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Aviation Turbine Fuel Properties and Their Trends

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ABSTRACT

This paper is an examination of published Jet A inspection data covering selected property distributions, averages, and trends for the period from 1969 to 1979. Yearly median values of aromatics, mercaptan sulfur content, 10-percent distillation temperature, smoke point, and freezing point are changing with time, approaching their specification limit values, particularly in the last three years. A near-specification property is defined as one within a stated tolerance band around the specification limit. On this basis, most fuel samples have one to three near-specification properties, the most common being aromatics, smoke point, and freezing point.

THE PURPOSE OF THIS PAPER is to determine the trends in important aviation turbine fuel properties by a statistical study of actual fuel inspection data. Historical considerations are therefore secondary to those of recent measurements which can provide projections for anticipating trends to the near future. An important element in this study is the relationship of actual fuel properties to their specification-limit requirements. Relaxation of certain aviation turbine fuel specification limits has been recommended as one means of coping with the refining and market pressures caused by limited and costly petroleum supplies and shifts in competing fuel product demands (1-5).*

Previous investigators have noted the trend of average aromatics content of Jet A aviation turbine fuel, in which this property has been increasing toward its specification limit (4,6). This shift reflects the changing composition of the crude petroleum feedstocks used in aviation fuel refining. One may expect similar trends in the average values of other properties for the same reason and also because of changing demands for aviation fuel and competing refinery products. The refinery product mix is altered, for the most part, by adjusting the boiling range of the various products. This in turn affects many of the properties. The sensitivity of aviation fuel refining yield to variations in key property values is readily demonstrated by refinery model calculations (7,8) or through questionnaire surveys (9).

In this paper, fuel property values and their trends are studied through a review of a recognized, wide-ranging sample population from actual fuel inspection data. The compilation covers 676 fuel samples of Jet A aviation turbine fuel reported for the eleven-year period of 1969 to 1979 from the Department of Energy (and predecessor agencies) fuel inspection reports (10). The fuel sample analyses are reported by the manufacturers through a cooperative agreement between the American Petroleum Institute and the Department of Energy (DOE). The DOE regards the reported values as close reflections of average fuel quality produced by United States refiners.

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*Numbers in parentheses designate References at the end of the paper.

DISTRIBUTION OF PROPERTY VALUES

The distribution of aviation turbine fuel property values is illustrated by histograms, or bar graphs, of seven selected properties for Jet A for the accumulated inspection data from 1969 to 1979. The histograms plot the probability, or fraction of the total sample population, for each discrete property range interval represented by bars. The properties illustrated and their definitions are:

Fig. 1 - aromatics content: the fraction of benzene-ring hydrocarbon compounds,

Fig. 2 - mercaptan sulfur content: the fraction of compounds with hydrogen-sulfur (SH) groups,

Fig. 3 - distillation temperature, 10 percent recovered: the temperature where this volume fraction of fuel is vaporized in a simple laboratory still,

Fig. 4 - distillation temperature, final boiling point: the temperature for complete vaporization,

Fig. 5 - flash point: the minimum temperature for ignition of vapors above a liquid sample,

Fig. 6 - smoke point: the maximum flame height achieved without smoking in a standard lamp apparatus,

Fig. 7 - freezing point: the temperature (melting point) of disappearance of solid crystals.

The distributions for aromatics (Fig. 1) and flash point (Fig. 5) resemble bell-shaped normal, or Gaussian, probabilities. Aromatics in an aviation fuel are undesirable because of elastomeric degradation and because aromatics, with low hydrogen contents, have poor combustion properties of high flame luminosity and smokiness. Fig. 1 shows that the distribution of aromatics content is approximately symmetrical, but there is a sharper cutoff of probabilities at the high value side, near the specification limit of 20 percent maximum (25 percent maximum when reported by the supplier). The mode, or highest probability value, is at the interval centered at 17 percent aromatics. Flash point is an important property as a measure of the fuel volatility and safety in fuel handling. Fig. 5 shows that the flash point distribution is nearly symmetrical with equal cutoffs of probabilities at the high and low extremes. In contrast to the aromatics distribution, the flash point mode of 52° C is well above the specification limit of 37° C minimum, and only a negligible fraction (one sample) has a flash point at the limit.

Mercaptans impart a disagreeable odor to fuels and have poor compatibility with some elastomers and metals. The distribution for mercaptan sulfur (Fig. 2) shows the upper half of a normal distribution with the mode at the interval centered at 0.0001 percent. The near-zero interval includes all measurements approaching zero content asymptotically, and expansion of this interval, using logarithmetic spacing of intervals, could transform the distribution to a more symmetrical shape. The specification limit for mercaptan sulfur content is 0.003 percent maximum.

The distributions for 10 percent distillation (Fig. 3), final boiling point (Fig. 4), and smoke point (Fig. 6) show bands of high-probability values, more or less, rather than the distinct single mode characterizing normal distributions. The two distillation temperatures control refining yield and volatility of the fuel and influence, indirectly, the values of several other fuel properties. Fig. 3, the 10-percent distillation distribution, has a range of high-probability values over the intervals centered from 184° C to 194° C. The probabilities cut off sharply at the high-temperature extreme near the 204° C maximum specification limit but tail off gradually at the low extreme. Fig. 4, the final boiling point distribution, shows a band of high-probability values from 260° C to 274° C. The distribution is somewhat skewed toward higher temperatures but extreme high values are well below the specification maximum of 300° C. Smoke point is a practical measurement of combustion quality, and there is, in many cases, a correlation of high aromatics with (undesirable) low smoke points. Fig. 6, the smoke point distribution, has a range of high-probability values from 20 to 25 mm. The small number of intervals produces a histogram with considerable nonuniformity, but the intervals conform to the precision of smoke point measurements. The smoke point specification limit is 20 mm minimum (18 mm minimum when reported by the supplier).

The significance of freezing point is obvious with respect to flowability in handling and flight. Fig. 7 shows that the distribution of freezing points differs from those of the other selected properties. The histogram appears to be two superimposed distributions, one with a mode at -42° C, the other with a mode at -48° C. The entire distribution is distinctly skewed toward the specification limit of -40° C maximum.

The seven properties illustrated by the distribution plots are selected from 22 properties defined by their specification limits in the standards for Jet A, the American Society for Testing and Materials (ASTM) D 1655-80a (11). Distribution plots were constructed, in all, for 15 properties which are quantitative and amenable to this type of analysis. This paper, however, includes only the seven properties shown by subsequent results to be most dominant in the direction of their trends and approach to specification limits.

The discrete intervals used for the histograms of Figs. 1 to 7 were chosen to make the modal probability lie in a range of between 8 and 16 percent. The intervals also are reasonably representative of the precision of the measurements.

