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EFFECTS OF SEVERAL EQ FUEL LOADINGS
ON ALUMINUM PROCESS TUBE LIFE

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EFFECTS OF SEVERAL EQ FUEL LOADINGS

ON ALUMINUM PROCESS TUBE LIFE

By

C. G. Hough

July 24, 1964

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EFFECTS OF SEVERAL EQ FUEL LOADINGS ON ALUMINUM PROCESS TUBE LIFE

INTRODUCTION

This report contains the results of tube life estimates for five small reactor enriched fuel loadings which you requested. The TUBE-3 code¹ was used to estimate tube life. The five cases are compared to a base case corresponding to the present 32-piece natural fuel loading. Methods are given for comparing the total or cumulative tube life for a full reactor loading to the base case.

SUMMARY

Tube life estimates for the base case and the five study cases are given in Table 6 for 6.6 and 7.0 pH. The fuel sizes and operating conditions for each case are summarized in Table 1. Information on the mixer position that gives maximum tube life for each case is shown in Tables 2, 3, 4, and 5.

A tube life distribution was calculated for the base case using the outlet temperature distribution for 1197 central zone tubes at B reactor and is shown in Figures 3 and 4. Average tube life for the 1197 tubes was estimated to be 3.0 years (100 percent TOE) for operation at 6.6 pH, and the outlet temperature corresponding to average tube life was 107°C. Similar numbers could be calculated for the study cases if estimates of the outlet temperature distributions were available.

DISCUSSION

Definition of Base Case

The base case must be accurately defined in order for tube life estimates to have meaning in the absolute sense. Normally, this involves definition of an average process tube operating at average inlet and outlet temperatures, flow, axial flux, etc. This is very difficult to do because a tube operating at average outlet temperature is not necessarily representative of all central-zone tubes. This is true because the distribution of central-zone outlet temperatures is not normal or symmetric with respect to the mean temperature. Furthermore, a tube operating at average outlet temperature is not an average corroding tube because aluminum corrosion rates approximately double for each 12-degree increase in outlet temperature.

¹RD Jensen, TUBE-3 Fortran Program: Technical Description, HW-79518, November 4, 1963.

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To define the base case for this study, the distribution of outlet temperatures at B reactor taken from temperature maps during the month of April, 1964, was obtained from Production Computing. The distribution is shown in Figure 1. The central zone was arbitrarily defined as all tubes having an outlet temperature equal to or greater than 95°C. There are 1197 such tubes at B reactor. This definition of central zone does not correspond to the reactivity definition implied by location of the enrichment ring. The average temperature of the 1197 tubes is 108.3°C. There are 650 tubes with outlet temperatures greater than this average and 547 tubes with outlet temperatures less than this average. The outlet temperature distribution of Figure 1 was weighted by relative tube life defined as follows:

$$\text{Relative Tube Life} = 1 / \text{RELATIVE CORROSION RATE}$$

$$\begin{aligned} &= \frac{1}{\frac{\exp(0.057)(t_i)}{\exp(0.057)(t_a)}} \\ &= \frac{\exp(0.057)(108.3)}{\exp(0.057)(t_i)} \\ &= \frac{478.18}{\exp(0.057)(t_i)} \end{aligned}$$

Where: t_i = the i th tube outlet temperature
 t_a = the average tube outlet temperature = 108.3°C

The resulting weighted temperature distribution shown in Figure 2 is directly proportional to tube life. Then, the outlet temperature of a tube having average tube life is 106.7°C, and there are approximately 693 effective tubes with outlet temperatures greater than this average (shorter tube life) and 504 effective tubes with outlet temperatures less than this average (longer tube life). Thus, a tube having average tube life is defined as a tube operating at an outlet temperature of 107°C.

Definition of Study Cases

The main differences between the five study cases are the fuel size, tube flow, and mixer position. These differences and other operating conditions are shown for the base case and the five study cases in Table 1. Tube dimensions are the same for all cases and represent an average uniform wall tube.

Mixer Position

The TUBE-3 code was used to determine the mixer position that gives maximum tube life for each case. To do this it was necessary to select an outlet temperature representative of the central-zone temperature distribution. For the base case, 110°C was used.* Outlet temperatures of 110°C, 114°C, and 118°C were used for

* It was previously shown that 107°C corresponded to average tube life. 110°C was used by mistake and the difference in optimum mixer placement was not considered great enough to justify repeating the TUBE-3 IBM runs at 107°C.

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the five study cases. As a matter of interest outlet temperatures of 114°C and 118°C were run for the base case also. The mixer positions that give maximum tube life are shown in Table 2. The mixer position (number of fuel pieces from rear of charge) for the base case is based on a 32-piece natural charge. The mixer position for the five study cases is based on a 43-piece enriched charge.

