERAGE	525.3	2.429				429.7				
STANDARD DEVIATION	24.6	6.943				47.2				
RANGE: MAXIMUM	579	3.59				524				
MINIMUM	502	1.46				368				

TABLE II (continued)

COMPLETE DISTILLATION DATA FOR THE TEN MIDDLE DISTILLATE TEST FUELS

ASTM D 86 DISTILLATION, F

FUEL NO.	% OFF, F									
	50%		60%	70%		80%	90%		95%	FBP
	READ	CORR.	READ	READ	CORR.	READ	READ	CORR.	READ	READ
1	503	509	528	552	563	577	605	624	627	652
2	510	517	526	544	554	568	601	619	630	640
3	536	545	548	558	569	576	600	615	618	636
4	505	511	522	541	550	566	592	608	616	631
5	503	509	512	527	535	543	558	569	572	584
6	500	506	528	560	572	597	618	640	656	663
7	500	506	534	565	577	597	633	659	659	672
8	525	533	542	566	574	580	609	629	630	644
9	564	576	574	584	599	597	619	641	637	647
10	548	558	562	575	589	588	612	632	632	641
SUM								6236		
AVERAGE								623.6		
STANDARD DEVIATION								22.9		
RANGE: MAXIMUM								659		
MINIMUM								569		

TABLE III

INTER-RELATIONSHIPS AMONG FUEL PHYSICAL INSPECTIONS

API 2547 GRAVITY, API

		GRAVITY = 26.38 +0.1975 ANILINE -0.04624 DIST. 10%			GRAVITY = 12.77 +0.1549 ANILINE		
FUEL NO.	OBS.	CALC.	OBS.- CALC.	ERROR ORDER	CALC.	OBS.- CALC.	ERROR ORDER
1	31.6	31.8	-0.3	5	30.4	1.2	8
2	35.6	34.8	0.8	8	35.2	0.4	7
3	34.3	34.8	-0.5	3	35.2	-0.9	4
4	29.2	29.5	-0.3	4	30.9	-1.7	3
5	34.3	33.4	0.9	10	34.3	0.0	5
6	40.1	40.7	-0.6	1	37.6	2.5	9
7	41.2	40.4	0.8	9	37.2	4.0	10
8	37.9	38.4	-0.5	2	37.5	0.4	6
9	34.3	34.3	0.0	7	38.0	-3.7	1
10	36.1	36.4	-0.3	6	38.2	-2.1	2

STANDARD ERROR OF ESTIMATE		0.67		2.38
FRACTION OF EXPLAINED VARIANCE		0.973		0.620
F-RATIO FOR THE REGRESSION		127.3		13.0
DETERMINANT OF THE CORRELATION MATRIX		0.88		1.00
COEFFICIENTS:	ESTIMATED ERROR	0.01294	0.004808	0.04287
	F-RATIO	232.9	92.5	13.0
	T-RATIO	15.3	9.6	3.6
	COVARIANCE RATIO	0.12		0.0

TABLE IV

INTER-RELATIONSHIPS AMONG FUEL PHYSICAL INSPECTIONS

ASTM D611 ANILINE POINT, F

		ANILINE = -126.97 +4.915 GRAVITY +0.2310 DIST. 10%			ANILINE = 4.605 +4.003 GRAVITY		
FUEL NO.	OBS.	CALC.	OBS.-CALC.	ERROR ORDER	OBS.	OBS.-CALC.	ERROR ORDER
1	114.0	113.3	0.7	5	131.1	-17.1	1
2	145.0	148.9	-3.9	2	147.1	-2.1	6
3	145.0	142.8	2.2	8	141.9	3.1	7
4	117.0	116.3	0.7	6	121.5	-4.5	4
5	139.0	143.7	-4.7	1	141.9	-2.9	5
6	160.5	157.0	3.5	10	165.1	-4.6	3
7	158.0	161.4	-3.4	3	169.5	-11.5	2
8	160.0	157.0	3.0	9	156.3	3.7	8
9	163.0	162.6	0.4	4	141.9	21.1	10
10	164.0	162.5	1.5	7	149.1	14.9	9

STANDARD ERROR OF ESTIMATE		3.36		12.09
FRACTION OF EXPLAINED VARIANCE		0.974		0.620
F-RATIO FOR THE REGRESSION		132.4		13.0
DETERMINANT OF THE CORRELATION MATRIX		0.92		1.00
COEFFICIENTS:	ESTIMATED ERROR	0.3221	0.02353	1.1083
	F-RATIO	232.9	96.4	13.0
	T-RATIO	15.3	9.8	3.6
	COVARIANCE RATIO	0.08		0.0

TABLE V

INTERRELATIONSHIPS AMONG FUEL PHYSICAL INSPECTIONS

ASTMD 2500 CLOUD POINT, F

CLOUD =
-177.1
+0.3017 DIST. 90%

FUEL NO.	OBS	CALC	OBS-CALC	ERROR ORDER
1	12	11	1	6
2	14	10	4	8
3	10	8	2	7
4	4	6	-2	4
5	-8	-5	-3	3
6	22	16	6	10
7	18	22	-4	2
8	12	13	-1	5
9	8	16	-8	1
10	18	14	4	9

STANDARD ERROR OF ESTIMATE		4.6
FRACTION OF EXPLAINED VARIANCE		0.734
F-RATIO FOR THE REGRESSION		22.1
COEFFICIENT:	ESTIMATED ERROR	0.06417
	F-RATIO	22.1
	T-RATIO	4.7

TABLE VI

INTERRELATIONSHIPS AMONG FUEL PHYSICAL INSPECTIONS

DISTILLATION VABP, F

		DIST. VABP = 327.8 +0.4596 DIST. 10%		
FUEL NO.	OBS	CALC	OBS-CALC	ERROR ORDER
1	502	497	5	6
2	521	529	-8	3
3	533	529	4	4
4	508	526	-18	2
5	507	531	-24	1
6	505	501	4	5
7	508	499	9	8
8	530	522	8	7
9	579	569	10	10
10	560	551	9	9

STANDARD ERROR OF ESTIMATE		13.1
FRACTION OF EXPLAINED VARIANCE		0.775
F-RATIO FOR THE REGRESSION		27.5
COEFFICIENT:	ESTIMATED ERROR	0.08759
	F-RATIO	27.5
	T-RATIO	5.2

TABLE VII

INTER-RELATIONSHIPS AMONG FUEL PHYSICAL INSPECTIONS

DISTILLATION SLOPE, F/%

FUEL NO.	OBS.	SLOPE = 5.213 -0.01250 DIST. 10% +0.01243 DIST. 90%			SLOPE = 8.206 -0.01344 DIST. 10%		
		CALC.	OBS.- CALC.	ERROR ORDER	CALC.	OBS.- CALC.	ERROR ORDER
1	3.20	3.21	-0.01	4	3.26	-0.06	4
2	2.28	2.28	0.00	5	2.33	-0.05	5
3	2.25	2.22	0.03	10	2.32	-0.07	3
4	2.20	2.21	-0.01	2	2.40	-0.20	2
5	1.59	1.59	-0.01	1	2.26	-0.67	1
6	3.30	3.30	0.00	6	3.15	0.15	8
7	3.59	3.59	0.00	9	3.20	0.39	10
8	2.58	2.58	0.00	8	2.52	0.06	6
9	1.46	1.47	-0.01	3	1.16	0.03	9
10	1.84	1.84	0.00	7	1.69	0.15	7

STANDARD ERROR OF ESTIMATE		0.013		0.314
FRACTION OF EXPLAINED VARIANCE		1.000		0.836
F-RATIO FOR THE REGRESSION		14,333.500		40.7
DETERMINANT OF THE CORRELATION MATRIX		0.98		1.00
COEFFICIENTS:	ESTIMATED ERROR	0.000088	0.000181	0.002106
	F-RATIO	20,218.0	4698.7	40.7
	T-RATIO	142.2	68.5	6.4
	COVARIANCE RATIO	0.02		0.0

TABLE VIII

INTER-RELATIONSHIPS AMONG FUEL PHYSICAL INSPECTIONS

DISTILLATION 10%. F

FUEL NO.	OBS.	DIST. 10% = 438.7 -79,97 DIST. SLOPE +0.9925 DIST. 90%			DIST. 10% = 580.7 -62.18 DIST. SLOPE		
		CALC.	OBS.-CALC.	ERROR ORDER	CALC.	OBS.-CALC.	ERROR ORDER
1	368	368	0	5	382	-14	2
2	437	437	0	4	439	-2	5
3	438	435	0	10	441	-3	4
4	432	433	-1	2	444	-12	3
5	442	443	-1	1	482	-40	1
6	376	376	0	6	376	0	6
7	372	372	0	7	358	14	8
8	423	423	0	9	420	3	7
9	524	524	0	3	490	34	10
10	485	485	0	8	466	19	9

STANDARD ERROR OF ESTIMATE		1.0		21.4
FRACTION OF EXPLAINED VARIANCE		1.000		0.836
F-RATIO FOR THE REGRESSION		10,362.6		40.7
DETERMINANT OF THE CORRELATION MATRIX		0.71		1.00
COEFFICIENTS:	ESTIMATED ERROR	0.562	0.01705	9.741
	F-RATIO	20,218.0	3395.4	40.7
	T-RATIO	142.2	58.3	6.4
	COVARIANCE RATIO	0.29		0.0

TABLE IX

INTERRELATIONSHIPS AMONG FUEL PHYSICAL INSPECTIONS

DISTILLATION 90%, F

		DIST. 90% = 596.8 +2.434 CLOUD		
FUEL NO.	OBS	CALC	OBS-CALC	ERROR ORDER
1	624	626	-2	6
2	619	631	-12	1
3	615	621	-6	5
4	608	607	1	7
5	569	577	-8	4
6	640	650	-10	2
7	659	641	18	9
8	629	626	3	8
9	641	616	25	10
10	632	641	-9	3

STANDARD ERROR OF ESTIMATE		13.2
FRACTION OF EXPLAINED VARIANCE		0.734
F-RATIO FOR THE REGRESSION		22.1
COEFFICIENT:	ESTIMATED ERROR	0.5178
	F-RATIO	22.1
	T-RATIO	4.7

TABLE X

DESCRIPTIVE STATISTICS FOR THE TEN MIDDLE DISTILLATE TEST FUELS

FUEL COMPOSITION VARIABLES

					n-PARAFFIN DISTRIBUTION			
FUEL	CONCENTRATION, WT %				QUARTILE			SEMI-INTERQUARTILE
NO.	AROMATICS	NAPHTHENES	PARAFFINS	n-PARAFFINS	25%	MEDIAN	75%	RANGE
1	46.6	24.3	29.5	11.9	12.8	15.6	17.9	2.55
2	28.0	31.3	40.7	20.4	12.5	14.8	16.6	2.05
3	32.9	32.1	35.0	16.7	13.1	15.1	17.4	2.15
4	43.4	19.9	36.7	24.0	13.3	14.7	16.8	1.75
5	35.0	28.2	36.8	21.5	13.4	14.9	16.4	1.50
6	19.3	33.7	47.0	23.4	11.5	14.0	17.1	2.80
7	25.5	25.4	49.1	23.3	10.6	13.2	16.5	2.90
8	21.6	38.9	39.5	19.5	12.3	15.0	16.8	2.25
9	21.0	47.4	31.6	10.5	14.8	16.3	17.8	1.50
10	22.4	37.3	39.9	19.3	14.5	16.0	17.6	1.55
SUM	295.7	318.9	385.8	190.5	128.8	149.6	170.9	22.55
AVERAGE	29.57	31.89	38.58	19.05	12.88	14.96	17.09	2.255
STANDARD DEVIATION	9.14	7.64	5.83	4.46	1.20	0.86	0.52	0.544
RANGE: MAXIMUM	46.6	47.4	49.1	24.0	14.8	16.3	17.9	2.95
MINIMUM	19.3	19.9	29.5	10.5	10.6	13.2	16.4	1.50

