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Effect of Some Nitrogen Compounds on Thermal Stability of Jet A

Albert C. Antoine
Lewis Research Center
Cleveland, Ohio

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National Aeronautics and Space Administration
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Summary

This study investigated the effect of known concentrations of some nitrogen-containing compounds on the thermal stability of a conventional fuel, namely, Jet A. The concentration range from 0.01 to 0.1 wt% nitrogen was examined. Solutions were made containing, individually, pyrrole, indole, quinoline, pyridine, and 4-ethylpyridine at 0.01, 0.03, 0.06, and 0.1 wt% nitrogen concentrations in Jet A. The measurements were all made by using a standard ASTM test for evaluating fuel thermal oxidation behavior, namely, ASTM D3241, "Thermal Oxidation Stability of Turbine Fuels (JFTOT Procedure)." Measurements were made at two temperature settings, and "breakpoint temperatures" were determined. The results show that the pyrrole and indole solutions have breakpoint temperatures substantially lower than those of the Jet A used in this study. The pyridine, quinoline, and 4-ethylpyridine solutions have breakpoint temperatures comparable to or somewhat lower than those of the Jet A. However, for these solutions not all of the deposits produced were retained in the test section of the jet fuel thermal oxidation tester (JFTOT) tube, and thus some deposits could not be measured. This fact has to be considered in interpreting the breakpoint temperature results for these solutions. Solutions were also made containing both indole and 4-ethylpyridine in varying concentrations totaling 0.1 wt% nitrogen. The results for these solutions further show that solutions with pyridine-like nitrogen compounds exhibit test results with deposits not all retained in the test section.

Introduction

This study was conducted to investigate the effect of known concentrations of some nitrogen-containing compounds on the thermal stability of a conventional fuel, namely, Jet A. The reason for making such a study was that some aircraft fuels of the future may contain significantly larger concentrations of nitrogen-containing compounds than are present in today's jet fuels. In a study of the thermal stability of some aircraft turbine fuels derived from oil shale and coal syncrudes containing up to 0.24 wt% nitrogen (ref. 1), it was shown that nitrogen-containing compounds most likely contribute to fuel thermal instability. The kind of instability observed could affect the performance of a fuel in an aircraft system by gum or deposit formation or by particulates that could inhibit flow. In an other study (ref. 2) it was shown that the type of nitrogen compound involved (as measured by the basic nitrogen content) influenced the type of instability (deposit formation or inhibition of flow by particulates) observed. In both studies (refs. 1 and 2) the thermal stability determinations were made by using a standard ASTM test for evaluating fuel thermal oxidation behavior, namely ASTM D3241, "Thermal Oxidation Stability of Turbine Fuels (JFTOT Procedure)," (ref. 3). There are two criteria used in this procedure for evaluating the instability of a fuel: (1) the amount of deposit formed on a heated surface, and (2) the amount of deposit or particulate formed and not collected on the heated surface but trapped downstream by a filter and thus leading to an increase in pressure drop across the filter.

The present investigation was undertaken to determine the effect on stability (of Jet A) of some known nitrogen-containing compounds at several concentrations, when present alone or in combination. The compounds chosen were of the type and volatility one would expect to be present in a fuel prepared from a syncrude. The two previous studies (refs. 1 and 2) for the most part used fuels that had been processed from syncrudes and consequently contained many more compounds. In reference 2, however, some work was done with pure nitrogen compounds added to a petroleum-derived JP-5. With one exception the compounds were added at one concentration only and also limited to a maximum of 0.0134 wt% nitrogen. In this study the concentration range from 0.01 to 0.1 wt% nitrogen was examined. Solutions were made containing, individually, pyrrole, indole, quinoline, pyridine, and 4-ethylpyridine at 0.01, 0.03, 0.06, and 0.1 wt% nitrogen concentrations. In addition, solutions were made containing both indole and 4-ethylpyridine in varying concentrations totaling 0.1 wt% nitrogen. The thermal stability measurements were all made by using the JFTOT procedure.

Experimental Procedure

The thermal stability data were obtained by using the Alcor, Inc., jet fuel thermal oxidation tester (JFTOT) apparatus and procedure that are described in detail in ASTM D3241 (ref. 3). A cross-sectional sketch of the test section is shown in figure 1. In the test prefiltered, aerated fuel flows upward, under a pressure of 3.4 MPa (500 psig) through an annulus formed between the outer housing and an aluminum inner heater tube and then out through a test filter. The residence time in the annulus is approximately 12 seconds. Figure 2 shows a typical temperature profile that is obtained by a traversing thermocouple located inside the heater tube. The maximum temperature, usually at a position index of about 40 (40 mm from the fuel inlet position), is the temperature recorded as the JFTOT temperature. In this test, instability is determined by measuring the amount of deposits on the test heater tube surface (fig. 1) and by measuring any increasing pressure drop with time across the test filter (fig. 1).

The test filter pressure drop is recorded during the test procedure. The heater tube deposit is checked at the end of the test. The tube deposit is rated with an Alcor Mark 8A tube deposit rater (TDR), which is a light reflectance measurement device in which the heater tube is spun on its axis to give an average circumferential reading. While the tube is being spun, it can be scanned axially. The TDR scale is so calibrated that a zero reading indicates a clean tube and a 50 reading (the maximum) indicates a very heavy deposit. In current practice, for research and comparison purposes, a "breakpoint temperature" is determined (ref. 1). The breakpoint temperature is defined as that temperature at which a maximum spun TDR value of 13 is reached, and it is determined from a plot of maximum TDR values against test temperatures.

Results

Jet A

The effect of the nitrogen compounds on the stability of Jet A can be evaluated by determining the changes in breakpoint temperature of those solutions from that of pure Jet A. In this study the measurements were made over an extended period of time, and three samples of Jet A were used for making the solutions. Thus, to obtain a meaningful reference measurement for pure Jet A, JFTOT tests were made on each new batch of Jet A. Repeat tests were also made on one sample. The results are shown in figure 3, in which spun tube deposit rater (TDR) values are plotted against tube position, designated as position index. From the data shown in figures 3(a) and (b), for the first two batches, breakpoint temperatures of 267° and 269° C were determined. Data shown in figures 3(c) and (d) were obtained from the third batch. Similar results were obtained, but because the maximum deposit levels were less than 13, the breakpoint temperatures had to be higher than 270° C. Values of 279° and 275° C were obtained by extrapolation. A breakpoint temperature of 275° C was determined from the data shown in figure 3(e), which were obtained by making measurements at higher temperatures. The test temperatures, maximum axial spun TDR values, and the derived breakpoint temperatures are listed in table I.