MEDIAN PROPERTY VALUES AND THEIR TRENDS

The histograms of Figs. 1 to 7 are each an accumulation of eleven years of inspection data to provide a large statistical population. This construction averages out possible trends in the annual distribution of values. Distribution of values was, of course, examined for each of the annual inspection reports, and these results are shown as trends of average values.

For examination of yearly changes of properties, this study uses the median, or 50 percent accumulated probability, the value with equal probabilities of lesser or greater expectations. The Department of Energy inspection data reports (10) compile arithmetic mean values. The present study selected the median, however, as a central value for representative fuel properties better suited to skewed distributions and less sensitive to outlying values. For properties with nearly normal distributions, differences between the mean and median are trivial. For those with more skewed distributions, the median lies closer to the specification limit and shows more annual variations.

The trends in the seven selected Jet A property medians are plotted in Figs. 8 to 14, which show data points for yearly medians, connected by line segments for illustration, although interpolated values between years have no significance. Appropriate specification limits are indicated by broken lines. Each property value ordinate is scaled to represent the relative changes in the medians fairly without exaggeration or attenuation, consistent with the scaling used for histogram intervals.

In general, one notes that the median values of aromatics, smoke point, and freezing point lie close to their specification limits, whereas the median values of mercaptan sulfur, 10-percent distillation, final boiling point, and flash point are relatively distant from their specification limits.

The yearly changes in the median values of the selected properties are as noteworthy as the relationship of the values to their specification limits. Median aromatics content (Fig. 8) increases almost uniformly with time from 16 percent in 1969 to 17.9 percent in 1979. This is a trend in aviation turbine fuel properties that has been noted in previous literature (Rudey and Grobman (6), for example). Median aromatics content is rapidly reducing the margin with respect to the standard 20 percent specification limit, although the "reportable" limit relaxation (shown as a shaded area in Fig. 8) offers considerable leeway for further increases. The increase in average aromatic content of fuel deliveries is obviously a major factor in instituting this specification provision.

The trend in median smoke points (Fig. 13) is a decrease toward the minimum specification limit, from 23 mm in 1969 to 22 mm in 1979. Although this change appears relatively small, it is significant, representing a change of a full integer unit in the median. As with aromatics content, a "reportable" limit relaxation provides some relief in specification-limit margins.

The trend in median freezing points is shown in Fig. 14. Time-related changes have appreciable oscillations, but a distinct increasing trend toward the specification limits occurs in the last four years, from -45.7° C in 1976 to -43.3° C in 1979. It is interesting to note that the decrease of the specification limit in 1973 apparently produced a small decrease in the median for two years, but the present increasing trend resumed thereafter.

The trends in the other four selected properties are of interest, although the medians are well within the specification limits.

Median mercaptan sulfur content (Fig. 9) increases rapidly with time, from 0.00023 in 1969 to 0.00064 in 1979, although the latter is still one-fifth of the specification limit. Median 10-percent distillation temperature (Fig. 10) indicates a slight increase toward the specification limit, from 187° C in 1969 to 191.5° C in 1979. The increase is most noticeable in the last three years. Median final boiling points (Fig. 11) show considerable variation but no apparent trend with time. A relaxation of the specification maximum in 1974 has no influence on the yearly median values. In fact, the histogram (Fig. 4) shows that there are only 0.1 percent of the samples (actually just one sample) with a final boiling point between 288° C and 300° C to take advantage of the specification relaxation. Median flash point (Fig. 12) shows an irregular increasing trend from 52° C in 1969 to 55.5° C in 1979. In this case, the trend is away from the specification limit, and flash point is unique among the selected properties in having a favorable trend with respect to specification-limit margins.

NEAR-SPECIFICATION PROPERTIES

DEFINITIONS - The aviation turbine fuel specification limits are absolute and are not subject to tolerances in their values (footnote A, ASTM D 1655-80a (11)). As a result, one may suppose that fuel suppliers ordinarily apply some leeway in meeting limits to avoid off-specification measurements i acceptance reports. A realistic technique of investigating specification-limit properties would be to define a plausible range of values encompassing the specification limit. In this study, a near-specification range is defined by the ASTM reproducibility, ASTM Designation E 456-72 (12), which is the precision of measurements expected from tests by different observers or laboratories. Most of the ASTM test methods used for the Jet A properties report a reproducibility, determined from a survey of cooperating laboratories. By applying the reproducibility as a tolerance about the specification limit, one obtains a reasonable near-specification band of properties regarded as sufficiently close to their specification limit. This concept is by no means original to the author; Dixon and Karvelas (9) applied the same discriminator for smoke point observations, but they used a broader tolerance for freezing points.

Table 1 is a listing of the near-specification property range for the 22 properties that comprise the Jet A specification standards. Each near-specification range is calculated by addition of the reproducibility, where available, to the acceptable side of the specification limit. Table 1 also shows the associated ASTM test methods for reference. The near-specification definitions in Table 1 are for the current specification limits; the same reproducibility bands at different absolute levels are applied to earlier specification limits where applicable.

SURVEY OF NEAR-SPECIFICATION PROPERTIES - Table 2 summarizes the general findings of near-specification properties among the 676 inspection data samples covered in this eleven-year survey. Approximately 21 percent of the samples have no near-specification properties, 30 percent have one property, 35 percent have two properties, and 12 percent have three properties near-specification. Very few samples have more than three properties near-specification, none more than five. A specification-limit fuel used for design and performance calculations is a hypothetical construction; one would not expect a real fuel to have all properties at-specification. Still, the fact that the representative fuels rarely have more than a small select number of near-specification properties is surprising.

Table 3 identifies all the data samples by their near-specification properties or combinations of properties. As expected from the histograms, various combinations of aromatics, smoke point, and freezing point dominate the near-specification properties. Since high aromatics are associated with poor smoke points, the association of these two properties near specification is expected, although there are many samples with aromatics or smoke point alone near specification. Freezing point also occurs near specification alone and in combination with aromatics, aromatics and smoke point, or smoke point (less frequently). The common association of near-specification freezing point and aromatics is perhaps contradictory, since aromatics as a class have low freezing points. This observation, however, simply confirms the complexity of freezing point correlations, which are functions of distillation range and other factors as well as fuel composition (13).

The 12 percent remainder of all other combinations, listed in Table 1, includes those properties whose occurrence near specification is rare. Certain properties otherwise of importance to aviation fuel specifications, such as total sulfur, flash point, density, heat of combustion, and thermal stability are in this category.