TABLE XI

FUEL COMPOSITION CALCULATED FROM PHYSICAL INSPECTIONS

AROMATIC CONTENT, WT%

		AROMATICS = 104.36 -0.5103 ANILINE		
FUEL NO.	OBS	CALC	OBS-CALC	ERROR ORDER
1	46.6	46.2	0.4	6
2	28.0	30.4	-2.4	2
3	32.9	30.4	2.5	10
4	43.4	44.7	-1.3	3
5	35.0	33.4	1.6	7
6	19.3	22.5	-3.2	1
7	25.5	23.7	1.8	9
8	21.6	22.7	-1.1	4
9	21.0	21.2	-0.2	5
10	22.4	20.7	1.7	8

STANDARD ERROR OF ESTIMATE	2.05
FRACTION OF EXPLAINED VARIANCE	0.960
F-RATIO FOR THE REGRESSION	190.8
COEFFICIENT: ESTIMATED ERROR	0.03694
F-RATIO	190.8
T-RATIO	13.8

TABLE XII

FUEL COMPOSITION CALCULATED FROM PHYSICAL INSPECTIONS

NAPHTHENIC CONTENT, WT %

		NAPHTHENES = -57.38 +0.1910 DIST VABP			NAPHTHENES = -93.96 +0.1883 DIST VABP			NAPHTHENES = -106.34 +0.2632 DIST VABP		
FUEL NO.	OBS.	CALC.	OBS.- CALC.	ERROR ORDER	CALC.	OBS.- CALC.	ERROR ORDER	CALC.	OBS.- CALC.	ERROR ORDER
1	24.3	21.1	3.2	10	21.5	2.8	8	25.3	-1.5	5
2	31.3	31.7	-0.4	4	30.8	0.5	5	30.8	0.5	6
3	32.1	32.1	0.0	5	33.1	-1.0	4	33.9	-1.8	4
4	19.9	23.4	-3.5	2	23.2	-3.3	3	27.3	-7.4	1
5	28.2	26.4	1.8	7	27.1	1.1	6	27.1	1.1	7
6	33.7	31.9	1.8	6	30.6	3.1	9	26.5	7.1	10
7	25.4	30.1	-4.7	1	30.7	-5.3	1	17.3	-1.9	3
8	38.9	35.8	-3.1	9	35.2	3.7	10	33.1	5.8	9
9	47.4	45.4	2.0	8	45.0	2.4	7	46.0	1.4	8
10	37.7	41.2	-3.5	3	41.6	-3.9	2	41.0	-3.3	2

STANDARD ERROR OF ESTIMATE		3.34		3.65		4.52
FRACTION OF EXPLAINED VARIANCE		0.866		0.840		0.720
F-RATIO FOR THE REGRESSION		22.7		18.4		20.6
DETERMINANT OF THE CORRELATION MATRIX		0.73		0.67		1.00
COEFFICIENTS:	ESTIMATED ERROR	0.05017	0.13632	0.05714	0.08031	0.05799
	F-RATIO	14.5	7.7	10.9	5.2	20.6
	T-RATIO	3.8	2.8	3.3	2.3	4.5
	COVARIANCE RATIO	0.27		0.33		0.0

TABLE XIII

FUEL COMPOSITION CALCULATED FROM PHYSICAL INSPECTIONS

PARAFFINIC CONTENT, WT %

		PARAFFINS = 100 -AROMATICS (calc.) -NAPHTHENES (calc.)			PARAFFINS = -7.986 +1.594 GRAVITY -0.3121 NAPHTHENES			PARAFFINS = -10.29 +1.378 GRAVITY		
FUEL NO.	OBS.	CALC.	OBS.- CALC.	ERROR ORDER	CALC.	OBS.- CALC.	ERROR ORDER	CALC.	OBS.- CALC.	ERROR ORDER
1	29.5	32.7	-3.2	2	34.8	-5.3	1	33.3	-3.8	2
2	40.7	37.9	2.8	8	39.0	1.7	8	38.8	1.9	7
3	35.0	37.5	-2.5	3	36.7	-1.1	2	37.0	-2.0	4
4	36.7	31.9	4.8	10	32.3	4.4	10	30.0	6.7	10
5	36.8	40.2	-3.4	1	37.9	-1.1	3	37.0	-0.2	5
6	47.0	45.6	1.4	6	45.4	1.6	7	45.0	2.1	8
7	49.1	46.2	2.9	9	49.8	-0.7	5	46.5	2.6	9
8	39.5	41.5	-2.0	4	40.3	-0.8	4	41.9	-2.4	3
9	31.6	33.4	-1.8	5	31.9	-0.3	6	37.0	-5.4	1
10	39.9	38.1	1.8	7	37.8	2.1	9	39.5	0.4	6
MEAN	38.6	38.5								

STANDARD DEV.	2.10
SUM OF SQUARES	0.03
MEAN SQUARED	0.03
F-RATIO	0.00

STANDARD ERROR OF ESTIMATE	2.98		3.76
FRACTION OF EXPLAINED VARIANCE	0.817		0.666
F-RATIO FOR THE REGRESSION-	15.7		15.9
DETERMINANT OF THE CORRELATION MATRIX-	0.903		1.00
COEFFICIENTS: ESTIMATED ERROR	0.2872	0.1296	0.34511
F-RATIO	30.8	5.8	15.9
T-RATIO	5.5	2.4	4.0
COVARIANCE RATIO	0.10		0.0

TABLE XIV

FUEL COMPOSITION CALCULATED FROM PHYSICAL INSPECTIONS

n-PARAFFINIC CONTENT, WT %

		n-PARAFFINS = +54.16 0.7702 PARAFFINS -0.1040 DIST. 90%			n-PARAFFINS = +4.478 +0.5674 PARAFFINS -0.2295 NAPHTHENES			n-PARAFFINS = -18.33 +0.7960 PARAFFINS +0.2255 AROMATICS		
FUEL NO.	OBS.	CALC.	OBS.- CALC.	ERROR ORDER	CALC.	OBS.- CALC.	ERROR ORDER	CALC.	OBS.- CALC.	ERROR ORDER
1	11.9	21.0	-0.1	7	15.6	-3.7	1	15.7	-3.8	1
2	20.4	21.2	-0.8	3	20.4	0.0	6	20.4	0.0	6
3	16.7	17.2	-0.5	4	17.0	-0.3	4	17.0	-0.3	5
4	24.0	19.2	4.8	10	20.7	3.3	10	20.7	3.3	10
5	21.5	23.4	-1.9	1	18.9	2.6	9	18.9	2.6	9
6	23.4	23.8	-0.4	5	23.4	0.0	5	23.4	-3.6	2
7	23.3	23.5	-0.2	6	26.5	-3.2	2	26.5	-3.2	3
8	19.5	19.2	0.3	9	18.0	1.5	8	18.0	1.5	8
9	10.5	11.9	-1.4	2	11.5	-1.0	3	11.6	-1.1	4
10	19.3	19.2	0.1	8	18.5	0.8	7	18.5	0.8	7

STANDARD ERROR OF ESTIMATE		2.04		2.56		2.58	
FRACTION OF EXPLAINED VARIANCE		0.853		0.769		0.766	
F-RATIO FOR THE REGRESSION		20.3		11.7		11.5	
DETERMINANT OF THE CORRELATION MATRIX		0.83		0.99		0.70	
COEFFICIENTS:	ESTIMATED ERROR	.12178	.030979	.14003	.10672	.16756	.10684
	F-RATIO	40.0	11.3	16.4	4.6	22.6	4.5
	T-RATIO	6.3	3.4	4.1	2.2	4.8	2.1
	COVARIANCE RATIO	0.17		0.01		0.30	

TABLE XIV (continued)

FUEL COMPOSITION CALCULATED FROM PHYSICAL INSPECTIONS

n-PARAFFINIC CONTENT, WT %

		n-PARAFFINS = -8.606 +0.7917 PARAFFINS -0.2625 CLOUD			n-PARAFFINS = -4.176 +0.60201 PARAFFINS		
FUEL NO.	OBS.	CALC.	OBS.- CALC.	ERROR ORDER	CALC.	OBS.- CALC.	ERROR ORDER
1	11.9	11.6	0.3	6	13.6	-1.7	3
2	20.4	19.9	0.5	7	20.3	0.1	8
3	16.7	16.5	0.2	5	16.9	-0.2	6
4	24.0	19.4	4.6	10	17.9	6.1	10
5	21.5	22.6	-1.1	3	18.0	3.5	9
6	23.4	22.8	0.6	8	24.1	-0.7	4
7	23.3	25.5	-2.2	2	25.4	-2.1	2
8	19.5	19.5	0.0	4	19.6	-0.1	7
9	10.5	14.3	-3.8	1	14.8	-4.3	1
10	19.3	18.3	1.0	9	19.8	-0.5	5

STANDARD ERROR OF ESTIMATE		2.50		3.09
FRACTION OF EXPLAINED VARIANCE		0.780		0.617
F-RATIO FOR THE REGRESSION		12.4		12.9
DETERMINANT OF THE CORRELATION MATRIX		0.73		1.00
COEFFICIENTS:	ESTIMATED ERROR	.15913	.11498	.16769
	F-RATIO	24.8	5.2	12.9
	T-RATIO	5.0	2.3	3.6
	COVARIANCE RATIO	0.27		0.00

TABLE XV

n-PARAFFIN COMPOSITION CALCULATED USING FUEL VARIABLES

MEDIAN n-PARAFFIN CARBON NUMBER

		n-P MEDIAN = 9.324 -.09665 PARAFFINS			n-P MEDIAN = 19.58 -0.1196 PARAFFINS			n-P MEDIAN = 18.84 -0.1196 n-PARAFFINS		
FUEL NO.	OBS.	CALC.	OBS.- CALC.	ERROR ORDER	CALC.	OBS.- CALC.	ERROR ORDER	CALC.	OBS.- CALC.	ERROR ORDER
1	15.6	15.4	0.2	8	16.0	-0.4	3	15.3	0.3	9
2	14.8	14.7	0.1	7	14.7	0.1	7	14.9	-0.1	5
3	15.1	15.4	-0.3	2	15.4	-0.3	4	15.4	-0.3	4
4	14.7	14.8	-0.1	4	15.2	-0.5	2	14.5	0.2	7
5	14.9	14.8	0.1	6	15.2	-0.3	5	15.2	-0.3	3
6	14.0	13.8	0.2	9	14.0	0.0	6	13.9	0.1	6
7	13.2	13.6	-0.4	1	13.7	-0.5	1	13.7	-0.5	1
8	15.0	15.0	0.0	5	14.8	0.2	8	14.8	0.2	8
9	16.3	16.6	-0.3	3	15.8	0.5	9	16.6	-0.3	2
10	16.0	15.5	0.5	10	14.8	1.2	10	15.3	0.7	10