A feature of interest should be noted in the results shown in figure 3, namely, the deposit pattern with respect to tube position determined from the axial scan. For the most part the pattern is symmetrical, following the temperature profile depicted in figure 2. Some obvious exceptions, with more than one maximum and some asymmetry, can be seen. This kind of pattern has been observed before (ref. 1) with various fuel samples.

Pyrrole Solutions

The axial spun TDR data as a function of position index for the pyrrole solutions are shown in figure 4. Measurements were made on solutions containing 0.01, 0.03, 0.06, and 0.1 wt% nitrogen, with duplicate tests (at different times) made on the 0.03 and 0.1 wt% solutions. For the most part the values exhibited a symmetry around the maximum-temperature location (a position index of about 40). At a temperature of 260° C, however, double maximums occurred for the 0.03 wt% solutions as well as for the 0.1 wt% solutions. This is shown for tests 4b, 4c, 4e, and 4f in figure 4. In general, there was little or no effect of nitrogen concentration for the test conditions used.

The reproducibility of the tests for the 0.03 wt% solutions was good, but a comparison of the duplicate tests at 245° C for the 0.1 wt% solutions showed a difference of about 15 in maximum spun TDR values. This is 1.5 times the magnitude noted for the duplicate Jet A tests. The tests at lower temperatures, 220° to 235° C, all showed a similar pattern, with deposits from 5 to 25. The spun TDR maximum values, the test temperatures, and the breakpoint temperatures derived therefrom are given in table II. The breakpoint temperatures for the 0.01 and 0.03 wt% nitrogen solutions were not very different, namely, 235° C and 238° to 239° C. The value for the 0.06 wt% solution (222° C) was obtained by extrapolation since the deposit maximums for the two temperatures tested were above 13. The values determined for the two sets of 0.1 wt% solutions differed by about 15° C. This was due primarily to the almost identical maximum spun TDR values recorded for the lowest temperatures in each set, namely, 9.9 and 10.0 at 235° and 220° C, respectively.

For the pyrrole solutions, breakpoint temperatures ranged from 222° to 239° C. Comparing these values to Jet A values of 267° to 275° C shows that the addition of pyrrole to Jet A reduced its stability.

Indole Solutions

The results for the indole solutions are shown in figure 5, in which the axial spun TDR data are plotted against position index. The results show, for the most part, a symmetrical pattern. There are, however, some asymmetry and double-maximum patterns for different solutions at the same 0.01 and 0.03 wt% concentrations at 260° C. Breakpoint temperatures, test temperatures, and maximum spun TDR values are given in table III. The breakpoint temperatures, with one exception, range from 246° to 252° C and ostensibly show little dependence on nitrogen concentration. The breakpoint temperature outside the range, 232° C, was obtained by extrapolation since the maximum TDR value at the lower temperature was larger than 13. Comparing the breakpoint temperature values of the indole solutions with those of Jet A shows that the addition of the nitrogen compound reduced the stability of Jet A.

Pyridine Solutions

The results for the pyridine solutions are shown in figure 6, in which axial spun TDR values are plotted as a function of position index. These results are varied, showing symmetry, asymmetry, and multiple deposit peaks. For the 0.01 wt% concentration there are results from two sets of tests. One set shows considerably more deposits than the other. In the first set, light deposits are evident even up to 280° C; the other set shows heavy deposits at 275° C. However, both sets show deposits not only on the test section but also high on the tube - at the upper shoulder (position index 60) and above. The tube deposit rater cannot make tube deposit measurements above position index 54. For the 0.03 wt% concentration there are also results from two sets of tests. One set shows symmetry at 275° C but also deposits beyond the test section. The other set shows a symmetric pattern at 270° C and multiple peaks at 280° C, together with deposits beyond the test section. For the 0.06 wt% concentration little deposit is evident up to 270° C, but at 280° and 285° C deposits are heavy. There are also some asymmetric peaks. And again, deposits are heavy high on the tube, beyond the test section. Data for the 0.1 wt% concentration were obtained only up to 280° C. Although little deposit was produced in the measurable test section, deposits past the test section were heavy. Figure 7 shows some heater tubes after a JFTOT test. Figure 7(a) shows the results for one run at 270° C for a pyridine solution.

Maximum spun TDR values are given in table IV, together with the breakpoint temperatures that were determined from them. For those instances where the maximum TDR values were uncertain, the breakpoint temperatures derived were labeled as "estimated."

All of the results for the pyridine solutions are clouded by the fact that in all instances not all of the deposit formed was in position to be measured. It was obvious that no estimate could be made of the amount not being measured under the existing experimental conditions. Other observations should be made, however, on the results obtained with the pyridine solutions. The results for the 0.01 wt% solutions show a difference (of 40) in deposit maximums for nearly the same temperatures, 280° and 275° C, and this is much larger than the differences noted before for similar comparisons. The difference for the 0.03 wt% solutions was not as great, but a marked change in pattern occurred at 280° C. It should be remembered, however, that such a pattern was also observed with pure Jet A. In contrast to the previous differences, a refreshing parallelism was observed with the 0.06 wt% solutions as the two-maximum asymmetric pattern was repeated and enhanced in going from 280° to 285° C. Finally, for a number of the tests at the lower temperatures, 260° C for the 0.01 and 0.03 wt% solutions, 275° C for the 0.06 wt% solutions, and 260° and 270° C for the 0.1 wt% solutions, it seems that larger deposits have occurred further up the tube as the highest deposit reading is at position 54 and the shape of the curve is tending upward.

The breakpoint temperature values (not including those estimated or extrapolated) determined for the pyridine solutions range from 265° to 275° C. These values are quite similar to those for pure Jet A and ostensibly show that these solutions have about the same thermal stability.