Table 3 gives the failure mode for the mixer positions given in Table 2. As an example, the code T-B means tube life is limited by top wall corrosion with no mixer and is limited by bottom wall corrosion with a mixer in the indicated position. Similarly, B-B means tube life is limited by bottom wall corrosion with no mixer and with the mixer in the indicated position.

Table 4 gives the estimated tube life (years at 100 per cent TOE) for the mixer positions shown in Table 2. Table 5 shows the additional tube life for the mixer positions of Table 2 relative to no mixer at all, i.e., tube life with mixer minus tube life with no mixer.

All tube life estimates obtained with the TUBE-3 code assume that a new process tube having nominal dimensions operated its complete life with nominal fuel elements, the same inlet and outlet temperature, the same mixer position, the same pH, the same axial flux, and the same goal exposure.

Tube Life Estimates

The TUBE-3 code was used to obtain tube life estimates for the complete outlet temperature range using the optimum mixer positions shown in Table 2 corresponding to 110°C . The results are shown in Table 6 for 6.6 and 7.0 pH.

The results of Table 6 indicate the present enriched fuel size (case 1) gives the best tube life for a given outlet temperature. However, the table does not reflect the effect of increased flow and corresponding reduction in outlet temperature that would occur with a smaller fuel element relative to the base case (or case 1). In order to properly evaluate the five cases relative to the base case, it would be necessary to balance net increase in production because of increased flow against the additional tube replacement losses.

One way to compare tube replacement losses between cases is to calculate the tube life distribution from the anticipated outlet temperature distributions for each case using Table 6 to convert outlet temperature to tube life. This requires knowledge of the outlet temperature distribution for each study case. As an example, the tube life distribution was calculated for the base case using the known outlet temperature distribution of Figure 1 and the tube life estimates of Table 6. The tube life for each outlet temperature (interpolate Table 6) is multiplied by the number of tubes operating at each outlet temperature (Figure 1) to obtain the total tube life for all tubes operating at each particular temperature. The resulting tube life distribution is plotted in histogram form (Figure 3), and the cumulative tube life distribution is shown in Figure 4. From these figures, the average outlet temperature corresponding to average tube life is found to be 107.3°C . This compares favorably with our previous estimate (Figure 2) of 106.7°C obtained by using a simple relative tube life relationship to weight the outlet temperature distribution of Figure 1.

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The average tube life is 3.0 years at 100 per cent TOE, and the cumulative total tube life for all 1197 tubes is 3544 years (100 per cent TOE).

Similar numbers could be calculated for the five study cases if estimates of the outlet temperature distributions were available.

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TABLE 1
OPERATING CONDITIONS FOR CASE STUDIES

	<u>BASE CASE</u>	<u>CASE ONE</u>	<u>CASE TWO</u>	<u>CASE THREE</u>	<u>CASE FOUR</u>	<u>CASE FIVE</u>
FUEL TYPE	03N	03E	Enr.	Enr.	03E	Enr.
NO. OF PIECES	32	43	43	43	43	43
FUEL OD (Inches)	1.444	1.443	1.436	1.432	1.443	1.440
FUEL ID (Inches)	0.314	0.314	0.353	0.375	0.314	0.330
FLOW - gpm	47.7	48.2	50.5	52.5	50.8	52.0
TUBE OD (Inches)	1.729	1.729	1.729	1.729	1.729	1.729
TOP WALL (Inches)	0.066	0.066	0.066	0.066	0.066	0.066
BOTTOM WALL (Inches)	0.064	0.064	0.064	0.064	0.064	0.064
RIB PLUS WALL (Inches)	0.148	0.148	0.148	0.148	0.148	0.148
INITIAL R-TOP	1.18	1.18	1.10	1.07	1.18	1.12
GOAL EXPOSURE (MWD/T)	600	800	800	800	800	800
AXIAL FLUX SKEWING	0	0	0	0	0	0
AXIAL FLUX PEAKING (%)	4	11	11	11	11	11
INLET TEMPERATURE, °C	12	12	12	12	12	12
REPLACEMENT WALL THICKNESS (Inches)	0.030	0.030	0.030	0.030	0.030	0.030

TABLE 2

MIXER POSITION FOR MAXIMUM TUBE LIFE
NO. OF PIECES FROM REAR OF CHARGE

<u>CASE</u>	<u>FUEL</u>	<u>6.6 pH</u>			<u>7.0 pH</u>		
		<u>110°C</u>	<u>114°C</u>	<u>118°C</u>	<u>110°C</u>	<u>114°C</u>	<u>118°C</u>
BASE	32-03N	7	9	9	10	12	12
ONE	43-03E	10	10	10	13	13	13
TWO	43-E*	10	10	10	10	10	10
THREE	43-E*	10	10	10	10	10	10
FOUR	43-03E	10	10	10	13	13	13
FIVE	43-E*	9	9	9	7	7	7

* Fuel dimensions are shown in Table 1.