The yearly variations of near-specification fractions of several properties reveal interesting trends. Fig. 15 plots the yearly near-specification fractions of aromatics, smoke point, freezing point, and final boiling points as data points connected for illustration by line segments. Reference to the corresponding trends in median aromatics, smoke point, and freezing point (Figs. 8, 13, and 14, respectively) shows that the recent increases in near-specification fractions agree with the increases in the median values of these properties. Note that the fraction of near-specification freezing points is low until 1973, when the specification limit was tightened by a 2° C decrease. On the other hand, all the near-specification final boiling points are from the years prior to 1973, when the specification limit was relaxed by a 12° C increase.

Clearly, the choice of the precision band for the near-specification definition will affect the number of samples in the range. Because the precision for each measurement is different, the near-specification intervals in Table 1 are quite dissimilar. The influence of the inconsistent near-specification band widths on the observations and assessments related to the properties, however, may be small. Those properties which are almost never near specification are those with distributions with low probabilities near the specification limit, and near-specification fractions would remain small even if the tolerance band about the specification limit is expanded. On the other hand, better precision in the measurement of aromatics and smoke point could improve the reproducibility and lower the near-specification fractions. The stated reproducibility is, however, a fair figure of merit for the fluorescent indicator adsorption method for aromatics, which is the currently accepted measurement.

CONTROLLING NEAR-SPECIFICATION PROPERTIES - Another viewpoint of the approach of properties to their specification limit is that of the controlling near-specification property, if any, for each of the samples in this survey. The controlling near-specification property is obviously the one property near specification for samples with just one such property. For samples with combinations of near-specification properties, the controlling near-specification property is defined as the one closest to its specification limit. For a few samples with properties equally near their limits, the controlling property is arbitrarily established by choosing freezing point over smoke point in turn over aromatics, as applicable.

Table 4 is the summary of the controlling near-specification properties. The table shows the 21 percent of samples with no properties near specification, to complete the totals to 100 percent of the samples. Again, aromatics, freezing point, and smoke point dominate the controlling near-specification properties. In fact, the only other property with any small significance is mercaptan sulfur, controlling in about 3 percent of the samples.

Figure 16 presents further details on the controlling near-specifications properties, showing the yearly trends of these properties. The figure is an illustration of the apportionment of controlling properties, cumulative to 100 percent for each year. The areas enclosed by the curves represent the yearly fractions of samples controlled by the properties shown. For example, the data for 1969 show that 22 percent of the samples were controlled by near-specification aromatics, an additional 24 percent (to a total of 46 percent) by smoke point, an additional 7 percent by freezing point, and an additional 10 percent by other near-specification properties. The remaining samples, constituting 37 percent of the total in 1969, had no properties near specification. The increasing trend of samples with the three dominant near-specification properties of aromatics, smoke point, and freezing point is quite evident. The sum of aromatics and smoke point controlled samples (and these two are frequently found in combination) increases from 46 percent in 1969 to a peak of 66 percent in 1976 and 57 percent in 1979. The freezing point controlled samples are low, 5 to 7 percent, from 1969 to 1972, but then they increase rapidly with time reaching 25 percent by 1979. Conversely, the fraction of samples with no near-specification properties decreases with time. While the overall fraction of no near-specification samples is given as 21 percent in Table 4, the yearly fractions change from 37 percent in 1969 to 12 percent in 1979.

"REPORTABLE" AROMATICS CONTENT AND SMOKE POINT - The definitions of near-specification aromatics content and smoke point ignore the so-called "reportable" specification-limit extensions of these properties. These extensions have, since 1974, permitted relaxation of the specification limits to a maximum of 25 percent aromatics, and a minimum of 18 mm smoke point, when reported by the supplier within 90 days of the date of shipment. (Prior to 1980, notification had no reporting time limit.)

Table 5 illustrates the extent of samples with properties in the "reportable" category, that is, with aromatics and/or smoke points that would ordinarily be off-specification but are permissible with the reportable extension. The table lists the number of samples with reportable-range aromatics, smoke points, and total reportable-range (aromatics only, smoke only, and both in combination). The ratio of reportable properties is also shown, with respect to the corresponding near-specification samples and to the total samples. Reportable aromatics have increased greatly in the last three years, being noted in 4.6 percent of all samples in 1977 and 20.0 percent in 1979. Reportable smoke point shows a much lesser increase in the same period.

The near-specification property ranges of Table 1 are based on the standard limits for aromatics and smoke point, and all the reportable samples are included as near specification, a fair and consistent representation of the data. If the near-specification limits were shifted to apply the reproducibility band at the extended, reportable specification limits, the near-specification fraction for aromatics in 1979 would decrease from 65 percent (Fig. 15) to 8 percent. The same treatment for smoke point would decrease the near-specification smoke point only from 58 percent to 37 percent in 1979 because of the lesser reportable fraction.

United Airlines (UAL) maintains a data bank of inspection properties representing some 60 to 70 percent of deliveries to domestic airlines. Through the courtesy of the airline propulsion department, some of the data were furnished to the author. Figure 17 is a comparison of the total "reportable" fuel samples of UAL and the Department of Energy (DOE) data otherwise used in this paper. The DOE data are shown as yearly bar segments, and they are plotted from the totals shown in the last row of data in Table 5. The UAL data are quarterly points connected by line segments, and they are those reported by Campbell (14) with updating to 1979 from the furnished data. The UAL data oscillate extremely, and the cycles suggest but do not necessarily correlate with seasonal variations. The overall trends of the two data sets agree well, particularly with respect to the relatively large increase in reportable samples from 1977 to 1979.

FURTHER DISCUSSION ON THE FREEZING-POINT DISTRIBUTION - The unusual distribution of sample freezing points is noted in an earlier section of this paper (Fig. 7). The concept of controlling near-specification properties suggests that the distribution may consist of two groups of samples with different controlling properties. The group with the distribution centered at -42° C is probably freezing point controlled. The other group centered at -48° may consist of those samples with other controlling properties predominantly aromatics or smoke point, since aromatics as a class have low freezing points. A review of the properties of the individual samples appears to confirm this reasonable hypothesis, but the sample population is insufficient for a more quantitative analysis of the freezing point distribution.

SUMMARY AND CONCLUSIONS

This paper is an examination of published inspection data covering 676 samples of Jet A aviation turbine fuel for the eleven-year period of 1969 to 1979. The study covered the 22 properties which comprise the requirements of the commercial fuel specifications, but detailed analyses are confined to seven selected properties. Data output include presentation of the distribution of property values, median values, the probability of properties approaching their specification limits, and the trends of all of these with time.