Quinoline Solutions

Results obtained for solutions of quinoline in Jet A are shown in figure 8. Most of the test results for the 0.01 and 0.03 wt% concentrations show a symmetric deposit pattern, although the peaks occur somewhat above position 40. For the one run at 280° C for the 0.01 wt% solution, an asymmetric double peak was observed. For these solutions, also, deposits beyond the test section were noted. The results for the 0.06 and 0.1 wt% solutions are similar in that both show a definite asymmetry. The two tests showing the heaviest deposits, 0.06 wt% solutions at 275° C and 0.1 wt% solutions at 270° C, have peaks at and below position 40 but definite indications of more deposits farther up the tube. A heater tube from a run at 270° C is shown in figure 7(b). The other tests, with peaks above 40, also gave indications that more deposits should be expected beyond the test section. The breakpoint temperatures are given in table V, together with the test temperatures and maximum spun TDR values. The breakpoint temperatures range from 257° to 273° C, with no dependence on concentration observed. Any dependence present is masked by the precision of the measurements. Comparing the values with those for Jet A leads to the conclusion that adding quinoline to Jet A had very little effect on the stability.

4-Ethylpyridine Solutions

The data from the 4-ethylpyridine solutions were informative. Asymmetry and deposits beyond the test section were again found. Plots of TDR deposit ratings against position index, shown in figure 9, may not be indicative of true results since the indications are that in some instances the heaviest deposits, beyond the test section, are not being recorded. This was particularly noted for the 0.06 and 0.1 wt% concentrations, where the peaks in deposits appear not to have been reached. A heater tube from a run at 260° C is shown in figure 7(c). Breakpoint temperatures estimated from such data may then be too high and were not derived. The data for the solutions are given in table VI. Estimated breakpoint temperatures for the 0.01 and 0.03 wt% concentrations were derived and are slightly lower than those observed for Jet A, suggesting that 4-ethylpyridine solutions have stabilities near those for Jet A.

Comparison of Breakpoint Temperatures

The breakpoint temperatures of Jet A and solutions of nitrogen compounds in Jet A are given in figure 10. In figure 10(a) the breakpoint temperatures are plotted as a function of nitrogen concentration. In figure 10(b) breakpoint temperature ranges are shown. The results indicate that the effect of concentration is small and that the breakpoint temperatures for both the pyrrole and indole solutions are lower than those for Jet A. The values for the pyridine, quinoline, and 4-ethylpyridine solutions are about comparable to, or somewhat lower than, the Jet A breakpoint temperature range. It should be noted, however, that for these solutions some of the deposits were not retained in the test section of the JFTOT tube. Thus the breakpoint temperatures of these solutions most likely are quite a bit lower, comparable to those of the other solutions, and any interpretation of these results without that recognition would not be accurate.

Evaluation of Solvent Action of Fuel Additives on Heater Tube Deposits

In an earlier study (ref. 2) on the effect of the concentration of basic nitrogen compounds, it was noted that after an initial increase in TDR values with an increase in concentration, further increases in concentration produced lower TDR values. It was also noted that deposits were found at the cooler section of the JFTOT test tube (above position 54). This phenomenon was interpreted as being a result of some solvent action of the fuel being tested. A number of the results found in the present study could be interpreted in the same way. To further test the interpretation, a series of tests were made at 270° C with increasing concentrations of 4-ethylpyridine. The results are shown in figure 11 and can be interpreted as a displacement of the deposits, with such displacement increasing with increasing concentration of 4-ethylpyridine.

Another series of tests were made with 4-ethylpyridine and indole mixtures in Jet A. The mixtures were made to give a total concentration of 0.1 wt% nitrogen but varied between the two components to give ratios of 4-ethylpyridine to indole of 0.025:0.075, 0.05:0.05, and 0.075:0.025. These tests were made at 260° C. The results are shown in figure 12 together with additional tests of the two components, each at 0.1 wt% nitrogen. The deposit pattern for the 0.1 wt% concentration of 4-ethylpyridine was as expected from the previous tests with this solution. The solution with 0.075 wt% 4-ethylpyridine still shows the strong influence of the high 4-ethylpyridine concentration, and the deposits are concentrated toward the upper end of the tube. Heavier deposits were found on the test section of the JFTOT tube for both the 50:50 and 25:75 4-ethylpyridine and indole solutions, but with some asymmetry. For the 0.1 wt% indole solution, still more deposits were located in a more symmetric pattern on the test section.

Pressure Drop Measurements

It was mentioned earlier in this report that another type of fuel instability can be measured by the JFTOT test, namely, the tendency to form particulates that can plug the test filter. It was noted in reference 2 that adding basic nitrogen to a JP-5 fuel did not always increase deposits at the test section but did at those times increase the pressure drop more quickly (measured as the time to reach 25 torr). Those results were obtained at 260° C. In this work pressure drops reaching 25 torr did occur with the pyrrole solutions at 260° C. The results, given in table VII, show that an increase in nitrogen concentration did cause the pressure drop limit to be reached more quickly. With the exception of one ethylpyridine solution, none of the other solutions examined in this study at 260° C or below showed a pressure drop reaching 25 torr. Pressure drop results at higher temperatures were not evaluated.

Concluding Remarks

This study was conducted to investigate the effect of some individual nitrogen compounds on the thermal stability of a conventional fuel like Jet A. The results show that even with concentrations as low as 0.01 wt% nitrogen significant changes in stability occur. The results further show that for solutions of pyridine, quinoline, and ethylpyridine in Jet A the ostensible results for tube deposit ratings are not accurate because deposits occur beyond the test section and cannot be measured. This is in contrast to the solutions with pyrrole and indole, whose results do not show this inaccuracy. It can be concluded, however, that most fuels, which will have a mixture of nitrogen types, may be subject to this kind of inaccuracy. The JFTOT results will have to be evaluated with this in mind.

Summary of Results

In this investigation of the effect of nitrogen compounds on the thermal stability of Jet A fuel, the following results were obtained:

1. Solutions containing pyrrole and indole in Jet A were less stable than Jet A, that is, they had breakpoint temperatures substantially lower than those of the Jet A used in this study.

2. Solutions containing pyridine, quinoline, and 4-ethylpyridine appeared to have breakpoint temperatures comparable to or only slightly lower than those of the Jet A. However, for all of these solutions the breakpoint temperature measurements could not be made accurately because some of the deposits occurred beyond the test section and could not be measured.

3. Solutions containing both indole and 4-ethylpyridine further showed that solutions with pyridine-like nitrogen compounds exhibit test results with deposits not all retained in the test section.