STANDARD ERROR OF ESTIMATE		0.34		0.57	0.41	
FRACTION OF EXPLAINED VARIANCE		0.890		0.654	0.844	
F-RATIO FOR THE REGRESSION		28.4		15.1	18.9	
DETERMINANT OF THE CORRELATION MATRIX		0.91		1.00	0.93	
COEFFICIENTS:	ESTIMATED ERROR	.019450	.004596	0.03075	.02994	.19250
	F-RATIO	24.7	15.0	15.1	16.0	11.7
	T-RATIO	5.0	3.9	3.9	4.0	3.4
	COVARIANCE RATIO	0.09		0.00	0.07	

TABLE XV (continued)

n-PARAFFIN COMPOSITION CALCULATED USING FUEL VARIABLES

MEDIAN n-PARAFFIN CARBON NUMBER

		n-P MEDIAN = 17.77 -0.1474 n-PARAFFINS			n-P MEDIAN = -0.8764 +0.5343 n-P 25% +0.5240 n-P 75%			n-P MEDIAN = 6.485 +0.6580 n-P 25%		
FUEL NO.	OBS.	CALC.	OBS.- CALC.	ERROR ORDER	CALC.	OBS.- CALC.	ERROR ORDER	CALC.	OBS.- CALC.	ERROR ORDER
1	15.6	16.0	-0.4	2	15.3	0.3	8	14.9	0.7	10
2	14.8	14.8	0.0	6	14.5	0.3	9	14.7	0.1	8
3	15.1	15.3	-0.2	4	15.2	-0.1	4	15.1	0.0	5
4	14.7	14.2	0.5	9	15.0	-0.3	1	15.2	-0.5	1
5	14.9	14.6	0.3	8	14.9	0.0	7	15.3	-0.4	2
6	14.0	14.3	-0.3	3	14.2	-0.2	3	14.1	-0.1	4
7	13.2	14.3	-1.1	1	13.4	-0.2	2	13.5	-0.3	3
8	15.0	14.9	0.1	7	14.5	0.5	10	14.6	0.4	9
9	16.3	16.2	-0.1	5	16.3	0.0	6	16.2	0.1	7
10	16.0	14.9	1.1	10	16.1	-0.1	5	16.0	0.0	6

STANDARD ERROR OF ESTIMATE		0.62	0.31		0.39
FRACTION OF EXPLAINED VARIANCE		0.584	0.911		0.839
F-RATIO FOR THE REGRESSION		11.2	36.0		91.8
DETERMINANT OF THE CORRELATION MATRIX		1.00	0.71		1.00
COEFFICIENTS:	ESTIMATED ERROR	0.04482	0.09596	0.21957	0.10173
	F-RATIO	11.2	31.0	5.7	41.8
	T-RATIO	3.3	5.6	2.4	6.5
	COVARIANCE RATIO	0.00	0.29		0.00

TABLE XVI

n-PARAFFIN COMPOSITION CALCULATED USING FUEL VARIABLES

n-PARAFFIN CARBON NUMBER SEMI-INTERQUARTILE RANGE

FUEL NO.	OBS	n-PARAFFIN RANGE= 0.3890 +0.7044 DIST. SLOPE			n-PARAFFIN RANGE= 1.640 +0.05592 CLOUD		
		CALC	OBS-CALC	ERROR ORDER	CALC	OBS-CALC	ERROR ORDER
1	2.55	2.64	-0.09	3	2.31	0.24	7
2	2.05	2.00	0.05	7	2.42	-0.37	2
3	2.15	1.97	0.18	10	2.20	-0.05	6
4	1.75	1.94	-0.19	1	1.86	-0.11	3
5	1.50	1.51	-0.01	5	1.19	0.31	9
6	2.80	2.71	0.09	9	2.87	-0.07	4
7	2.90	2.92	-0.02	4	2.65	0.25	8
8	2.25	2.20	0.04	6	2.31	-0.06	5
9	1.50	1.42	0.08	8	2.09	-0.59	1
10	1.55	1.69	-0.14	2	2.65	0.45	10

		DIST. SLOPE	CLOUD
STANDARD ERROR OF ESTIMATE		0.119	0.341
FRACTION OF EXPLAINED VARIANCE		0.955	0.686
F-RATIO FOR THE REGRESSION		169.1	17.5
COEFFICIENTS:	ESTIMATED ERROR	0.054167	0.013370
	F-RATIO	169.1	17.5
	T-RATIO	13.0	4.2

TABLE XVII

n-PARAFFIN COMPOSITION CALCULATED USING FUEL VARIABLES

n-PARAFFIN 25% CARBON NUMBER

		n-P 25% = 17.87 -1.366 DIST SLOPE			n-P 25% = 16.57 -1.520 DIST SLOPE			n-P 25% = -6.207 +1.276 n-P MEDIAN		
FUEL NO.	OBS.	CALC.	OBS.- CALC.	ERROR ORDER	CALC.	OBS.- CALC.	ERROR ORDER	CALC.	OBS.- CALC.	ERROR ORDER
1	12.8	12.5	0.3	8	11.7	1.1	10	13.7	-0.9	1
2	12.5	13.0	-0.5	1	13.1	-0.6	2	12.7	-0.2	3
3	13.1	13.3	-0.2	5	13.2	-0.1	6	13.1	0.0	5
4	13.3	12.8	0.5	9	13.2	0.1	7	12.5	0.8	10
5	13.4	13.8	-0.4	2	14.2	-0.8	1	12.8	0.6	9
6	11.5	11.3	0.2	7	11.6	-0.1	5	11.7	-0.2	4
7	10.6	10.9	-0.3	4	11.1	-0.5	3	10.6	0.0	5
8	12.3	12.6	-0.3	3	12.7	-0.4	4	12.9	-0.6	2
9	14.8	15.0	-0.2	6	14.4	0.4	8	14.5	0.2	7
10	14.5	13.7	0.8	10	13.8	0.7	9	14.2	0.3	8

STANDARD ERROR OF ESTIMATE		0.51		0.64	0.54
FRACTION OF EXPLAINED VARIANCE		0.873		0.774	0.839
F-RATIO FOR THE REGRESSION		24.1		27.4	41.8
DETERMINANT OF THE CORRELATION MATRIX		0.93		1.00	1.00
COEFFICIENTS:	ESTIMATED ERROR	0.2419	0.037617	0.1905	0.1973
	F-RATIO	31.9	5.5	27.4	41.8
	T-RATIO	5.6	2.3	5.2	6.5
	COVARIANCE RATIO	0.07		0.0	0.0

TABLE XVIII

n-PARAFFIN COMPOSITION CALCULATED USING FUEL VARIABLES

n-PARAFFIN 75% CARBON NUMBER

		n-P 75% = 18.61 -0.1158 n-PARAFFINS +0.1425 n-P @ 20 F			n-P 75% = 18.89 -0.09455 n-PARAFFINS		
FUEL NO.	OBS.	CALC.	OBS.- CALC.	ERROR ORDER	CALC.	OBS.- CALC.	ERROR ORDER
1	17.9	17.7	0.2	8	17.8	0.1	7
2	16.6	17.0	-0.4	1	17.0	-0.4	2
3	17.4	17.3	0.1	7	17.3	0.1	6
4	16.8	16.5	0.3	10	16.6	0.2	8
5	16.4	16.6	-0.2	2	16.9	-0.5	1
6	17.1	16.8	0.3	9	16.7	0.4	9
7	16.5	16.6	-0.1	4	16.7	-0.2	4
8	16.8	16.9	-0.1	5	17.0	-0.2	3
9	17.8	17.8	0.0	6	17.9	-0.1	5
10	17.6	17.7	-0.1	3	17.1	0.5	10

STANDARD ERROR OF ESTIMATE		0.26		0.35
FRACTION OF EXPLAINED VARIANCE		0.827		0.648
F-RATIO FOR THE REGRESSION		16.7		14.7
DETERMINANT OF THE CORRELATION MATRIX		0.85		1.00
COEFFICIENTS:	ESTIMATED ERROR	0.02008	0.05298	0.024632
	F-RATIO	33.2	7.2	14.7
	T-RATIO	5.8	2.7	3.8
	COVARIANCE RATIO	0.15		0.0

TABLE XIX

n-PARAFFIN SEPARATION VARIABLES FOR THE TEN MIDDLE DISTILLATE FUELS

n-PARAFFIN CONCENTRATION/TEMPERATURE PROFILES

FUEL NO.	CLOUD POINT F	n-PARAFFIN SEPARATION RATE WT%/ F	n-PARAFFIN CONCENTRATION, WT %					
			+10 F	0 F	-10 F	-20 F	-30 F	-40 F
1	+12	0.10	-----	1.01	1.86	2.68	4.28	5.10
2	+14	0.16	-----	2.21	2.52	4.50	7.24	9.69
3	+10	0.15	-----	1.21	3.00	5.06	5.67	8.87
4	+4	0.19	-----	-----	3.44	4.84	8.66	6.25
5	-8	0.30	-----	-----	1.18	4.64	4.96	9.60
6	+22	0.15	1.27	3.23	5.78	7.00	7.76	8.73
7	+18	0.12	0.67	2.56	3.82	3.93	5.92	7.38
8	+12	0.14	-----	1.11	3.08	6.06	4.44	5.70
9	+8	0.12	-----	0.90	1.99	3.20	3.83	5.86
10	+18	0.26	1.41	4.91	9.23	7.69	9.10	14.00
SUM	110	1.70				48.30		81.89
AVERAGE	11.0	0.170				4.830		8.190
STANDARD DEVIATION	8.1	0.061				1.692		2.375
RANGE: MAXIMUM	+22	0.30				9.10		14.00
MINIMUM	-8	0.10				3.00		5.10

TABLE XX

n-PARAFFIN SEPARATION VARIABLES FOR THE TEN MIDDLE DISTILLATE FUELS

SUMMARY OF n-PARAFFIN CARBON NUMBER/TEMPERATURE PROFILES

	MEDIAN							
FUEL NO.	INITIAL	|RATE| |C/ F|	+10 F	0 F	-10 F	-20 F	-30 F	-40 F
1	21.1	0.052	-----	20.5	20.1	19.6	18.7	18.4
2	20.7	0.066	-----	19.4	18.9	18.6	17.8	17.1
3	19.9	0.048	-----	19.4	18.8	18.5	18.1	17.5
4	19.1	0.048	-----	-----	18.4	17.9	17.1	17.4
5	17.0	0.020	-----	-----	17.0	16.7	16.7	16.4
6	22.0	0.070	21.4	20.5	19.7	19.0	18.4	17.9
7	22.1	0.076	21.5	20.5	20.0	19.1	18.4	17.7
8	19.6	0.048	-----	19.1	18.2	17.9	17.5	17.1
9	19.6	0.048	-----	19.2	18.7	18.2	17.8	17.3
10	19.0	0.038	18.8	18.6	17.8	17.5	17.1	16.9
SUM	200.1	0.514				183.0		173.7
AVERAGE	20.01	0.0514				18.30		17.37
STANDARD DEVIATION	1.46	0.0154				-		-
RANGE: MAXIMUM	22.1	0.076				19.6		18.4
MINIMUM	17.0	0.020				16.7		16.4

Note: The temperature change in the rates is expressed as the number of degrees below the fuel cloud points.