The uniqueness of the present study lies in the examination of a recognized sample of fuel properties, representing actual fuels in production and delivery. This provides the advantage of conclusions confirmed by actual properties, as opposed to those based on hypothetical calculated or estimated properties. For example, from plausible reasoning, both Dalton (15) and Momenthy (16) argue that future aviation turbine fuel properties need not change to meet demand or competition requirements. Market and price incentives are sufficient, in their views, to shift the refinery output distribution to favor aviation fuel as necessary. The present review of fuel inspection properties shows that, on the contrary, in the real marketplace adjustments are occurring, and averages of certain important fuel properties show trends of movement toward their specification limits.

The results and conclusions of this paper are summarized as follows:

1. The distribution of almost all the properties is reasonably described by a nearly symmetrical normal distribution. The distributions for aromatics and smoke point are skewed with greater probabilities near the specification-limit extreme. The distributions for distillation temperature and flash point are symmetrical with extremes well within the specification limit. Mercaptan sulfur shows the upper half of a normal distribution, centered near zero percent.

2. The distribution of freezing points is different from those of the other properties, exhibiting a skewed configuration that suggests two superimposed distributions. A predominant portion of the samples has a distribution centered only 2° C below the specification maximum of -40° C. A secondary distribution, most likely influenced by the approach to specification limits of properties other than freezing point, is centered 8° C below the specification limit.

3. The median, or 50-percent probability value, is selected as the average most representative of the central tendency, especially for the skewed distributions. Time-related plots of median aromatics content, mercaptan sulfur, distillation temperature at 10 percent recovered, freezing point, and smoke point indicate trends toward their specification limits, particularly in the last few years.

4. Near-specification property values are defined as those within a range of their specification values corresponding to American Society of Testing and Materials reproducibility precision for the test method appropriate for each property. The majority of the samples are near specification for at least one of three properties: aromatics, freezing point, and

smoke point. Samples occasionally have near-specification acidity, mercaptan sulfur, 10 percent distillation temperature, and final boiling point. Properties otherwise of importance to aviation fuel specifications, such as total sulfur, flash point, density, heat of combustion, and thermal stability are rarely if ever near specification.

5. About 21 percent of all the samples for the overall eleven-year period have no near-specification properties. This fraction shows a decreasing trend with time, reaching 12 percent in 1979.

6. The majority of the samples has one to three near-specification properties. Only a very small fraction have more than three; none have more than five. Thus, although designers must consider a specification-limit fuel for safety and performance guarantees, such a fuel is a hypothetical construction. On the other hand, because of the statistical distribution of property values about their reported averages, apparent margins between average fuel properties and their specification limits may not be available for yield improvements.

7. This paper also characterizes the fuel samples in terms of the controlling near-specification property, defined as the single near-specification property or the most important one of several. Apportionment of samples by the controlling near-specification property confirms the dominance of aromatics, freezing point, and smoke point, and the approach of these properties toward their specification limit with time.

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Table 1 - Definition of Near-Specification Properties

Property and units	ASTM Test method[a]	Reproducibility	Near-specification Property range	
Acidity, mg KOH/g	D 974	0.04	0.06 to	0.10
Aromatics, vol. %	D 1319	3.2	16.8 to	20
Sulfur, mercaptan, wgt. %	D 1323[b]	0.0006	0.0024 to	0.003
Sulfur, total, wgt. %	D 1266	0.0175	0.283 to	0.3
Distillation temp., 10% recovered, ° C	D 86	4.4	200 to	204
Distillation, final boiling point, ° C	D 86	10.5	290 to	300
Distillation residue, vol. %	D 86	None		1.5
Distillation loss, vol. %	D 86	None		1.5
Flash point, ° C	D 56	2.2	40.0 to	37.8
Density at 15° C, kg/m^3	D 1298	1.4[c]	776.3 to	775
			838.5 to	840
Freezing point, ° C	D 2386	2.6	-42.6 to	-40
Viscosity[d] at -34° C, $m^2/s \times 10^6$ (cs)	D 445	0.11	14.89 to	15
Net heat of combustion, KJ/kg	D 1405	0.035	42.84 to	42.80
Smoke point, mm	D 1322	3	23 to	20
Naphthalenes, vol. %	D 1840	0.11	2.89 to	3.0
Luminometer Number	D 1740	8.8	53.8 to	45
Corrosion, copper strip tarnish no.	D 130	None		No. 1
Thermal stability, coker press. drop, kPa	D 1660	None		10
Thermal stability, coker preheater deposit	D 1660	None		Code 3
Existent gum, mg/100 ml	D 381	3.5[e]	3.5 to	7
Water reaction, separation rating	D 1094	None		No. 2
Water reaction, interface rating	D 1094	None		No. 1b

Footnotes:

[a]Test methods prescribed by ASTM D 1655-80a, Jet A (11). Where there are choices or alternatives, method shown are those cited for the inspection data (10).

[b]ASTM D 1655-80a requires method D 3227, but earlier specifications and all inspection data use D 1323.

[c]Nominal conversion from 0.3° API gravity.

[d]Viscosity measurement temperature now obsolete but corresponds to that of inspection data.

[e]Estimate from graph in ASTM method.

Table 2 - Near-Specification Properties, 1969-1979
Summary by Number of Properties per Sample

	Number	%
Samples with no properties near specification	144	21.3
Samples with one property near specification	202	29.9
Samples with two properties near specification	236	34.9
Samples with three properties near specification	84	12.4
Samples with four properties near specification	9	1.3
Samples with five properties near specification	1	0.2
Total	676	100.0

Table 3 - Near-Specification Properties, 1969-1979
Identification of Most Common Property Combinations

	Number of samples	%
No properties near specification	144	21.3
Aromatics and smoke pt. near spec.	153	22.6
Smoke pt. only near spec.	76	11.2
Aromatics only near spec.	67	9.9
Freezing point, aromatics, and smoke pt. near spec.	43	6.4
Freezing point only near spec.	38	5.6
Freezing point and aromatics near spec.	37	5.5
Freezing point and smoke pt. near spec.	14	2.1
Final boiling point only near spec.	10	1.5
Aromatics, smoke pt., and 10% distillation near spec.	8	1.2
Aromatics, smoke pt., and final boiling point near spec.	7	1.0
All other combinations	79	11.7
Total	676	100.0

Table 4 - Controlling Near-Specification Properties

Property	Samples where property is controlling: Number	%
Acidity	8	1.2
Aromatics	170	25.2
Sulfur, mercaptan	19	2.8
Distillation temp., 10% recovered	7	1.0
Distillation, final boiling point	10	1.5
Distillation residue	1	0.1
Flash point	3	0.5
Density-maximum	1	0.1
Freezing point	98	14.5
Smoke point	210	31.1
Thermal stability, coker press. drop	4	0.6
Existent gum	1	0.1
No property near-specification	144	21.3
Total	676	100.0