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, January 15, 1982

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1. Reynolds, Thaine W.: Thermal Stability of Some Aircraft Turbine Fuels Derived from Oil Shale and Coal. NASA TM X-3551, 1977.
2. Nowack, C. J.; and Delfosse, R. J.: Thermal Oxidative Stability of Synthetic Jet Fuels. Presented at the Naval Air Systems Command—Naval Research Laboratory Workshop on Basic Research Needs for Synthetic Hydrocarbon Jet Aircraft Fuels, June 1978, pp. 127–148.
3. Thermal Oxidation Stability of Turbine Fuels (JFTOT Procedure). ASTM D3241-77. 1981 Annual Book of ASTM Standards, 1981, vol. 25, pp. 138–160.

TABLE I. - JFTOT TEST RESULTS FOR JET A

Test	Temperature, °C			Breakpoint temperature, °C
	260	270	280	
	Maximum spun tube deposit rater (TDR) values			
3a	1.4	14.2	----	267
3b	1.6	18.4	----	269
3c	4.1	10.1	----	[a]279
3d	1.9	8.5	----	[a]275
3e	---	8.3	18.1	275

[a]Extrapolated value.

TABLE II. - JFTOT TEST RESULTS FOR PYRROLE SOLUTIONS

Test	Nitrogen concentration, wt%	Temperature, °C						Breakpoint temperature, °C
		220	225	230	235	245	260	
		Maximum spun tube deposit rater (TDR) values						
4a	0.01	----	----	5.4	----	30.5	----	235
4b	.03	----	----	----	9.3	----	43.3	238
4c	.03	----	----	----	8.8	----	38.2	239
4d	.06	----	15.2	----	20.0	----	----	[a]222
4e	.1	----	----	----	9.9	18.0	----	239
		----	----	----	----	33.1	----	237
		----	----	----	----	----	41.0	238
4f	.1	10.0	----	24.9	----	----	----	222
		----	----	----	----	38.5	----	223
		----	----	----	----	----	45.0	224

[a]Extrapolated value.

TABLE III. - JFTOT TEST RESULTS FOR INDOLE SOLUTIONS

Test	Nitrogen concentration, wt%	Temperature, °C			Breakpoint temperature, °C
		240	250	260	
		Maximum spun tube deposit rater (TDR) values			
5a	0.01	5.0	----	19.0	252
5b	.01	4.7	----	27.0	248
5c	.03	3.1	----	25.7	249
5d	.03	17.8	----	26.8	[a]232
5e	.05	5.0	----	23.0	249
5f	.06	----	12.8	35.3	250
5g	.1	6.2	----	28.2	246

[a]Extrapolated value.

TABLE IV. - JFTOT TEST RESULTS FOR PYRIDINE SOLUTIONS

Test	Nitrogen concentration, wt%	Temperature, °C					Breakpoint temperature, °C
		260	270	275	280	285	
		Maximum spun tube deposit rater (TDR) values					
6a	0.01	----	5.3	----	9.1	---	[a]288
6b	.01	[b]3.3	-----	48.5	----	---	[b]263
6c	.03	[b]2.7	-----	>50	----	---	[b]263
6d	.03	----	1.9	----	24.9	---	275
6e	.06	0	-----	[b]6.0	----	---	[a,b]282
6f	.06	----	2.2	----	29.4	---	274
6g	.06	3.0	-----	[b]3.5	----	>50	265, [b]277
6h	.1	[b]8.0	[b]11.5	----	----	---	[a,b]273
6i	.1	----	[b]4.3	----	9.0	---	[a,b]288

[a]Extrapolated value.
[b]Maximum TDR value uncertain; breakpoint temperature estimated.

TABLE V. - JFTOT TEST RESULTS FOR QUINOLINE SOLUTIONS

Test	Nitrogen concentration, wt%	Temperature, °C						Breakpoint temperature, °C
		250	255	260	270	275	280	
		Maximum spun tube deposit rater (TDR) values						
8a	0.01	2.2	---	17.8	-----	----	----	257
8b	.01	----	---	----	6.2	----	24.0	273
8c	.03	----	2.5	14.0	-----	----	----	259
8d	.03	----	---	----	11.1	23.0	----	271
8e	.06	----	---	----	13.2	25.1	----	270
8f	.06	----	---	[a]4.0	-----	34.8	----	[a]265
8g	.1	[a]3.0	---	----	[a]34.0	----	----	[a]257
8h	.1	----	---	[a]3.0	17.8	----	----	[a]267

[a]Maximum spun TDR values uncertain; breakpoint temperature value estimated.

TABLE VI. - JFTOT TEST RESULTS FOR 4-ETHYLPYRIDINE SOLUTIONS

Test	Nitrogen concentration, wt%	Temperature, °C				Breakpoint temperature, °C
		245	260	270	275	
		Maximum spun tube deposit rater (TDR) values				
9a	0.01	----	[a]11.0	47.0	---	[a]261
9b	.03	----	[a]1.0	-----	>50	[a]264
9c	.06	----	[a]1.2	[a]19.2	---	----
9d	.1	[a]6.5	[a]40.0	-----	---	----
9e	.1	----	[a]7.9	[a]19.3	---	----

[a]Maximum spun TDR values uncertain; breakpoint temperature value estimated.

TABLE VII. - PRESSURE DROP MEASUREMENTS WITH PYRROLE SOLUTIONS

Nitrogen concentration, wt%	Time to reach 25 torr, min
0.1	54
.1	34
.03	86
.03	88

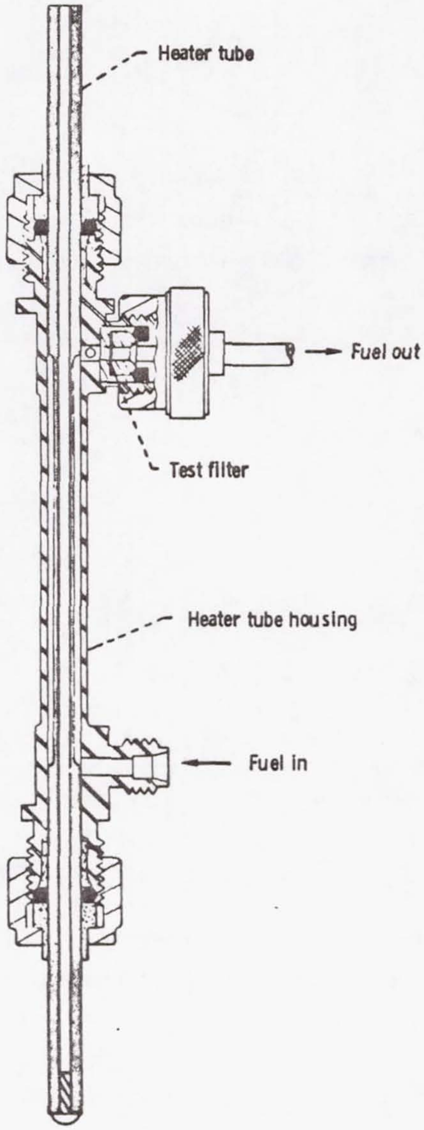


Figure 1. - JFTOT test section.