TABLE XX (continued)

n-PARAFFIN SEPARATION VARIABLES FOR THE TEN MIDDLE DISTILLATE FUELS

SUMMARY OF n-PARAFFIN CARBON NUMBER/TEMPERATURE PROFILES

		SEMI-INTERQUARTILE RANGE							
	FUEL NO.	INITIAL	RATE C/ F	+10 F	0 F	-10 F	-20 F	-30 F	-40 F
	1	1.02	0.0080	-----	1.15	1.15	1.25	1.40	1.40
	2	1.05	0.0088	-----	1.25	1.25	1.25	1.40	1.55
	3	0.75	0.0142	-----	1.10	1.00	0.95	1.35	1.40
	4	0.94	0.0113	-----	-----	1.10	1.20	1.45	1.30
	5	0.85	0.0000	-----	-----	0.85	0.85	0.80	0.85
	6	0.87	0.0177	1.00	1.30	1.50	1.55	1.80	1.90
	7	1.02	0.0143	1.20	1.25	1.35	1.50	1.70	1.90
	8	1.20	0.0000	-----	1.20	1.20	1.20	1.10	1.20
	9	1.05	0.0043	-----	1.10	1.10	1.15	1.25	1.20
	10	1.25	0.0000	1.30	1.25	1.25	1.25	1.25	1.20
SUM		10.00	0.0786				12.15		13.90
AVERAGE		1.000	0.00786				1.215		1.390
STANDARD DEVIATION		0.146	0.00624				-		-
RANGE:	MAXIMUM	1.25	0.177				1.55		1.90
	MINIMUM	0.75	0.000				0.85		0.85

Note: The temperature change in the rates is expressed as the number of degrees below the fuel cloud points.

TABLE XXI

COMPLETE n-PARAFFIN CARBON NUMBER/ TEMPERATURE PROFILES FOR FUEL NO. 1

FUEL CLOUD POINT: +12 F

CARBON	BASE		0 F		-10 F	
NUMBER	WT%	CUM.%	WT%	CUM.%	WT%	CUM.%
8	0.08	0.67	--	--	--	--
9	0.28	3.01	--	--	--	--
10	0.36	6.04	--	--	--	--
11	0.70	11.90	--	--	--	--
12	0.91	19.53	--	--	--	--
13	0.85	26.66	--	--	--	--
14	1.00	35.04	--	--	--	--
15	1.05	43.84	--	--	--	--
16	1.26	54.40	TR.	0.22	0.01	0.30
17	1.35	65.72	0.01	1.53	0.04	2.58
18	1.18	75.61	0.05	6.95	0.14	10.01
19	1.06	84.49	0.12	18.95	0.29	25.81
20	0.77	90.95	0.19	38.22	0.41	47.96
21	0.53	95.39	0.24	61.60	0.40	69.51
22	0.34	98.24	0.19	80.16	0.29	85.37
23	0.16	99.58	0.12	91.60	0.16	93.79
24	0.05	100.00	0.06	97.19	0.08	97.85
25	--	--	0.02	99.16	0.03	99.42
26	--	--	0.01	99.74	0.01	99.86
27	--	--	TR.	100.03	TR.	100.03
n-PARAFFINS	11.93		1.01		1.86	
PARAFFINS	--		--		--	
NAPHTHENES	--		--		--	
AROMATICS	--		--		--	
SOLIDS	--		1.02		1.88	

TABLE XXI (continued)

COMPLETE n-PARAFFIN CARBON NUMBER/ TEMPERATURE PROFILES FOR FUEL NO. 1

FUEL CLOUD POINT: +12 F

CARBON	-20 F		-30 F		-40 F	
NUMBER	WT%	CUM.%	WT%	CUM.%	WT%	CUM.%
8	--	--	--	--	--	--
9	--	--	--	--	--	--
10	--	--	--	--	--	--
11	--	--	--	--	--	--
12	--	--	--	--	--	--
13	--	--	--	--	--	--
14	0.01	0.19	0.01	0.15	--	--
15	0.01	0.54	0.04	1.20	0.06	1.23
16	0.04	1.88	0.20	5.89	0.34	7.94
17	0.13	6.88	0.52	18.03	0.78	23.14
18	0.34	19.48	0.79	36.36	0.96	41.88
19	0.51	38.57	0.88	56.88	0.92	59.96
20	0.56	59.67	0.71	73.57	0.78	75.20
21	0.47	77.54	0.52	85.71	0.61	87.11
22	0.32	89.31	0.33	93.42	0.38	94.44
23	0.18	96.24	0.17	97.46	0.19	98.06
24	0.08	99.19	0.08	99.26	0.08	95.56
25	0.03	100.31	0.03	99.85	0.02	100.00
26	0.01	100.58	0.01	100.00	--	--
27	--	--	--	--	--	--
n-PARAFFINS	2.68		4.28		5.10	
PARAFFINS	--		--		5.09	
NAPHTHENES	--		--		0.15	
AROMATICS	--		--		0.03	
SOLIDS	3.08		4.57		5.26	

TABLE XXII

COMPLETE n-PARAFFIN CARBON NUMBER/ TEMPERATURE PROFILES FOR FUEL NO. 2

FUEL CLOUD POINT: +14 F

CARBON	BASE		0 F		-20 F	
NUMBER	WT%	CUM.%	WT%	CUM.%	WT%	CUM.%
8	0.06	0.30	--	--	--	--
9	0.17	1.13	--	--	--	--
10	0.58	3.98	--	--	--	--
11	1.26	10.16	--	--	--	--
12	1.86	19.29	--	--	--	--
13	2.26	30.39	--	--	TR.	0.08
14	2.34	41.88	TR.	0.19	0.01	0.33
15	2.36	53.46	0.01	0.62	0.02	1.28
16	2.26	64.56	0.04	2.30	0.11	5.83
17	2.05	74.62	0.12	7.94	0.23	14.94
18	1.65	82.72	0.27	20.26	0.43	31.94
19	1.38	89.50	0.43	39.70	0.52	52.49
20	0.92	94.01	0.49	61.93	0.48	71.72
21	0.64	97.16	0.42	80.73	0.36	85.79
22	0.36	98.92	0.25	92.06	0.20	93.99
23	0.16	98.71	0.11	97.13	0.09	97.73
24	0.06	100.00	0.04	99.23	0.04	99.23
25	--	--	0.02	99.68	0.02	99.83
26	--	--	0.01	99.92	TR.	100.00
27	--	--	TR.	100.00	TR.	100.08
n-PARAFFINS	20.37		2.21		2.52	
PARAFFINS	--		--		--	
NAPHTHENES	--		--		--	
AROMATICS	--		--		--	
SOLIDS	--		2.46		2.55	

TABLE XXII (continued)

COMPLETE n-PARAFFIN CARBON NUMBER/ TEMPERATURE PROFILES FOR FUEL NO. 2

FUEL CLOUD POINT: +14 F

CARBON NUMBER	-20 F		-30 F		-40 F	
	WT%	CUM.%	WT%	CUM.%	WT%	CUM.%
8	--	--	--	--	--	--
9	--	--	--	--	--	--
10	--	--	--	--	--	--
11	--	--	--	--	--	--
12	--	--	--	--	--	--
13	--	--	0.03	0.41	0.11	1.01
14	--	--	0.12	2.01	0.41	5.30
15	0.05	1.01	0.38	7.20	0.83	13.83
16	0.21	5.75	0.83	18.66	1.59	30.22
17	0.52	17.35	1.36	37.43	1.81	48.86
18	0.89	37.11	1.34	55.94	1.53	64.65
19	0.97	58.65	1.20	72.45	1.24	77.46
20	0.79	76.18	0.88	84.58	0.95	87.30
21	0.56	88.55	0.60	92.82	0.64	93.93
22	0.32	95.73	0.35	97.62	0.38	97.85
23	0.13	96.56	0.13	99.48	0.16	99.47
24	0.04	99.51	0.04	99.94	0.05	100.00
25	0.02	100.00	--	--	--	--
26	--	--	--	--	--	--
27	--	--	--	--	--	--
n-PARAFFINS	4.50		7.24		9.69	
PARAFFINS	--		--		10.97	
NAPHTHENES	--		--		1.29	
AROMATICS	--		--		0.15	
SOLIDS	4.97		9.63		12.40	

TABLE XXIII

COMPLETE n-PARAFFIN CARBON NUMBER/ TEMPERATURE PROFILES FOR FUEL NO. 3

FUEL CLOUD POINT: +10 F

CARBON NUMBER	BASE		0 F		-10 F	
	WT%	CUM.%	WT%	CUM.%	WT%	CUM%
8	0.04	0.24	--	--	--	--
9	0.27	1.86	--	--	--	--
10	0.64	5.70	--	--	--	--
11	0.73	10.08	--	--	--	--
12	0.79	14.82	--	--	--	--
13	1.42	23.34	--	--	--	--
14	1.86	34.50	--	--	TR.	0.13
15	2.19	47.65	TR.	0.14	0.02	0.73
16	2.08	60.14	0.01	1.35	0.09	3.88
17	1.91	71.61	0.06	6.51	0.23	11.56
18	1.46	80.37	0.14	18.52	0.42	25.65
19	1.45	89.07	0.27	41.22	0.92	56.25
20	0.99	95.01	0.31	67.22	0.62	76.96
21	0.54	98.25	0.24	87.26	0.44	91.47
22	0.21	99.51	0.11	96.37	0.19	97.89
23	0.06	99.87	0.03	99.07	0.05	99.57
24	0.02	99.99	0.01	99.80	0.01	99.99
25	--	--	TR.	100.00	--	--
n-PARAFFINS	16.66		1.21		3.00	
PARAFFINS	--		--		--	
NAPHTHENES	--		--		--	
AROMATICS	--		--		--	
SOLIDS	--		1.22		3.16	

TABLE XXIII (continued)

COMPLETE n-PARAFFIN CARBON NUMBER/ TEMPERATURE PROFILES FOR FUEL NO. 3

FUEL CLOUD POINT: +10 F

CARBON	-20 F		-30 F		-40 F	
NUMBER	WT%	CUM.%	WT%	CUM.%	WT%	CUM.%
8	--	--	--	--	--	--
9	--	--	--	--	--	--
10	--	--	--	--	--	--
11	--	--	--	--	--	--
12	--	--	--	--	--	--
13	--	--	--	--	TR.	0.37
14	0.01	0.26	0.02	0.41	0.15	2.06
15	0.09	1.98	0.14	2.89	0.54	8.15
16	0.38	9.51	0.50	11.74	1.20	21.63
17	0.86	26.55	0.97	28.92	1.73	41.03
18	1.07	47.91	1.14	49.09	1.58	58.75
19	1.00	67.73	1.03	67.30	1.50	75.59
20	0.77	82.92	0.95	83.96	1.11	88.05
21	0.49	92.56	0.58	94.25	0.70	95.89
22	0.25	97.58	0.24	98.53	0.29	99.10
23	0.10	99.57	0.07	99.71	0.07	99.90
24	0.03	100.23	0.02	100.00	0.01	100.00
25	--	--	TR.	100.06	--	--
n-PARAFFINS	5.06		5.67		8.87	
PARAFFINS	--		--		8.08	
NAPHTHENES	--		--		0.99	
AROMATICS	--		--		0.36	
SOLIDS	6.68		5.83		9.43	