Table 5 - Trends of Samples In "Reportable" Range

Property	1974	1975	1976	1977	1978	1979
Aromatics:						
No. of samples in "reportable" range	2	4	4	3	5	12
Fraction of samples with near-spec. aromatics, %	6.1	10.8	10.5	7.5	13.5	30.8
Fraction of all samples, %	3.2	6.1	6.2	4.6	8.3	20.0
Smoke point:						
No. of samples in "reportable" range	0	1	1	0	4	3
Fraction of samples with near-spec. smoke points, %	0	2.9	3.1	0	11.1	8.6
Fraction of all samples, %	0	1.5	1.5	0	6.7	5.0
Total samples in "reportable" range:	2	5	4	3	8	13
Fraction of samples with near-spec. aromatics and smoke points, %	4.5	10.0	8.3	6.3	17.8	27.7
Fraction of all samples %	3.2	7.6	6.2	4.6	13.3	21.7

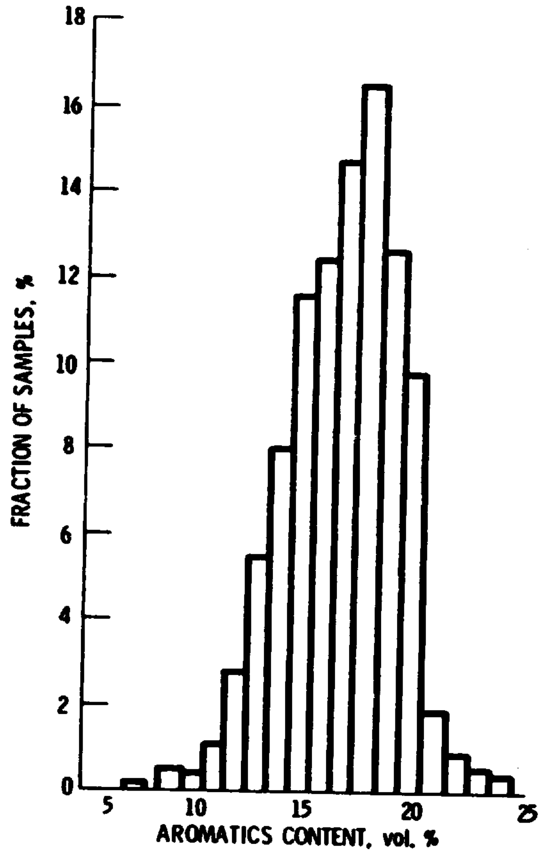

Figure 1. - Distribution of aromatics content, 1969 to 1979 inspection data.

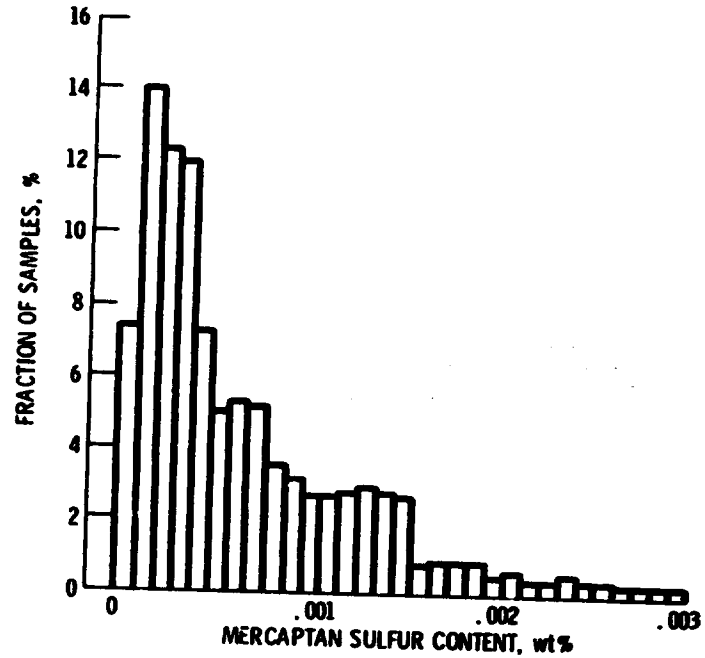

Figure 2. - Distribution of mercaptan sulfur content, 1969 to 1979 inspection data.

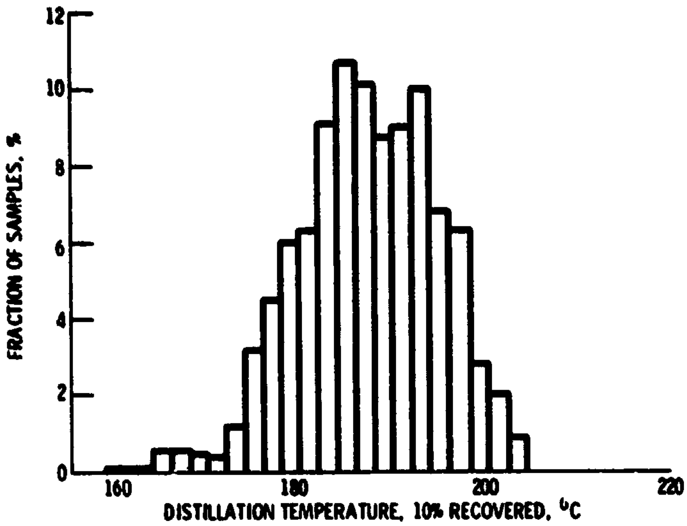

Figure 3. - Distribution of distillation temperature at 10% recovered, 1969 to 1979 inspection data.

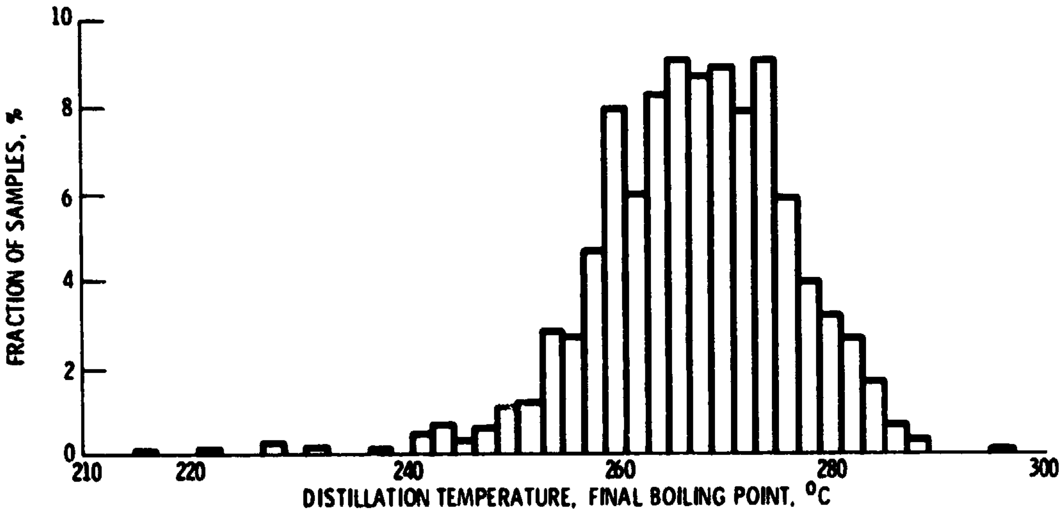

Figure 4. - Distribution of final boiling point, 1969 to 1979 inspection data.