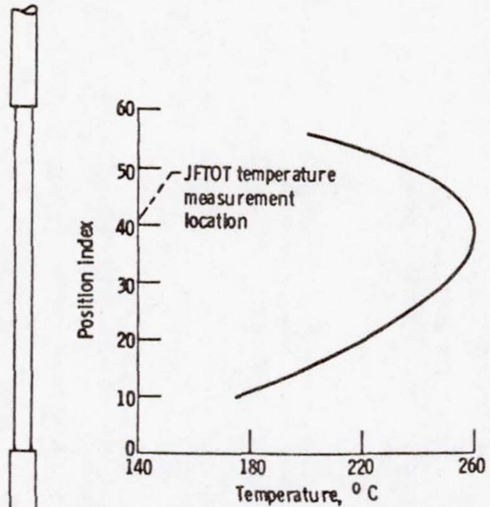


Figure 2. - Typical temperature profile in JFTOT tubes.

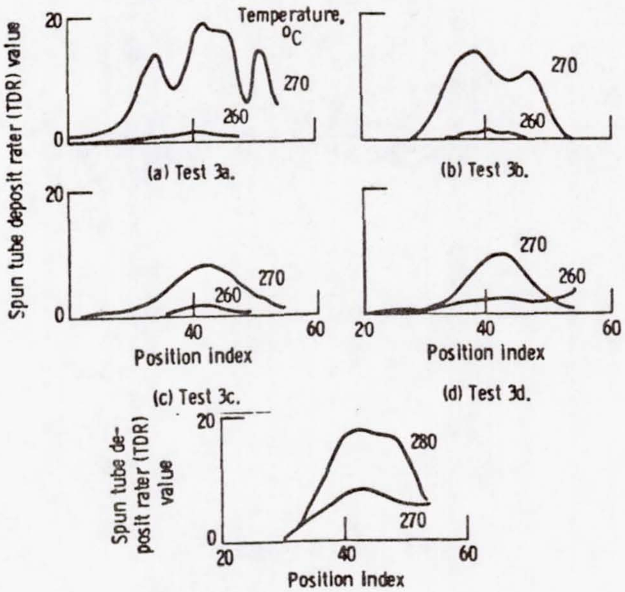


Figure 3. - Tube deposit ratings for Jet A.

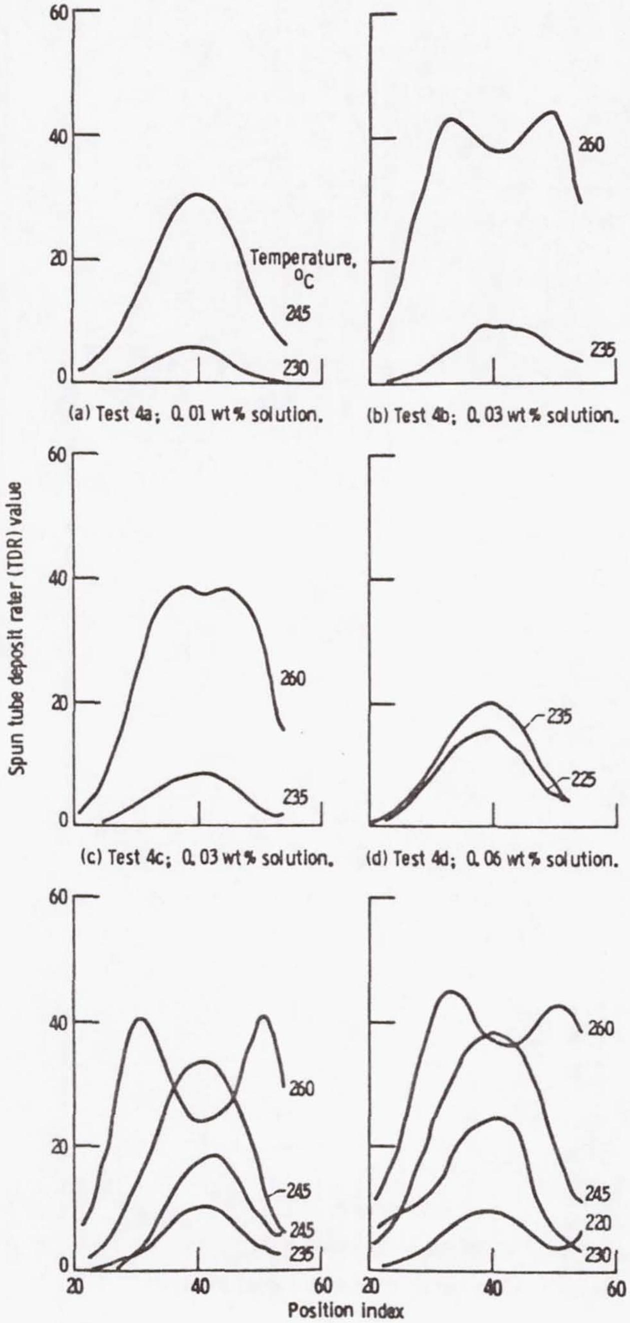


Figure 4. - Tube deposit ratings for pyrrole solutions.