TABLE XXIV

COMPLETE n-PARAFFIN CARBON NUMBER/ TEMPERATURE PROFILES FOR FUEL NO. 4

FUEL CLOUD POINT: +4 F

CARBON NUMBER	BASE		-10 F		-20 F	
	WT%	CUM.%	WT%	CUM.%	WT%	CUM.%
11	0.47	1.96	--	--	--	--
12	1.73	9.17	--	--	--	--
13	2.50	19.59	TR.	--	--	--
14	4.94	40.18	0.01	0.14	0.02	0.43
15	3.20	53.52	0.04	1.27	0.13	3.01
16	2.64	64.52	0.15	5.72	0.45	12.30
17	3.00	77.00	0.46	19.13	0.94	31.72
18	2.10	85.78	0.68	38.79	0.98	52.07
19	1.64	92.62	0.92	65.48	1.05	73.82
20	1.18	97.54	0.64	83.93	0.69	88.15
21	0.48	99.54	0.35	94.18	0.38	95.91
22	0.11	99.99	0.15	98.43	0.14	98.89
23	--	--	0.04	99.67	0.04	99.80
24	--	--	0.01	100.01	0.01	100.00
n-PARAFFINS	23.99		3.44		4.84	
SOLIDS	--		3.44		4.93	

TABLE XXIV (continued)

COMPLETE n-PARAFFIN CARBON NUMBER/ TEMPERATURE PROFILES FOR FUEL NO. 4

FUEL CLOUD POINT: +4 F

CARBON NUMBER	-30 F		-40 F	
	WT%	CUM.%	WT%	CUM.%
11	--	--	--	--
12	--	--	--	--
13	0.08	0.86	--	--
14	0.33	4.62	0.08	1.20
15	0.85	14.39	0.41	7.74
16	1.46	31.25	0.90	22.11
17	1.57	49.36	1.35	43.69
18	1.46	66.29	1.17	62.38
19	1.34	81.74	1.11	80.12
20	0.83	91.34	0.68	90.97
21	0.44	96.43	0.38	97.01
22	0.25	99.33	0.13	99.12
23	0.05	99.86	0.04	99.80
24	0.01	100.00	0.01	100.00
n-PARAFFINS	8.66		6.25	
SOLIDS	8.90		7.90	

TABLE XXV

COMPLETE n-PARAFFIN CARBON NUMBER/ TEMPERATURE PROFILES FOR FUEL NO. 5

FUEL CLOUD POINT: -8 F

CARBON NUMBER	BASE		-10 F		-20 F	
	WT%	CUM.%	WT%	CUM.%	WT%	CUM.%
10	0.26	1.21	--	--	--	--
11	0.70	4.46	--	--	--	--
12	0.94	8.83	--	--	--	--
13	2.05	18.36	--	--	0.01	0.21
14	3.65	36.31	TR.	0.20	0.07	1.59
15	3.36	53.28	0.04	3.62	0.33	8.40
16	3.86	68.90	0.17	18.11	1.01	29.47
17	3.20	83.77	0.37	49.72	1.52	61.15
18	2.35	94.70	0.32	76.54	1.06	83.16
19	0.90	98.46	0.21	94.02	0.62	96.03
20	0.24	99.58	0.06	99.14	0.16	99.43
21	--	--	0.01	100.00	0.03	100.00
n-PARAFFINS	21.51		1.18		4.64	
SOLIDS	--		1.44		4.88	

TABLE XXV (continued)

COMPLETE n-PARAFFIN CARBON NUMBER/ TEMPERATURE PROFILES FOR FUEL NO. 5

CARBON NUMBER	-30 F		-40 F	
	WT%	CUM.%	WT%	CUM.%
10	--	--	--	--
11	--	--	--	--
12	--	--	--	--
13	--	--	--	--
14	0.04	0.81	0.19	1.12
15	0.31	7.20	0.95	11.06
16	1.07	28.67	2.47	36.73
17	1.62	61.29	3.01	68.08
18	1.09	83.12	1.82	87.01
19	0.63	95.78	0.88	96.12
20	0.18	99.35	0.24	98.61
21	0.03	100.00	0.05	99.11
n-PARAFFINS	4.96		9.60	
SOLIDS	4.97		11.36	

TABLE XXVI

COMPLETE n-PARAFFIN CARBON NUMBER/ TEMPERATURE PROFILES FOR FUEL NO. 6

FUEL CLOUD POINT: +22 F

CARBON	BASE		+10 F		0 F		-10 F	
NUMBER	WT%	CUM.%	WT%	CUM.%	WT%	CUM.%	WT%	CUM.%
8	0.25	1.07	--	--	--	--	--	--
9	0.60	3.63	--	--	--	--	--	--
10	1.54	10.20	--	--	--	--	--	--
11	2.57	21.26	--	--	--	--	--	--
12	2.18	30.46	--	--	--	--	TR.	--
13	2.18	39.76	--	--	--	--	0.03	0.54
14	2.37	49.87	--	--	--	--	0.05	1.47
15	2.11	58.87	--	--	0.01	0.36	0.10	3.13
16	1.96	67.27	--	--	0.03	1.16	0.16	5.90
17	1.65	74.28	0.01	0.47	0.08	3.55	0.35	11.97
18	1.55	80.89	0.03	3.08	0.18	9.16	0.62	22.63
19	1.40	86.86	0.07	8.90	0.37	20.59	0.89	38.07
20	1.01	91.17	0.16	21.31	0.58	38.54	0.98	55.04
21	0.84	94.75	0.25	41.23	0.67	59.29	0.96	71.56
22	0.66	97.57	0.33	67.16	0.66	79.69	0.85	86.21
23	0.40	99.28	0.29	90.00	0.47	94.16	0.57	95.99
24	0.17	100.00	0.11	98.29	0.16	99.01	0.19	99.26
25	--	--	0.02	99.64	0.03	99.99	0.04	100.00
26	--	--	0.01	99.94	--	--	--	--
27	--	--	TR.	100.00	--	--	--	--
n-PARAFFINS	23.44		1.27		3.23		5.78	
SOLIDS	--		1.32		3.30		5.90	

TABLE XXVI (continued)

COMPLETE n-PARAFFIN CARBON NUMBER/ TEMPERATURE PROFILES FOR FUEL NO. 6

CARBON	-20 F		-30 F		-40 F	
NUMBER	WT%	CUM.%	WT%	CUM.%	WT%	CUM.%
8	--	--	--	--	--	--
9	--	--	--	--	--	--
10	--	--	--	--	--	--
11	--	--	--	--	--	--
12	--	--	--	--	--	--
13	--	--	0.06	0.72	0.03	0.39
14	0.02	0.26	0.16	2.73	0.19	2.52
15	0.11	1.82	0.35	7.29	0.57	9.07
16	0.41	7.63	0.69	16.18	1.16	22.34
17	0.81	19.16	1.01	30.05	1.34	37.71
18	1.10	34.92	1.17	45.17	1.20	51.43
19	1.12	50.95	1.11	59.48	1.07	63.73
20	1.01	65.42	1.00	72.40	0.95	74.58
21	0.88	78.01	0.84	83.18	0.84	84.22
22	0.79	89.29	0.69	92.00	0.73	92.60
23	0.53	96.79	0.44	97.68	0.46	97.83
24	0.18	99.39	0.14	99.52	0.16	99.60
25	0.04	100.00	0.04	100.00	0.04	100.00
26	--	--	--	--	--	--
27	--	--	--	--	--	--
n-PARAFFINS	7.00		7.76		8.73	
SOLIDS	7.28		10.93		12.00	

TABLE XXVII

COMPLETE n-PARAFFIN CARBON NUMBER/ TEMPERATURE PROFILES FOR FUEL NO. 7

FUEL CLOUD POINT: +18 F

CARBON NUMBER	BASE		+10 F		0 F		-10 F	
	WT%	CUM.%	WT%	CUM.%	WT%	CUM.%	WT%	CUM.%
8	0.36	1.55	--	--	--	--	--	--
9	1.29	7.09	--	--	--	--	--	--
10	2.59	18.22	--	--	--	--	--	--
11	2.58	29.27	--	--	--	--	--	--
12	2.22	38.81	--	--	--	--	--	--
13	2.04	47.57	--	--	--	--	TR.	0.11
14	1.97	56.04	--	--	TR.	0.07	0.01	0.37
15	1.84	63.95	--	--	0.01	0.31	0.02	0.80
16	1.69	71.21	TR.	0.09	0.02	0.92	0.04	1.95
17	1.66	78.34	TR.	0.62	0.05	2.90	0.14	5.65
18	1.33	84.06	0.01	2.49	0.15	8.58	0.35	14.94
19	1.15	89.00	0.04	7.94	0.31	20.71	0.57	29.91
20	0.90	92.87	0.08	19.65	0.46	38.74	0.73	48.97
21	0.68	95.79	0.13	39.46	0.56	60.64	0.71	67.62
22	0.49	97.90	0.15	62.31	0.45	78.30	0.57	82.56
23	0.29	99.14	0.12	80.16	0.29	89.54	0.36	92.10
24	0.16	99.83	0.08	92.25	0.17	96.08	0.20	97.23
25	0.04	100.00	0.03	97.44	0.07	98.74	0.08	99.23
26	--	--	0.01	99.24	0.02	99.61	0.02	99.86
27	--	--	TR.	99.85	0.01	99.89	0.01	100.00
28	--	--	TR.	99.99	TR.	99.99	--	--
n-PARAFFINS	23.27		0.67		2.56		3.82	
SOLIDS	--		0.68		2.64		3.96	

TABLE XXVII (continued)

COMPLETE n-PARAFFIN CARBON NUMBER/ TEMPERATURE PROFILES FOR FUEL NO. 7

CARBON NUMBER	-20 F		-30 F		-40 F	
	WT%	CUM.%	WT%	CUM.%	WT%	CUM.%
8	--	--	--	--	--	--
9	--	--	--	--	--	--
10	--	--	--	--	--	--
11	--	--	0.02	0.30	0.04	0.47
12	0.01	0.24	0.05	1.18	0.08	1.52
13	0.02	0.80	0.09	2.65	0.13	3.23
14	0.03	1.55	0.13	4.80	0.23	6.32
15	0.05	2.71	0.22	8.58	0.45	12.44
16	0.12	5.68	0.44	16.01	0.85	23.88
17	0.29	12.96	0.75	28.69	1.16	39.64
18	0.52	26.18	0.95	44.68	1.11	54.64
19	0.66	42.97	0.89	59.71	0.96	67.60
20	0.69	60.51	0.77	72.66	0.80	78.48
21	0.61	75.96	0.63	83.36	0.67	87.49
22	0.45	87.40	0.47	91.33	0.47	93.90
23	0.28	94.38	0.27	95.95	0.28	97.73
24	0.16	98.40	0.16	98.66	0.14	99.61
25	0.06	99.81	0.06	99.70	0.03	99.64
26	0.01	100.05	0.02	100.00	--	--
27	--	--	--	--	--	--
28	--	--	--	--	--	--
n-PARAFFINS	3.93		5.92		7.38	
SOLIDS	5.84		10.60		13.85	