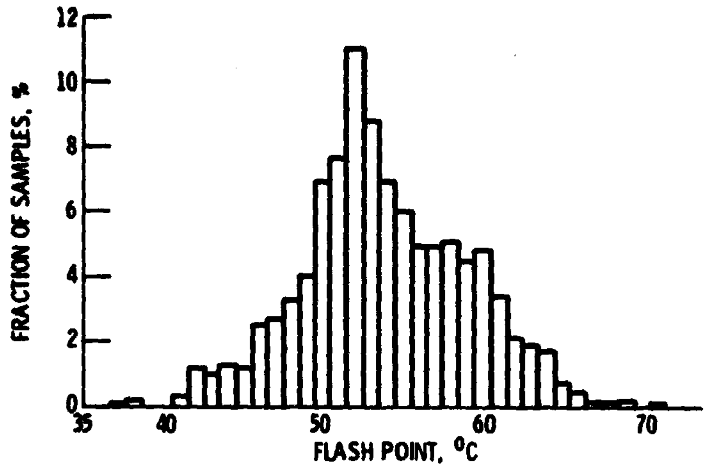

Figure 5. - Distribution of flash point, 1969 to 1979 inspection data.

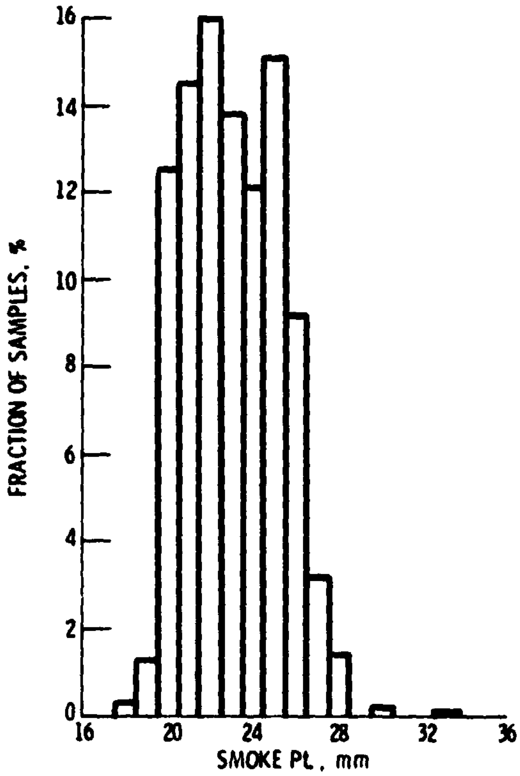

Figure 6. - Distribution of smoke point, 1969 to 1979 inspection data.

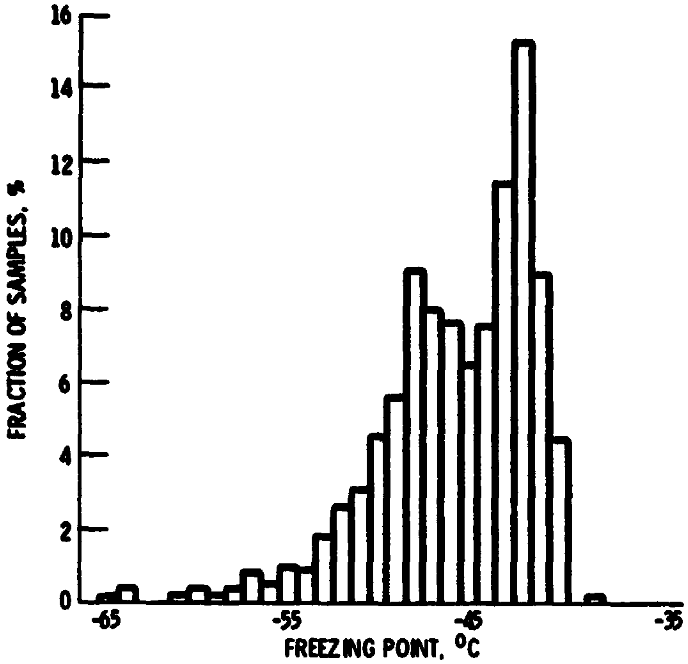

Figure 7. - Distribution of freezing point, 1969 to 1979 inspection data.

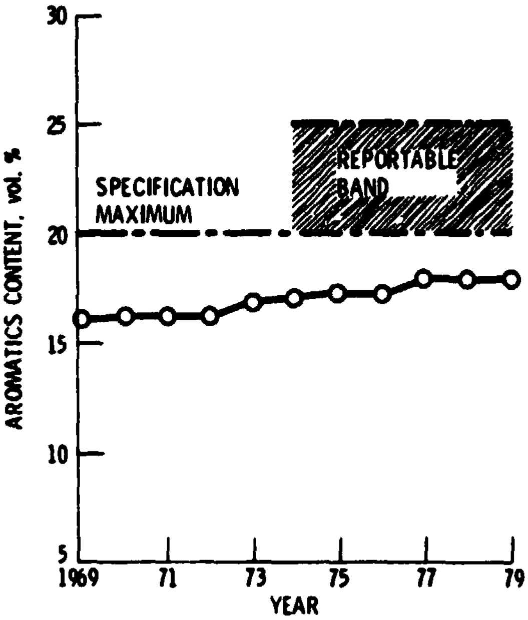

Figure 8. - Trends of inspection data medians for aromatics content.