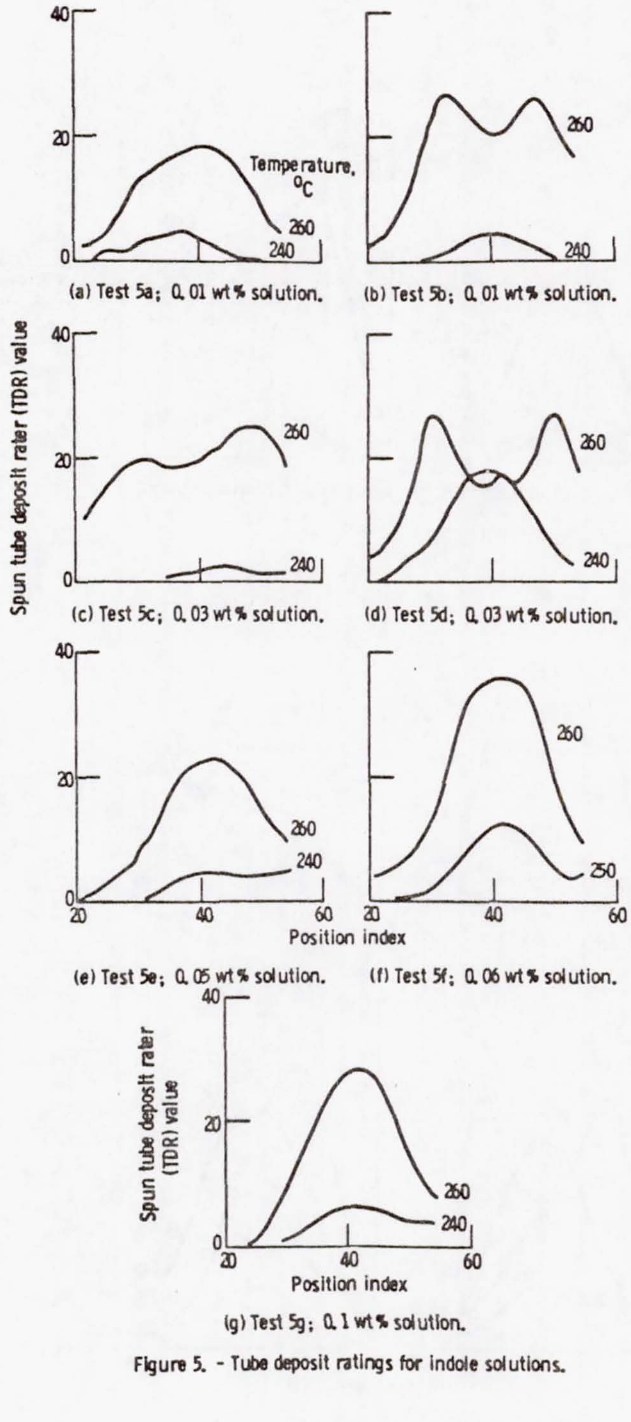


Figure 5. - Tube deposit ratings for indole solutions.

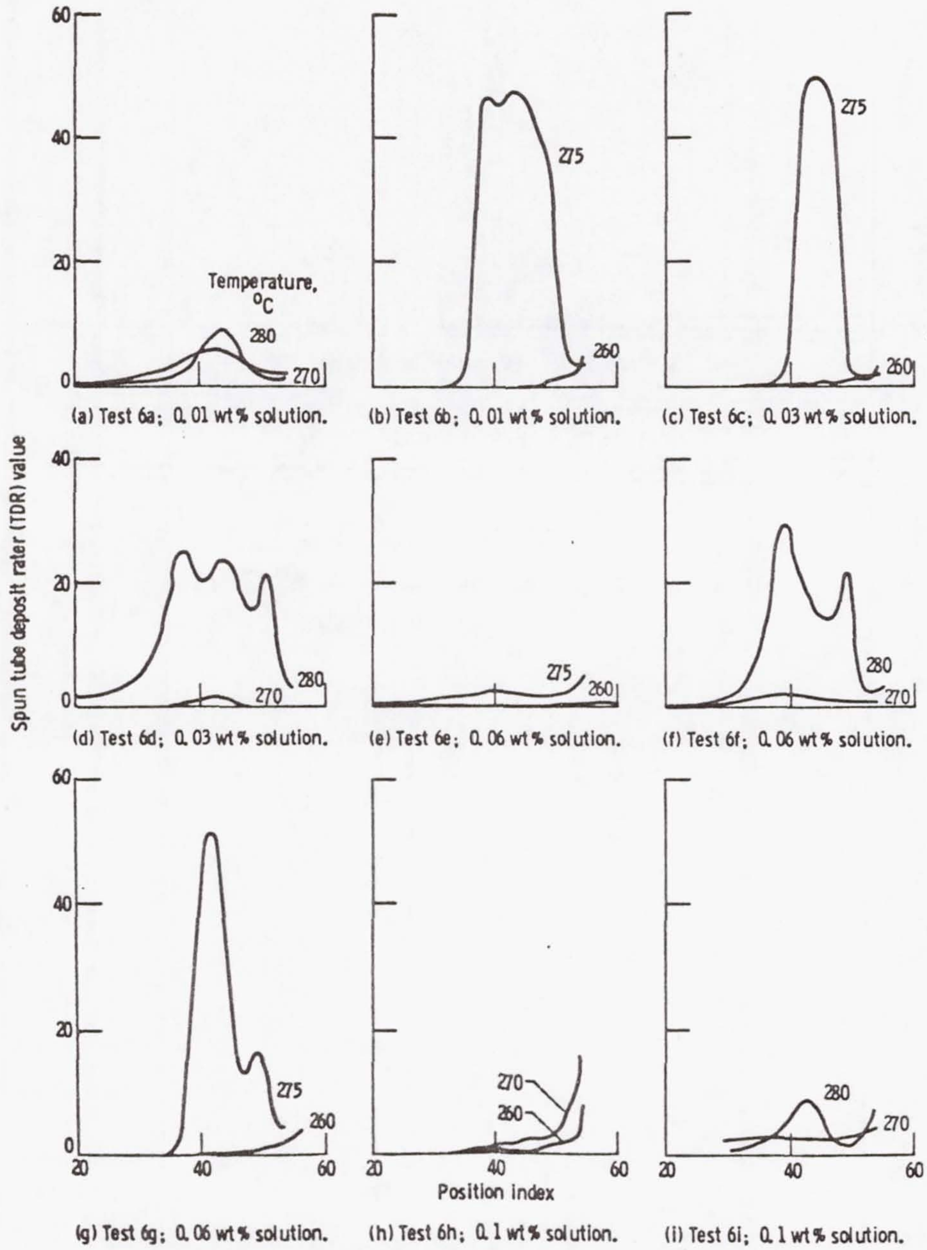
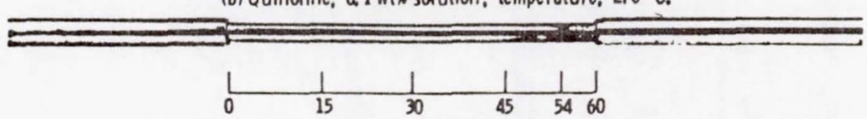


Figure 6. - Tube deposit ratings for pyridine solutions.

(a) Pyridine, 0.1 wt% solution; temperature, 270° C.