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TABLE 3FAILURE MODE* FOR MIXER POSITIONS OF TABLE 2

<u>CASE</u>	<u>6.6 pH</u>			<u>7.0 pH</u>		
	<u>110°C</u>	<u>114°C</u>	<u>118°C</u>	<u>110°C</u>	<u>114°C</u>	<u>118°C</u>
BASE	T-B	T-B	T-B	T-B	T-T	T-T
ONE	T-B	T-B	T-B	T-B	T-B	T-B
TWO	B-B	B-B	B-B	B-B	B-B	B-B
THREE	B-B	B-B	B-B	B-B	B-B	B-B
FOUR	T-B	T-B	T-B	T-B	T-B	T-B
FIVE	B-B	B-B	B-B	B-B	B-B	B-B

* For example, T-B means tube life is limited by top wall corrosion with no mixer and is limited by bottom wall corrosion with mixer located in the indicated position.

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TABLE 4

TUBE LIFE FOR MIXER POSITIONS OF TABLE 2
YEARS AT 100 PER CENT TOE

<u>CASE</u>	<u>6.6 pH</u>			<u>7.0 pH</u>		
	<u>110°C</u>	<u>114°C</u>	<u>118°C</u>	<u>110°C</u>	<u>114°C</u>	<u>118°C</u>
BASE	2.6	2.1	1.7	1.1	0.8	0.7
ONE	2.7	2.2	1.7	1.1	0.9	0.7
TWO	2.3	1.8	1.5	1.0	0.8	0.6
THREE	2.0	1.6	1.2	0.8	0.7	0.5
FOUR	2.7	2.2	1.7	1.1	0.9	0.7
FIVE	2.6	2.1	1.7	1.1	0.9	0.7

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TABLE 5

EFFECT OF MIXER ON TUBE LIFE
DIFFERENCE BETWEEN TUBE LIFE WITH MIXER AND TUBE LIFE WITHOUT MIXER
YEARS AT 100 PER CENT TOE

<u>CASE</u>	<u>6.6 pH</u>			<u>7.0 pH</u>		
	<u>110°C</u>	<u>114°C</u>	<u>118°C</u>	<u>110°C</u>	<u>114°C</u>	<u>118°C</u>
BASE	0.6	0.7	0.7	0.4	0.4	0.3
ONE	0.4	0.5	0.5	0.3	0.3	0.3
TWO	0.4	0.3	0.2	0.2	0.1	0.1
THREE	0.5	0.4	0.3	0.2	0.2	0.1
FOUR	0.4	0.5	0.5	0.3	0.3	0.3
FIVE	0.2	0.2	0.1	0.1	0.1	0.05

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TABLE 6

TUBE LIFE VS. OUTLET TEMPERATURE
YEARS AT 100 PER CENT TOE

<u>Temperature</u>	<u>pH</u>	<u>Base</u>	<u>Case 1</u>	<u>Case 2</u>	<u>Case 3</u>	<u>Case 4</u>	<u>Case 5</u>
95	6.6	5.7	6.0	5.0	4.2	5.9	5.6
100	6.6	4.4	4.6	3.9	3.2	4.5	4.3
105	6.6	3.4	3.5	3.0	2.5	3.5	3.3
110	6.6	2.6	2.7	2.2	1.9	2.6	2.5
115	6.6	2.0	2.1	1.7	1.5	2.0	1.9
120	6.6	1.3	1.5	1.3	1.1	1.5	1.5
125	6.6	0.9	1.0	1.0	0.8	1.0	1.1
95	7.0	2.6	2.6	2.2	1.9	2.6	2.5
100	7.0	2.0	2.0	1.7	1.5	1.9	1.9
105	7.0	1.5	1.5	1.3	1.1	1.4	1.4
110	7.0	1.1	1.1	1.0	0.8	1.1	1.1
115	7.0	0.8	0.8	0.7	0.6	0.8	0.8
120	7.0	0.6	0.6	0.5	0.5	0.6	0.6
125	7.0	0.4	0.5	0.4	0.3	0.5	0.5

See Table 1 for case definitions.

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FIGURE - I
B REACTOR FREQUENCY DISTRIBUTION OF
TUBE OUTLET TEMPERATURES - APRIL 1964

Average Temperature of 1197 Tubes $> 94^{\circ}\text{C} = 108.3^{\circ}\text{C}$

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FIGURE -2
FREQUENCY DISTRIBUTION OF WEIGHTED OUTLET
TEMPERATURES (PROPORTIONAL TO TUBE LIFE)
- 1197 TUBES > 94 °C
Average Temperature = 106.7 °C

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FIGURE - 3
TUBE LIFE DISTRIBUTION FOR BASE CASE
AS FUNCTION OF TUBE OUTLET TEMPERATURE

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FIGURE -4
CUMULATIVE TUBE LIFE DISTRIBUTION FOR BASE
CASE AS FUNCTION OF TUBE OUTLET TEMPERATURE

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