TABLE XXVIII

COMPLETE n-PARAFFIN CARBON NUMBER/ TEMPERATURE PROFILES FOR FUEL NO. 8

FUEL CLOUD POINT: +12 F

CARBON	BASE		0 F		-10 F	
NUMBER	WT%	CUM.%	WT%	CUM.%	WT%	CUM.%
8	0.16	0.82	--	--	--	--
9	0.46	3.19	--	--	--	--
10	1.00	8.33	--	--	--	--
11	1.45	15.78	--	--	--	--
12	1.38	22.88	--	--	--	--
13	1.56	30.90	--	--	--	--
14	1.87	40.51	--	--	0.02	0.48
15	2.32	52.44	0.01	0.46	0.02	2.87
16	2.56	65.00	0.02	2.57	0.25	10.41
17	2.18	76.81	0.08	9.98	0.50	26.36
18	1.62	85.14	0.17	25.06	0.62	46.95
19	1.35	92.08	0.24	46.52	0.61	66.72
20	0.81	96.25	0.24	67.84	0.45	81.17
21	0.42	98.41	0.18	84.24	0.28	90.18
22	0.21	99.49	0.10	93.57	0.18	96.14
23	0.07	99.85	0.05	97.80	0.07	98.46
24	0.03	100.00	0.02	99.40	0.04	99.58
25	--	--	0.01	99.88	0.01	100.00
26	--	--	TR.	100.00	--	--
n-PARAFFINS	19.45		1.11		3.08	
PARAFFINS	--		--		--	
NAPHTHENES	--		--		--	
AROMATICS	--		--		--	
SOLIDS	--		1.34		3.30	

TABLE XXVIII (continued)

COMPLETE n-PARAFFIN CARBON NUMBER/ TEMPERATURE PROFILES FOR FUEL NO. 8

FUEL CLOUD POINT: +12 F

CARBON NUMBER	-20 F		-30 F		-40 F	
	WT%	CUM.%	WT%	CUM.%	WT%	CUM.%
8	--	--	--	--	--	--
9	--	--	--	--	--	--
10	--	--	--	--	--	--
11	--	--	--	--	--	--
12	--	--	--	--	--	--
13	--	--	--	--	--	--
14	--	--	0.01	0.30	0.06	1.07
15	0.08	1.34	0.14	3.45	0.38	7.76
16	0.52	9.89	0.48	14.48	0.92	23.72
17	1.18	29.37	1.16	39.90	1.50	49.91
18	1.38	52.12	0.91	60.71	1.07	68.57
19	1.21	72.87	1.02	83.88	1.09	87.58
20	0.86	86.29	0.46	94.46	0.50	96.31
21	0.52	94.80	0.19	98.74	0.18	99.48
22	0.24	98.70	0.05	99.87	0.03	100.00
23	0.07	99.83	0.01	100.02	--	--
24	0.01	100.00	TR.	100.05	--	--
25	--	--	--	--	--	--
26	--	--	--	--	--	--
n-PARAFFINS	6.06		4.44		5.70	
PARAFFINS	--		--		6.69	
NAPHTHENES	--		--		0.44	
AROMATICS	--		--		0.12	
SOLIDS	6.38		4.94		7.25	

TABLE XXIX

COMPLETE n-PARAFFIN CARBON NUMBER/ TEMPERATURE PROFILES FOR FUEL NO. 9

FUEL CLOUD POINT: +8 F

CARBON	BASE		0 F		-10 F	
NUMBER	WT%	CUM.%	WT%	CUM.%	WT%	CUM.%
11	0.11	1.04	--	--	--	--
12	0.21	3.03	--	--	--	--
13	0.43	7.11	--	--	--	--
14	0.78	14.51	--	--	--	--
15	1.36	27.41	--	--	0.01	0.44
16	1.81	44.58	0.02	1.53	0.05	2.94
17	1.97	63.27	0.07	8.48	0.22	13.90
18	1.40	76.55	0.15	23.33	0.38	33.21
19	1.20	87.94	0.22	46.18	0.47	56.77
20	0.71	94.68	0.23	69.70	0.43	78.27
21	0.35	98.00	0.16	85.88	0.26	91.28
22	0.13	99.23	0.08	93.85	0.11	96.96
23	0.06	99.80	0.04	97.82	0.05	99.42
24	0.02	99.99	0.02	99.48	0.01	100.00
25	--	--	0.01	100.00	--	--
n-PARAFFINS	10.54		0.90		1.99	
PARAFFINS	--		--		--	
NAPHTHENES	--		--		--	
AROMATICS	--		--		--	
SOLIDS	--		1.00		2.72	

TABLE XXIX (continued)

COMPLETE n-PARAFFIN CARBON NUMBER/ TEMPERATURE PROFILES FOR FUEL NO. 9

FUEL CLOUD POINT: +8 F

CARBON NUMBER	-20 F		-30 F		-40 F	
	WT%	CUM.%	WT%	CUM.%	WT%	CUM.%
11	--	--	--	--	--	--
12	--	--	--	--	--	--
13	--	--	--	--	--	--
14	0.01	0.18	0.01	0.27	0.17	1.26
15	0.03	1.16	0.07	2.01	0.26	5.72
16	0.19	6.99	0.32	10.51	0.77	18.80
17	0.55	24.25	0.79	31.22	1.38	42.33
18	0.71	46.48	0.87	53.85	1.22	63.10
19	0.69	68.00	0.75	73.46	0.92	78.74
20	0.53	84.41	0.51	86.84	0.65	89.78
21	0.28	93.25	0.29	94.45	0.34	95.65
22	0.13	97.24	0.13	97.82	0.16	98.34
23	0.06	99.10	0.06	99.39	0.07	99.54
24	0.02	99.82	0.02	100.00	0.03	100.00
25	0.01	100.00	--	--	--	--
n-PARAFFINS	3.20		3.83		5.86	
PARAFFINS	--		--		7.97	
NAPHTHENES	--		--		3.15	
AROMATICS	--		--		1.17	
SOLIDS	4.18		5.71		12.30	

TABLE XXX

COMPLETE n-PARAFFIN CARBON NUMBER/ TEMPERATURE PROFILES FOR FUEL NO. 10

FUEL CLOUD POINT: +18 F

CARBON	BASE		+10 F		0 F		-10 F	
NUMBER	WT%	CUM.%	WT%	CUM.%	WT%	CUM.%	WT%	CUM.%
9	0.05	0.26	--	--	--	--	--	--
10	0.14	0.98	--	--	--	--	--	--
11	0.29	2.48	--	--	--	--	--	--
12	0.54	5.27	--	--	--	--	--	--
13	0.99	10.39	--	--	--	--	0.02	0.24
14	1.61	18.71	TR.	0.15	0.02	0.35	0.07	1.02
15	2.73	32.83	0.01	1.02	0.08	1.97	0.27	3.94
16	3.61	51.50	0.05	4.87	0.27	7.21	0.90	13.64
17	3.13	67.68	0.16	16.43	0.68	21.08	1.84	33.58
18	2.30	79.57	0.23	32.87	0.84	35.12	1.99	55.12
19	1.90	89.39	0.30	54.03	1.04	59.74	1.74	73.99
20	1.09	95.03	0.28	73.53	0.89	77.88	1.19	86.88
21	0.57	97.95	0.20	87.46	0.66	91.33	0.68	94.23
22	0.26	99.32	0.11	95.26	0.28	97.03	0.35	97.99
23	0.09	99.79	0.04	98.44	0.10	99.08	0.13	99.39
24	0.02	99.89	0.02	99.56	0.04	99.80	0.04	99.82
25	0.02	99.99	0.01	99.89	0.01	100.01	0.02	100.00
26	--	--	TR.	100.00	--	--	--	--
n-PARAFFINS	19.34		1.41		4.91		9.23	
PARAFFINS	--		--		--		--	
NAPHTHENES	--		--		--		--	
AROMATICS	--		--		--		--	
SOLIDS	--		1.44		5.18		9.80	

TABLE XXX (continued)

COMPLETE n-PARAFFIN CARBON NUMBER/ TEMPERATURE PROFILES FOR FUEL NO. 10

CARBON	-20 F		-30 F		-40 F	
NUMBER	WT%	CUM.%	WT%	CUM.%	WT%	CUM.%
9	--	--	--	--	--	--
10	--	--	--	--	--	--
11	--	--	--	--	--	--
12	--	--	--	--	--	--
13	--	--	0.10	0.91	0.09	0.63
14	0.06	0.78	0.22	3.01	0.30	2.80
15	0.27	4.29	0.78	10.30	1.23	11.59
16	0.96	16.75	1.64	25.64	2.71	30.98
17	1.72	39.06	2.51	49.19	3.41	55.34
18	1.62	60.15	2.05	68.43	2.38	72.32
19	1.34	77.50	1.47	82.20	1.75	84.80
20	0.91	89.27	0.95	91.14	1.17	93.13
21	0.53	96.13	0.54	96.17	0.60	97.40
22	0.24	99.22	0.27	98.66	0.27	99.30
23	0.06	100.00	0.10	99.57	0.10	99.67
24	--	--	0.05	100.00	0.05	100.00
25	--	--	--	--	0.01	100.01
26	--	--	--	--	--	--
n-PARAFFINS	7.69		9.10		14.00	
PARAFFINS	--		--		17.12	
NAPHTHENES	--		--		4.68	
AROMATICS	--		--		1.54	
SOLIDS	11.82		10.66		23.34	

TABLE XXXI

n-PARAFFIN SEPARATION CALCULATED FROM FUEL VARIABLES

n-PARAFFIN SEPARATION RATE, WT %/ F

		n-P SEP. = 0.1950 -3.328|C MED. RATE| +.007669 n-PARAFFINS			n-P SEP. = 0.1222 -4.438|C MED. RATE| +.007153 PARAFFINS			n-P SEP. = 0.7264 -0.03323 C MED. INIT. +.005697 n-PARAFFINS		
FUEL NO.	OBS.	CALC.	OBS.- CALC.	ERROR ORDER	CALC.	OBS.- CALC.	ERROR ORDER	CALC.	OBS.- CALC.	ERROR ORDER
1	0.10	0.11	-0.01	3	0.10	0.00	4	0.09	0.01	7
2	0.16	0.13	0.03	9	0.12	0.04	10	0.15	0.01	6
3	0.16	0.16	0.00	4	0.16	0.00	5	0.16	0.00	5
4	0.19	0.22	-0.03	2	0.17	0.12	8	0.23	-0.04	2
5	0.30	0.29	0.01	7	0.30	0.00	6	0.28	0.02	8
6	0.15	0.14	0.01	8	0.15	0.00	7	0.13	0.02	9
7	0.12	0.12	0.00	5	0.14	-0.02	2	0.12	0.00	4
8	0.14	0.18	-0.04	1	0.19	-0.05	1	0.19	-0.05	1
9	0.12	0.12	0.00	6	0.14	-0.02	3	0.13	-0.01	3
10	0.26	0.22	0.04	10	0.24	0.02	9	0.20	0.06	10

STANDARD ERROR OF ESTIMATE		0.029		0.028		0.033	
FRACTION OF EXPLAINED VARIANCE		0.840		0.858		0.792	
F-RATIO FOR THE REGRESSION		18.4		19.8		13.29	
DETERMINANT OF THE CORRELATION MATRIX		0.95		0.67		1.00	
COEFFICIENTS:	ESTIMATED ERROR	.6066	.002095	.7062	.001869	.007185	.02346
	F-RATIO	30.1	13.4	39.5	14.6	21.4	5.9
	T-RATIO	5.5	3.7	6.3	3.8	4.6	2.4
	COVARIANCE RATIO	0.04		0.33		0.00	

Note: The temperature change in the rate is expressed as the number of degrees below the fuel cloud points.