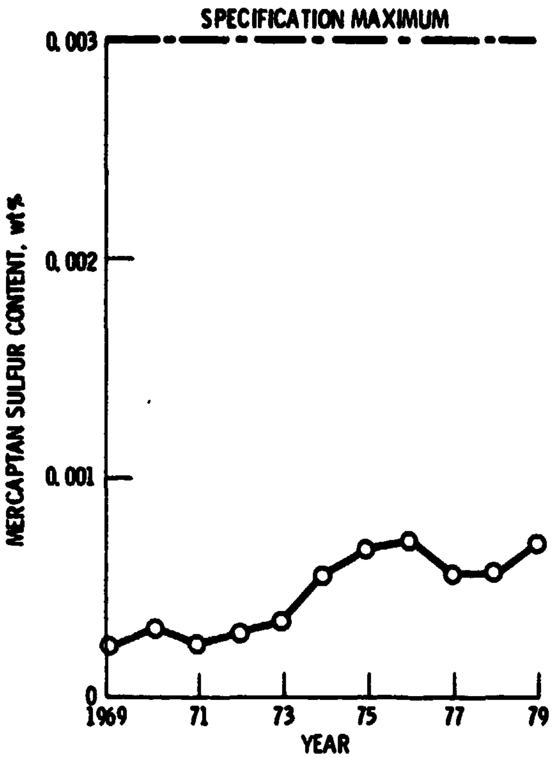

Figure 9. - Trends of inspection data medians for mercaptan sulfur content.

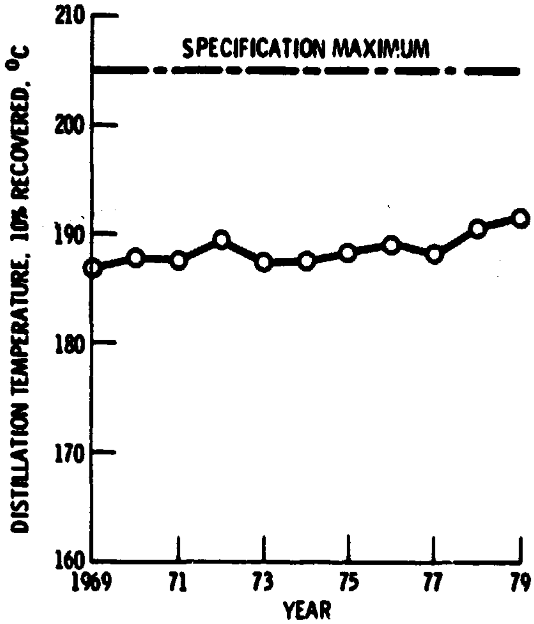

Figure 10. - Trends of inspection data medians for distillation temperature at 10% recovered.

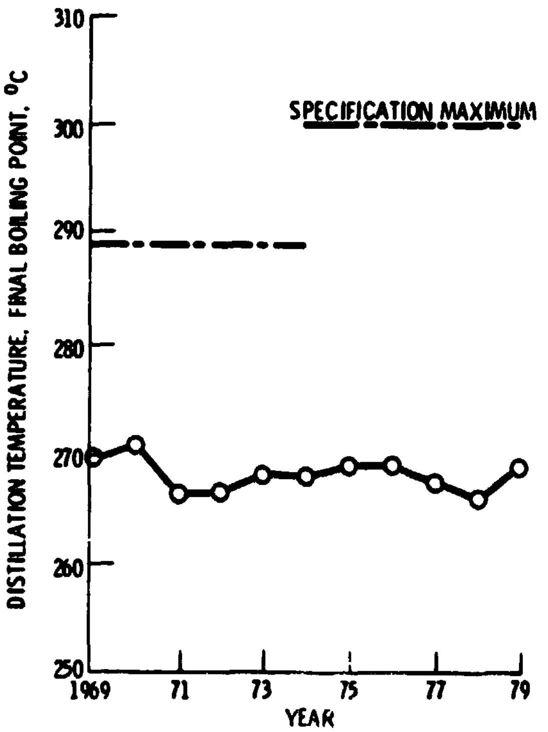

Figure 11. - Trends of inspection data medians for final boiling point.

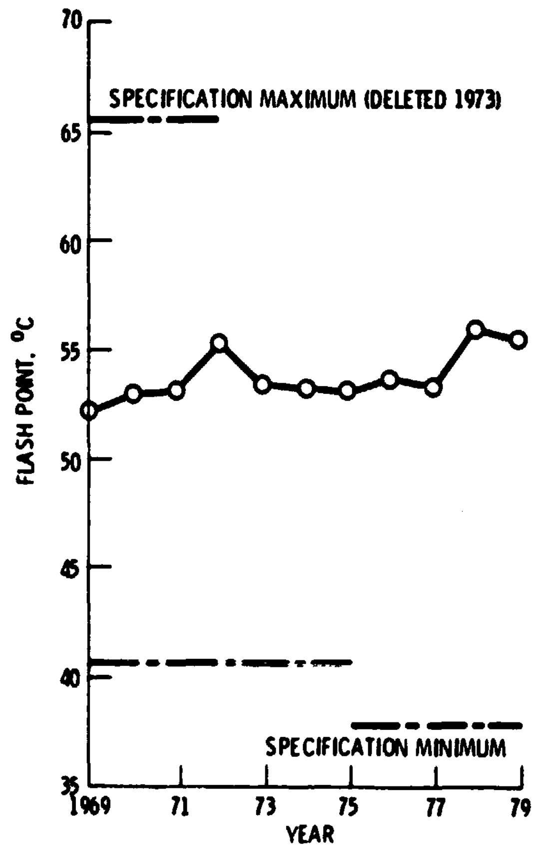

Figure 12. - Trends of inspection data medians for flash point.

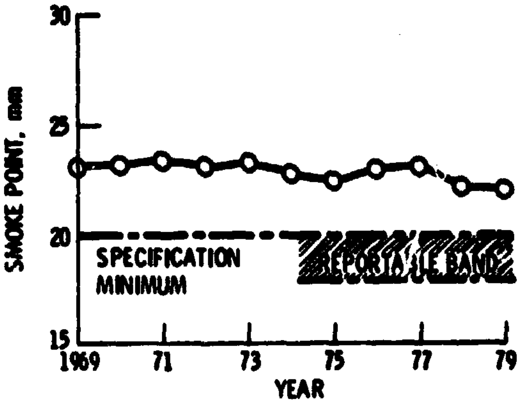

Figure 13. - Trends of inspection data medians for smoke point.

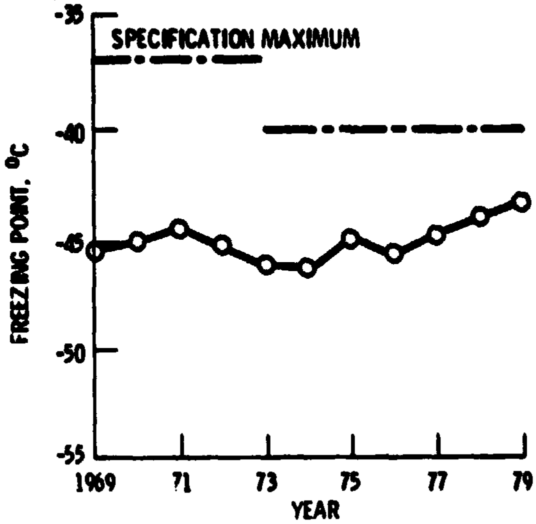

Figure 14. - Trends of inspection data medians for freezing point.