(b) Quinoline, 0.1 wt% solution; temperature, 270° C.



(c) Ethylpyridine, 0.1 wt% solution; temperature, 260° C.

Figure 7. - JFTOT heater tubes after testing.

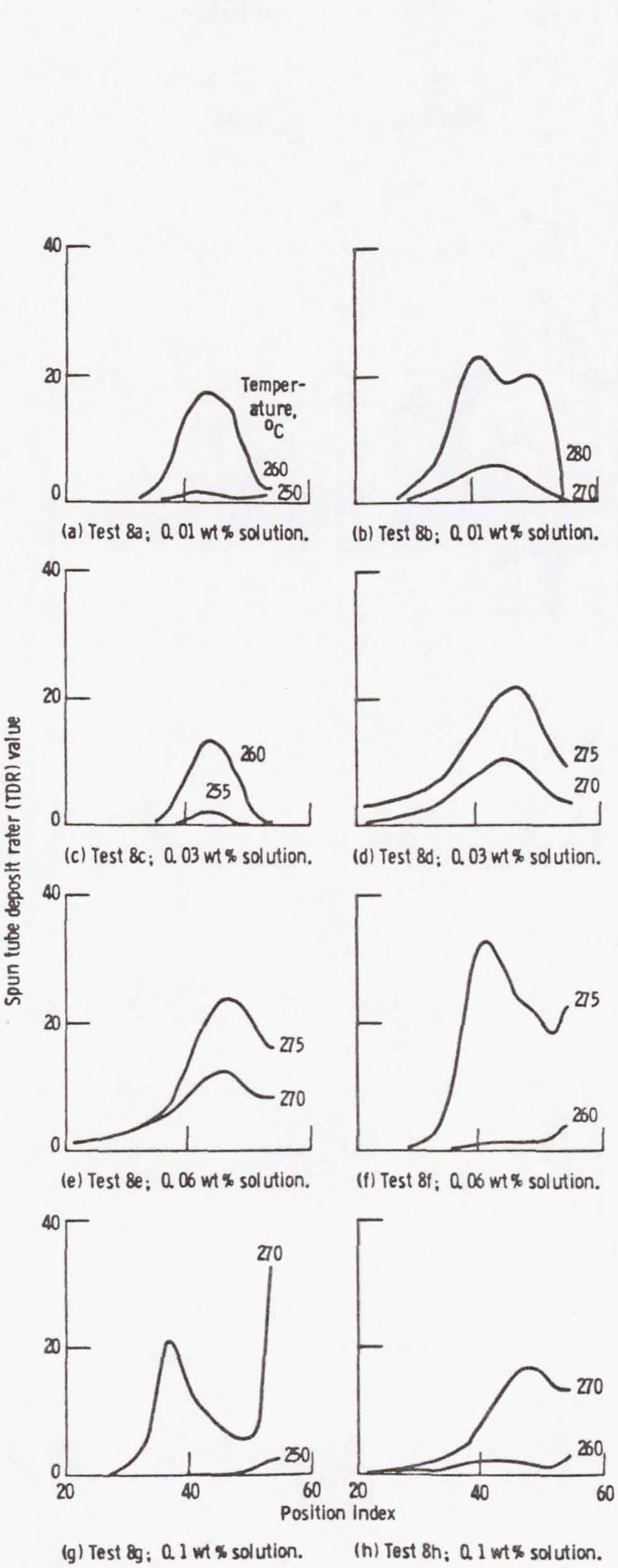


Figure 8. - Tube deposit ratings for quinoline solutions.