TABLE XXXI (continued)

n-PARAFFIN SEPARATION CALCULATED FROM FUEL VARIABLES

n-PARAFFIN SEPARATION RATE, WT %/ F

		n-P SEP. = 0.8135 -0.04222 C MED. INIT			n-P SEP. = 0.8235 -0.03266 C MED. INIT		
FUEL NO.	OBS.	CALC.	OBS.- CALC.	ERROR ORDER	CALC.	OBS.- CALC.	ERROR ORDER
1	0.10	0.07	0.02	9	0.13	-0.03	3
2	0.16	0.15	0.01	6	0.15	0.01	6
3	0.16	0.16	0.00	5	0.17	-0.01	4
4	0.19	0.20	-0.01	4	0.20	-0.01	5
5	0.30	0.29	0.01	7	0.27	0.03	8
6	0.15	0.13	0.02	8	0.11	0.04	9
7	0.12	0.14	-0.02	3	0.10	0.02	7
8	0.14	0.19	-0.05	1	0.18	-0.04	2
9	0.12	0.15	-0.03	2	0.18	-0.06	1
10	0.26	0.22	0.04	10	0.20	0.06	10

STANDARD ERROR OF ESTIMATE		0.031		0.042
FRACTION OF EXPLAINED VARIANCE		0.810		0.616
F-RATIO FOR THE REGRESSION		15.3		12.8
DETERMINANT OF THE CORRELATION MATRIX		0.79		1.00
COEFFICIENTS:	ESTIMATED ERROR	.007630	.0019093	.009118
	F-RATIO	30.6	7.5	12.8
	T-RATIO	5.5	2.7	3.6
	COVARIANCE RATIO	0.21		0.00

Note: The temperature change in the rate is expressed as the number of degrees below the fuel cloud points.

TABLE XXXII

n-PARAFFIN SEPARATION CALCULATED FROM FUEL VARIABLES

INITIAL MEDIAN n-PARAFFIN CARBON NUMBER

		C MED. INIT. = 23.81 +0.1272 CLOUD -0.01209 DIST. 10%			C MED. INIT. = 28.66 + 0.1544 CLOUD -0.01970 DIST. VABP			C MED. INIT. = -1.862 +1.239 DIST. SLOPE +0.03025 DIST. 90%		
FUEL NO.	OBS.	CALC.	OBS.- CALC.	ERROR ORDER	CALC.	OBS.- CALC.	ERROR ORDER	CALC.	OBS.- CALC.	ERROR ORDER
1	21.1	20.9	0.2	7	20.6	0.5	8	21.0	0.1	6
2	20.7	20.3	0.4	8	20.6	0.1	6	19.7	1.0	10
3	19.9	19.8	0.1	6	19.7	0.2	7	19.5	0.4	8
4	19.1	19.1	0.0	5	19.3	-0.2	4	19.2	-1.5	1
5	17.0	17.4	-0.4	3	17.4	-0.4	3	17.3	-0.3	5
6	22.0	22.1	-0.1	4	22.1	-0.1	5	21.6	0.4	9
7	22.1	21.6	0.5	9	21.4	0.6	9	22.5	-0.4	4
8	19.6	20.2	-0.6	2	20.1	-0.5	2	20.4	-0.8	2
9	19.6	18.5	1.1	10	18.5	1.1	10	19.3	0.3	7
10	19.0	20.2	-1.2	1	20.4	-1.4	1	19.5	-0.5	3

STANDARD ERROR OF ESTIMATE		0.74		0.79		0.61	
FRACTION OF EXPLAINED VARIANCE		0.821		0.793		0.878	
F-RATIO FOR THE REGRESSION		16.0		13.4		25.2	
DETERMINANT OF THE CORRELATION MATRIX		0.90		0.99		0.71	
COEFFICIENTS:	ESTIMATED ERROR	0.03046	0.005202	0.03121	0.010208	0.3298	0.01000
	F-RATIO	17.4	5.4	24.5	3.7	14.1	9.2
	T-RATIO	4.2	2.3	4.9	1.9	3.8	3.0
	COVARIANCE RATIO	0.10		0.01		0.29	

TABLE XXXII (continued)

n-PARAFFIN SEPARATION CALCULATED FROM FUEL VARIABLES

INITIAL MEDIAN n-PARAFFIN CARBON NUMBER

		C MED. INIT. = 16.26 +1.145 DIST. SLOPE +0.08829 CLOUD			C MED. INIT. = -0.3567 +2.405 DIST. SLOPE +0.02765 DIST. VABP			C MED. INIT. = 15.69 +1.780 DIST. SLOPE		
FUEL NO.	OBS.	CALC.	OBS.- CALC.	ERROR ORDER	CALC.	OBS.- CALC.	ERROR ORDER	CALC.	OBS.- CALC.	ERROR ORDER
1	21.2	21.0	0.1	6	21.2	-0.1	6	21.3	-0.3	4
2	20.7	20.1	0.6	9	19.5	1.2	10	19.7	1.0	9
3	19.9	19.7	0.2	8	19.8	0.1	7	19.7	0.2	7
4	19.1	19.1	0.0	4	18.9	0.2	8	19.6	-0.5	3
5	17.0	17.4	-0.4	3	17.4	-0.4	4	18.5	-1.5	1
6	22.0	22.0	0.0	5	21.5	-0.5	3	21.6	0.4	8
7	22.1	22.0	0.1	7	22.3	-0.2	5	22.1	0.0	5
8	19.6	20.3	-0.7	2	20.5	-0.9	1	20.3	-0.7	2
9	19.6	18.6	1.0	10	19.2	0.4	9	18.3	1.3	10
10	19.0	20.0	-1.0	1	19.5	-0.5	2	19.0	0.0	6

STANDARD ERROR OF ESTIMATE		0.64		0.67		0.86
FRACTION OF EXPLAINED VARIANCE		0.866		0.849		0.719
F-RATIO FOR THE REGRESSION		22.6		19.7		20.5
DETERMINANT OF THE CORRELATION MATRIX		0.62		0.59		1.00
COEFFICIENTS:	ESTIMATED ERROR	0.03765	0.031904	0.3998	0.011260	0.3936
	F-RATIO	9.5	7.7	36.2	6.0	20.5
	T-RATIO	3.1	2.8	6.0	2.5	4.5
	COVARIANCE RATIO	0.38		0.41		0.00

TABLE XXXII (continued)

n-PARAFFIN SEPARATION CALCULATED FROM FUEL VARIABLES

INITIAL MEDIAN n-PARAFFIN CARBON NUMBER

C MED. INIT. =
15.39
+89.83|C MED. RATE|

FUEL NO.	OBS.	CALC.	OBS.-CALC.	ERROR ORDER
1	21.1	20.1	1.0	9
2	20.7	21.3	-0.6	1
3	19.9	19.7	0.2	7
4	19.1	19.7	-0.6	2
5	17.0	17.2	-0.2	3
6	22.0	21.7	0.3	8
7	22.1	22.2	-0.1	4
8	19.6	19.7	-0.1	5
9	19.6	19.7	-0.1	5
10	19.0	18.8	0.2	6

STANDARD ERROR OF ESTIMATE		0.51
FRACTION OF EXPLAINED VARIANCE		0.902
F-RATIO FOR THE REGRESSION		73.9
DETERMINANT OF THE CORRELATION MATRIX		1.00
COEFFICIENTS:	ESTIMATED ERROR	10.447
	F-RATIO	73.9
	T-RATIO	8.6
	COVARIANCE RATIO	0.0

TABLE XXXIII

n-PARAFFIN SEPARATION CALCULATED FROM FUEL VARIABLES

ABSOLUTE RATE OF CHANGE OF MEDIAN n-PARAFFIN CARBON NUMBER WITH TEMPERATURE, C/ F (ABS.)

		|C MED RATE| = 0.1376 +0.001524 CLOUD			|C MED RATE| = 0.03519 +0.001474 CLOUD			|C MED RATE| = -0.1496 +0.01005 C MED INIT.		
FUEL NO.	OBS.	CALC.	OBS.- CALC.	ERROR ORDER	CALC.	OBS.- CALC.	ERROR ORDER	CALC.	OBS.- CALC.	ERROR ORDER
1	0.052	0.057	-0.005	3	0.053	-0.001	5	0.062	-0.010	1
2	0.066	0.057	0.009	8	0.056	0.010	9	0.058	0.008	9
3	0.048	0.048	0.000	6	0.050	-0.002	4	0.050	-0.002	3
4	0.048	0.044	0.004	7	0.041	0.007	8	0.042	0.006	8
5	0.020	0.026	-0.006	2	0.023	-0.003	3	0.021	-0.001	5
6	0.070	0.072	-0.002	5	0.068	0.002	7	0.071	-0.001	4
7	0.076	0.065	0.011	9	0.062	0.014	10	0.072	0.004	7
8	0.048	0.052	-0.004	4	0.053	-0.005	2	0.047	0.001	6
9	0.048.	0.036	0.012	10	0.047	0.001	6	0.047	0.001	6
10	0.038	0.055	-0.017	1	0.062	-0.024	1	0.041	-0.003	2

STANDARD ERROR OF ESTIMATE	0.0102		0.0110	0.0054
FRACTION OF EXPLAINED VARIANCE	0.692		0.594	0.902
F-RATIO FOR THE REGRESSION	7.9		11.7	73.9
DETERMINANT OF THE CORRELATION MATRIX	0.99		1.00	1.00
COEFFICIENTS: ESTIMATED ERROR	.0004027	.0001317	0.0004307	0.001168
F-RATIO	14.3	2.3	11.7	73.9
T-RATIO	3.8	1.5	3.4	8.6
COVARIANCE RATIO	0.01		0.00	0.00

Note: The temperature change in the rate is expressed as the number of degrees below the fuel cloud points.

TABLE XXXIV

n-PARAFFIN SEPARATION CALCULATED FROM FUEL VARIABLES

INITIAL n-PARAFFIN CARBON NUMBER SEMI-INTERQUARTILE RANGE

C RANGE INITIAL =
1.019
-21.96 C RANGE RATE
+0.01400 CLOUD

FUEL NO.	OBS.	CALC.	OBS.-CALC.	ERROR ORDER
1	1.02	1.01	0.01	5
2	1.05	1.02	0.03	8
3	0.75	0.84	-0.10	1
4	0.94	0.83	0.11	10
5	0.85	0.91	-0.06	3
6	0.87	0.94	-0.07	2
7	1.02	0.96	0.06	9
8	1.20	1.19	0.01	6
9	1.05	1.04	0.01	7
10	1.25	1.27	-0.02	4

STANDARD ERROR OF ESTIMATE	0.072
FRACTION OF EXPLAINED VARIANCE	0.833
F-RATIO FOR THE REGRESSION	17.4
DETERMINANT OF THE CORRELATION MATRIX	0.80

COEFFICIENTS:	ESTIMATED ERROR	4.044	0.003129
	F-RATIO	29.5	20.0
	T-RATIO	5.4	4.5
	COVARIANCE RATIO	0.20	

TABLE XXXV

n-PARAFFIN SEPARATION CALCULATED FROM FUEL VARIABLES

RATE OF CHANGE OF n-PARAFFIN CARBON NUMBER SEMI-INTERQUARTILE RANGE WITH TEMPERATURE, C/ F

C RANGE RATE =
0.01815
+0.3042|C MED. RATE|
-0.02593 C RANGE INITIAL

FUEL NO.	OBS.	CALC.	OBS.-CALC.	ERROR ORDER
1	0.0080	0.0075	0.0005	6
2	0.0088	0.0110	-0.0022	1
3	0.0142	0.0133	0.0009	8
4	0.0113	0.0084	0.0029	10.
5	0.0000	0.0022	-0.0022	2
6	0.0177	0.0169	0.0008	7
7	0.0143	0.0148	-0.0005	5
8	0.0000	0.0016	-0.0016	3
9	0.0043	0.0055	-0.0012	4
10	0.0000	-0.0027	0.0027	9

STANDARD ERROR OF ESTIMATE		0.00213	
FRACTION OF EXPLAINED VARIANCE		0.919	
F-RATIO FOR THE REGRESSION		39.5	
DETERMINANT OF THE CORRELATION MATRIX		1.00	
COEFFICIENTS:	ESTIMATED ERROR	0.04362	0.004599
	F-RATIO	48.6	31.8
	T-RATIO	7.0	5.6
	COVARIANCE RATIO	0.0	

Note: The temperature change in the rate is expressed as the number of degrees below the fuel cloud points.