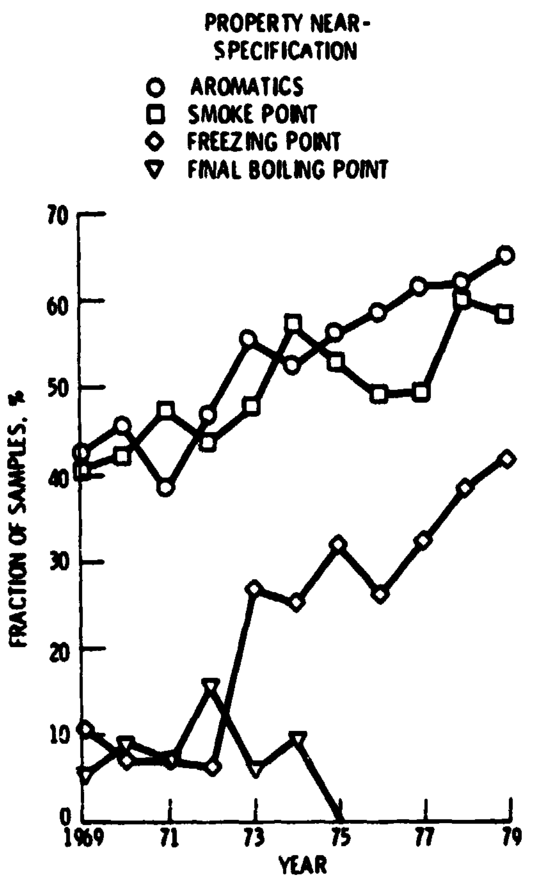

Figure 15. - Trends of near-specification inspection data for important properties.

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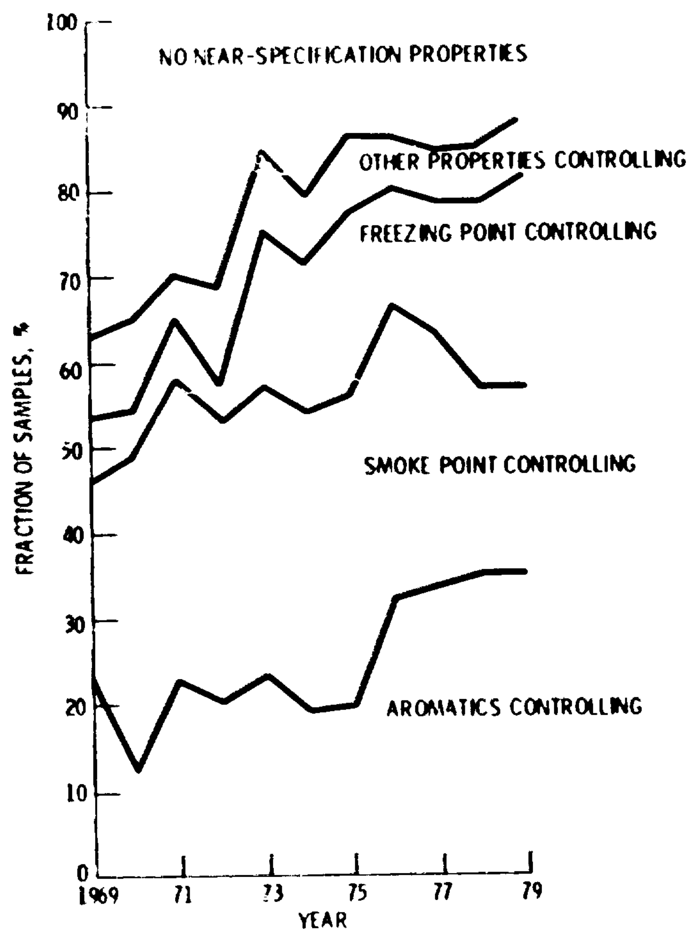

Figure 16. - Trends of identification of inspection data by controlling near-specification property.

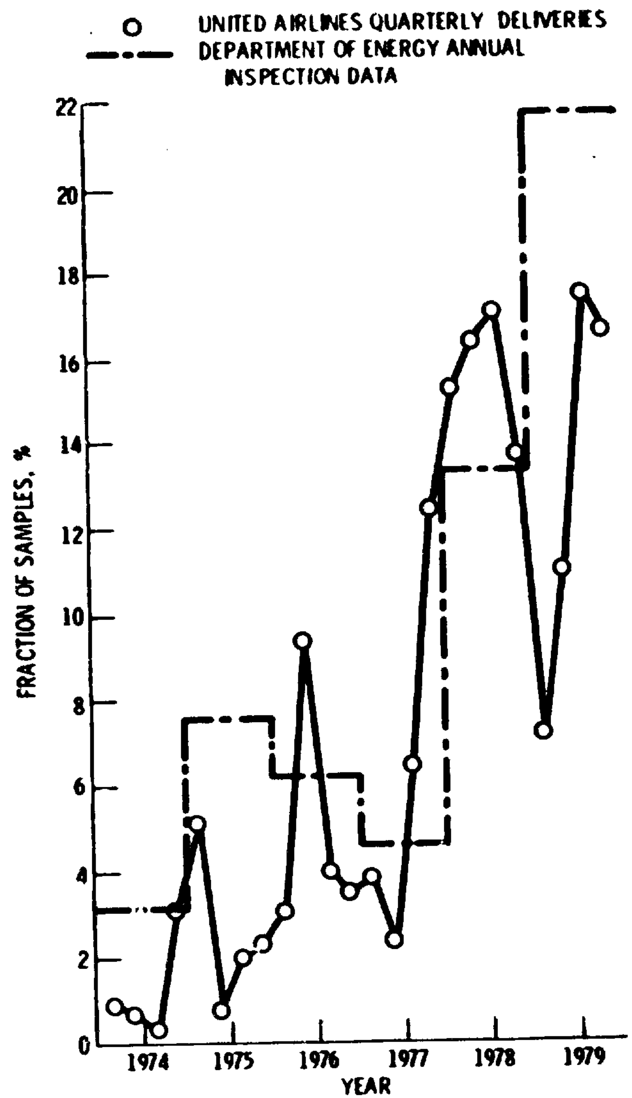

Figure 17. - Comparison of trends of inspection data for samples with aromatics or smoke point in the "reportable" range.