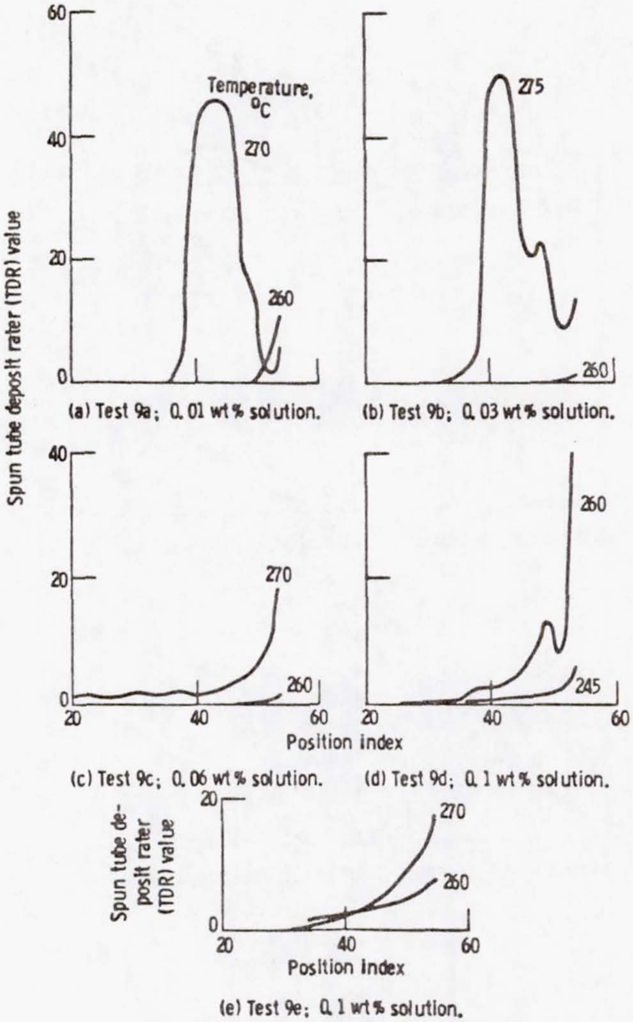
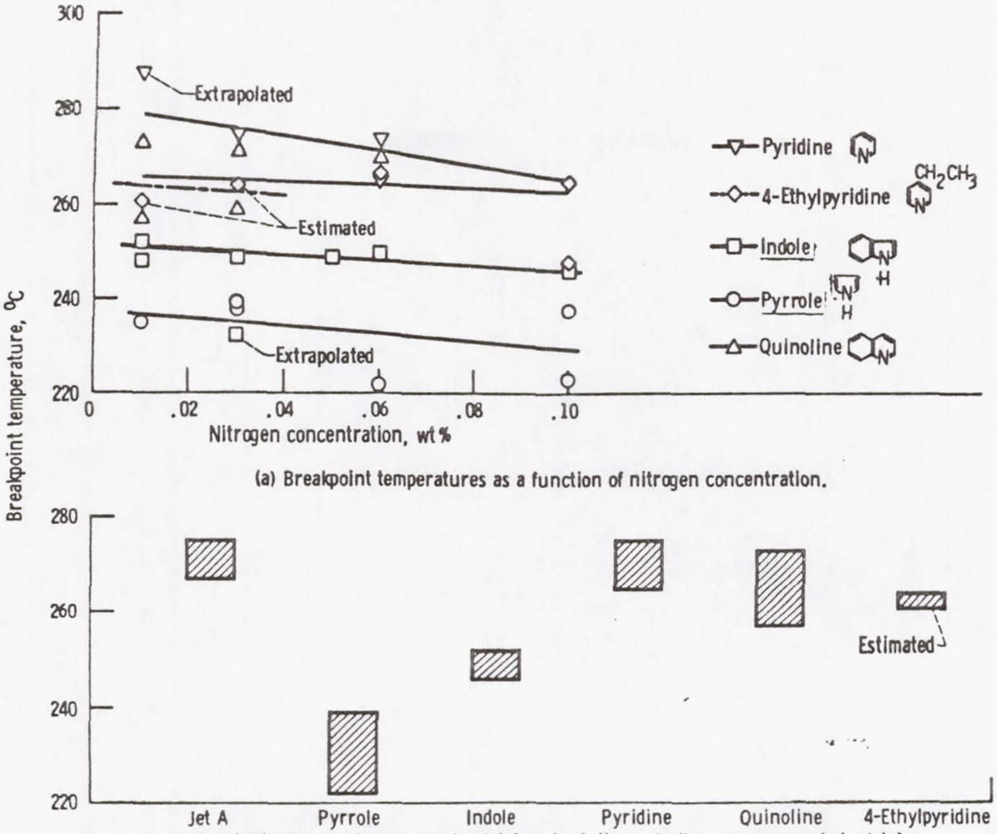
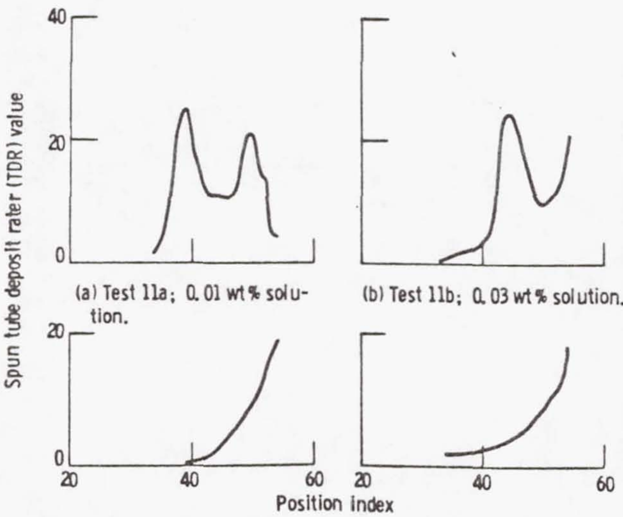


Figure 9. - Tube deposit ratings for 4-ethylpyridine solutions.



(b) Breakpoint temperature range for Jet A and solutions of nitrogen compounds in Jet A.

Figure 10. - Breakpoint temperatures of Jet A and solutions of nitrogen compounds in Jet A.



(c) Test 11c; 0.06 wt % solution. (d) Test 11d; 0.1 wt % solution.

Figure 11. - Tube deposit ratings for 4-ethylpyridine solutions at 270° C.

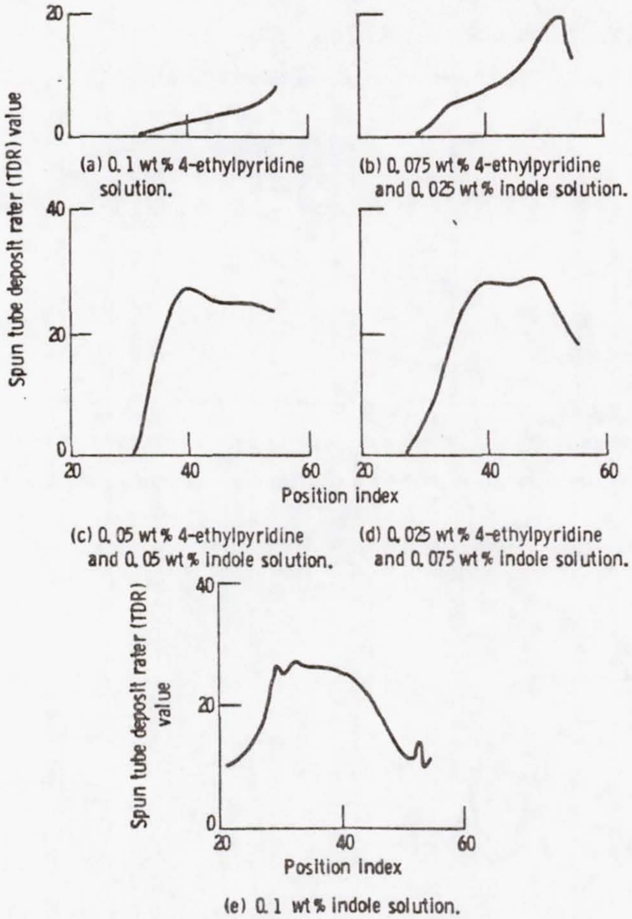


Figure 12. - Tube deposit ratings for 4-ethylpyridine solutions at 260° C.

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15. Supplementary Notes

16. Abstract

Thermal stability "breakpoint temperatures" were determined for solutions of some nitrogen-containing compounds in Jet A by JFTOT measurements. The solutions contained, individually, pyrrole, indole, quinoline, pyridine, and 4-ethylpyridine at 0.01, 0.03, 0.06, and 0.1 wt% nitrogen concentrations. The results show that the pyrrole and indole solutions have breakpoint temperatures substantially lower than those of the Jet A used in this study. The pyridine, quinoline, and 4-ethylpyridine solutions have breakpoint temperatures somewhat comparable to those of the Jet A. However, for these latter solutions not all of the deposits produced were retained in the test section of the JFTOT tube, and thus some deposits could not be measured. Solutions containing both indole and 4-ethylpyridine in varying concentrations further show that solutions with pyridine-like nitrogen compounds exhibit test results with deposits not all retained in the test section.

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