TABLE XXXVI

n-PARAFFIN SEPARATION CALCULATED USING n-PARAFFIN COMPOSITION

INITIAL MEDIAN n-PARAFFIN CARBON NUMBER

		C MED. INIT. = 5.012 91.77|C MED. RATE| +0.6016 n-P 75%			C MED. INIT. = 3.432 -1.294 n-P 25% +1.945 n-P 75%		
FUEL NO.	OBS.	CALC.	OBS.-CALC.	ERROR ORDER	CALC.	OBS.-CALC.	ERROR ORDER
1	21.1	20.6	0.5	10	21.7	-0.6	3
2	20.7	21.1	-0.4	3	19.5	1.2	10
3	19.9	19.9	0.0	5	20.3	-0.4	4
4	19.1	19.5	-0.4	2	18.9	0.2	7
5	17.9	16.7	0.3	9	18.0	-0.9	1
6	22.0	21.7	0.3	8	21.8	0.2	6
7	22.1	21.9	0.2	7	21.8	0.3	8
8	19.6	19.5	0.1	6	20.2	-0.6	2
9	19.6	20.1	-0.5	1	18.9	0.7	9
10	19.0	19.1	-0.1	4	18.9	0.1	5

STANDARD ERROR OF ESTIMATE		0.39		0.74	
FRACTION OF EXPLAINED VARIANCE		0.949		0.819	
F-RATIO FOR THE REGRESSION		64.8		15.8	
DETERMINANT OF THE CORRELATION MATRIX		0.99		0.71	
COEFFICIENTS:	ESTIMATED ERROR	8.129	0.23893	0.2322	0.5313
	F-RATIO	127.5	6.3	31.1	13.4
	T-RATIO	11.3	2.5	5.6	3.7
	COVARIANCE RATIO	0.01		0.29	

TABLE XXXVII

n-PARAFFIN SEPARATION CALCULATED USING n-PARAFFIN COMPOSITION

RATE OF CHANGE OF MEDIAN n-CARBON NUMBER, |C/ F|

C MED. RATE =
-0.04662
+0.01033 C MED. INITIAL
-0.006360 n-P 75%

FUEL NO.	OBS.	CALC.	OBS.-CALC.	ERROR ORDER
1	0.052	0.058	-0.006	1
2	0.066	0.062	0.004	9
3	0.048	0.048	0.000	6
4	0.048	0.044	0.004	8
5	0.020	0.025	-0.005	2
6	0.070	0.072	-0.002	3
7	0.076	0.077	-0.001	5
8	0.048	0.049	-0.001	4
9	0.048	0.043	0.005	10
10	0.038	0.038	0.000	7

STANDARD ERROR OF ESTIMATE	0.0042
FRACTION OF EXPLAINED VARIANCE	0.948
F-RATIO FOR THE REGRESSION	64.4
DETERMINANT OF THE CORRELATION MATRIX	0.98

COEFFICIENTS:	ESTIMATED ERROR	0.000915	0.0025434
	F-RATIO	127.5	6.3
	T-RATIO	11.3	2.5
	COVARIANCE RATIO	0.02	

Note: The temperature change in the rate is expressed as the number of degrees below the fuel cloud points.

TABLE XXXVIII

TOTAL CORRELATION MATRIX FOR MIDDLE DISTILLATE PHYSICAL INSPECTION VARIABLES

				DISTILLATION SUMMARY				WATSON
	API	ANILINE	CLOUD	% OFF				CHARACTERIZATION
	GRAVITY	POINT	POINT	10%	VABP	90%	SLOPE	FACTOR
PHYSICAL INSPECTIONS								
API GRAVITY	1.000							
ANILINE POINT	.787	1.000						
CLOUD POINT	.594	.449	1.000					
DISTILLATION SUMMARY: 10% OFF	-.288	.343	-.314	1.000				
VABP	-.014	.572	.084	.880	1.000			
90% OFF	.565	.503	.857	-.156	.269	1.000		
SLOPE	.478	-.084	.620	-.914	-.636	.543	1.000	
WATSON CHARACTERIZATION FACTOR	.900	.974	.544	.133	.402	.580	.125	1.000
HYDROCARBON COMPOSITION								
AROMATIC CONCENTRATION	-.786	-.980	.195	.667	.849	.310	-.439	-.960
NAPHTHENIC CONCENTRATION	.312	.769	-.495	-.302	-.520	-.522	.043	.648
PARAFFINIC CONCENTRATION	.816	.514	.522	-.411	-.305	.412	.517	.645
n-PARAFFINIC CONCENTRATION	.340	.062	.065	-.380	-.543	-.120	.273	.152
n-PARAFFIN DISTRIBUTION: 25% QUARTILE	-.612	.032	-.417	.868	.718	-.344	-.880	-.231
MEDIAN	-.549	-.036	-.239	.727	.709	-.196	-.699	-.209
75% QUARTILE	-.303	-.024	.267	.284	.524	.304	-.116	-.091
RANGE	.588	.019	.632	-.879	-.580	.556	.977	.218
n-PARAFFIN SEPARATION								
SEPARATION RATE	-.159	.022	-.515	.357	.029	-.697	-.591	-.053
CONCENTRATION AT -20 F	.316	.442	.533	.150	.236	.231	-.032	.433
MEDIAN CARBON NUMBER: |RATE|	.519	-.107	.771	-.523	-.246	.769	.761	.321
INITIAL	.502	.137	.826	-.612	-.261	.795	.848	.289
SEMI-INTERQUARTILE RANGE: INITIAL	.173	.345	.356	.262	.438	.409	-.062	.324
RATE	.197	-.136	.443	-.562	-.446	.375	.637	-.024

TABLE XXXIX

TOTAL CORRELATION MATRIX FOR MIDDLE DISTILLATE HYDROCARBON COMPOSITION VARIABLES

					n-PARAFFIN DISTRIBUTION			
	CONCENTRATION, WT.%				QUARTILE			SEMI-IQ
	AROMATICS	NAPHTHENES	PARAFFINS	n-PARAFFINS	25%	MEDIAN	75%	RANGE
HYDROCARBON COMPOSITION								
AROMATIC CONCENTRATION	1.000							
NAPHTHENIC CONCENTRATION	-.768	1.000						
PARAFFINIC CONCENTRATION	-.548	-.115	1.000					
n-PARAFFINIC CONCENTRATION	-.108	-.478	.786	1.000				
n-PARAFFINIC DISTRIBUTION:								
25% QUARTILE	.078	.451	-.715	-.543	1.000			
MEDIAN	.069	.537	-.809	-.764	.916	1.000		
75% QUARTILE	.057	.340	-.603	-.805	.540	.721	1.000	
RANGE	-.060	-.323	.524	.219	-.897	-.700	-.112	1.000
PHYSICAL INSPECTIONS								
API GRAVITY	-.786	.312	.816	.340	-.612	-.549	-.303	.558
ANILINE POINT	-.980	.769	.514	.062	.032	-.036	-.024	.019
CLOUD POINT	.195	-.495	.522	.065	-.417	-.239	.267	.632
DISTILLATION SUMMARY:								
10% OFF	.667	-.302	-.411	-.380	.868	.727	.284	-.879
VABP	.849	-.520	-.305	-.543	.718	.709	.524	-.580
90% OFF	.310	-.522	.412	-.120	-.344	-.196	-.304	.556
SLOPE	-.439	.043	.517	.273	-.880	-.699	-.116	.977
WATSON CHARACTER. FACTOR	-.960	.648	.645	.152	-.231	-.209	-.091	.218
n-PARAFFIN SEPARATION								
SEPARATION RATE	.037	-.077	.036	.393	.401	.143	-.321	-.641
CONCENTRATION AT -20 F	-.432	.151	.472	.393	.098	.008	.072	-.078
MEDIAN CARBON NUMBER:								
INITIAL	-.201	-.105	.458	.033	-.687	-.495	.124	.874
|RATE|	-.270	-.116	.577	.202	-.714	-.598	-.095	.791
SEMI-INTERQUARTILE RANGE:								
INITIAL	-.358	.385	.056	-.139	.194	.333	.166	-.147
RATE	.086	-.404	.395	.281	-.560	-.626	-.059	.678

TABLE XL

TOTAL CORRELATION MATRIX FOR MIDDLE DISTILLATE n-PARAFFIN TEMPERATURE PROFILE VARIABLES

	n-PARAFFIN		MEDIAN CARBON NUMBER		SEMI-INTERQUARTILE RANGE	
	SEPARATION RATE	CONCENTRATION AT -20 F	INITIAL	RATE	INITIAL	RATE
n-PARAFFIN SEPARATION						
SEPARATION RATE	1.000					
CONCENTRATION AT -20 F	.421	1.000				
MEDIAN CARBON NUMBER: INITIAL	-.785	.049	1.000			
RATE	-.731	.058	.950	1.000		
SEMI-INTERQUARTILE RANGE: INITIAL	-.051	.344	.008	.017	1.000	
RATE	-.488	-.009	.729	.741	-.595	1.000
PHYSICAL INSPECTIONS						
API GRAVITY	-.159	.316	.502	.519	.173	.197
ANILINE POINT	.022	.442	.137	.187	.345	-.136
CLOUD POINT	-.515	.533	.826	.771	.356	.443
DISTILLATION SUMMARY: 10% OFF	.357	.150	-.612	-.523	.262	-.562
VABP	.029	.236	-.261	-.246	.438	-.446
90% OFF	-.697	.231	.795	.769	.409	.375
SLOPE	-.591	-.032	.848	.761	-.062	.637
WATSON CHARACTERIZATION FACTOR	-.053	.433	.289	.321	.324	-.024
HYDROCARBON COMPOSITION						
AROMATIC CONCENTRATION	.037	-.432	-.201	-.270	-.358	.086
NAPHTHENIC CONCENTRATION	-.077	.151	-.105	-.116	.385	-.404
PARAFFINIC CONCENTRATION	.036	.472	.458	.577	.056	.395
n-PARAFFINIC CONCENTRATION	.393	.393	.033	.202	-.139	.281
n-PARAFFIN DISTRIBUTION: 25% QUARTILE	.401	.098	-.687	-.714	.194	-.560
MEDIAN	.143	.008	-.495	-.598	.333	-.626
75% QUARTILE	-.321	.072	.124	-.095	.166	-.059
RANGE	-.641	-.078	.874	.791	-.147	.678

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