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DEVELOPMENT OF AN EMPIRICAL MATHEMATICAL MODEL FOR A PULSE SIEVE-PLATE EXTRACTION COLUMN

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ABSTRACT

A satisfactory empirical mathematical model has been obtained to relate the extraction of uranium from an aqueous solution that pulsates through vertically-spaced horizontal sieve-plates in a short vertical column to the sieve-plate spacing, pulse frequency, pulse height, flow rate of aqueous solution, plate diameter, and to the position of the inlet for the organic extractant. This was done by multivariable regression analysis of 34 statistically designed tests. The final model is complex but it indicates, in general, that higher extractions are related to the result of the interaction between the pulse frequency and pulse height, to closer plate-spacing, to lower aqueous flow rates, to larger-diameter sieve-plates, and to the distance between the inlet for the organic extractant and the axis of the column.

It was also shown that assessment of optimum operating conditions for the column by traditional visual observations was not satisfactory for the tests described herein.

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LE DÉVELOPPEMENT D'UN MODÈLE EMPIRIQUE ET MATHÉMATIQUE POUR UNE COLONNE D'EXTRACTION

par

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RÉSUMÉ

Les auteurs ont obtenu un modèle empirique et mathématique pour relier l'extraction d'uranium d'une solution aqueuse qui jaillit par intermittence à travers des plaques criblées horizontales aux espaces verticaux dans une colonne courte et verticale à l'espacement de la plaque criblée, à la fréquence de pulsation, à l'hauteur de pulsation, au débit de la solution aqueuse, au diamètre du plateau et à la position de l'admission pour l'extraction organique. Les auteurs ont fait cela par l'analyse de la régression multivariable de 34 essais conçus du point vue de la statistique. Le modèle final est complexe mais celui-ci indique en général que les extractions supérieures se rapportent au résultat de l'action réciproque entre la fréquence de pulsation et la hauteur de pulsation, à l'espacement plus fermé de la plaque, aux débits aqueux plus inférieurs, au diamètre plus larges des plaques criblées et à la distance entre l'admission pour l'extraction organique et l'axe de la colonne.

Ils ont montré que l'évaluation des conditions à marche optimales pour la colonne par des observations visuelles et traditionnelles n'était pas satisfaisante pous ces essais.

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INTRODUCTION

Liquid-liquid sieve-plate pulse extraction columns have been tested on a pilot plant scale in this Division on several two-phase and multiphase systems[1,2]. The experience gained in that test work has permitted the setting of the operating variables to yield desired extractions for most of the systems tested. These methods do not, however, provide information on the quantitative effects of the variables of the system which would allow comparison of test results on different columns or provide scale-up of pilot plant columns to industrial columns.

This report describes an empirical study of the effects of some of the important operating variables of the sieve-plate pulse extraction column, using carefully controlled conditions and statistically designed experiments. It was hoped that a usable mathematical model could be developed resulting in a better understanding of the column operation.

Initially, at least, it was decided to study the effects of only the physical variables of the system. The chemical variables (type of organic extractant, temperature, pH, loading characteristics, etc.) would be set by preliminary bench-scale tests.

For these investigations, a small 7-ft sieve-plate pulse column, 2-in. I.D., was chosen. It differed only in length from the 30 to 40-ft columns used in the Extraction Metallurgy Division pilot plant. By choosing operating conditions for the smaller column similar to those for the longer, it was hoped

that useful correlations might be óbtained.

To further simplify the experimental conditions, it was decided to use an aqueous uranium solution as feed. It was known that almost complete extraction of the uranium occurs at an aqueous-to-organic (A/O) feed ratio of 5 to 1 in a 20-ft high column containing an aqueous solution of 1 g U/l and an organic solvent consisting of 5 % Alamine-336 with 5 % isodecanol in a kerosene diluent. In the 7-ft test column, then, it was hoped to reach a somewhat lower steady-state extraction so that the effect of changes in operating variables could be detected.

EXPERIMENTAL DESIGN

The results of two experimentally designed sets of tests are reported here. In Set 1, the A/O ratio was kept at 5 to 1 and the aqueous flow rate, the applied pulse frequency and pulse height were the independent variables. In Set 2, with the same A/O ratio, the flow rates were kept constant while the plate spacing, pulse frequency, and pulse height were varied. In Set 1, a 2^3 factorial design was used (three variables at two levels) plus four centre points (tests done at the mean levels of each variable). In Set 2, this same design was augmented by the six "star" points as well as by four repeated tests at the variable settings of the four centre points of Set 1. The star points are tests done at the mean levels of two variables and at high and low levels of the third variable. Statistically this method provides estimates of all the coefficients of a complete second-order fitted equation. The last four tests

of Set 2 were intended to provide a means of correlating the results of the two sets.

In both sets, the tests were done as much as possible in random order to minimize bias in setting the levels of the operating variables. In Table 1, the levels of the three variables and the random test numbers for the 12 tests of Set 1 are given. Table 2 lists the variable levels for each of the 22 tests in Set 2.

APPARATUS AND EXPERIMENTAL METHODS

The pulse column (Figure 1) used in these investigations was constructed of 7-ft x 2-in. KIMAX tempered glass pipe, with 2-ft x 4-in. settling chambers at the top and 2-ft x 6-in. settling chambers at the bottom. Details of the construction of a 40-ft column of similar design for pilot plant testing have been given elsewhere[3].

The pulse was applied to the column through a side port situated 8 in. below the organic feed port. It was generated by a diaphragm pump, as shown in Figure 1. An 8-in. Teflon diaphragm was used having a stroke frequency range between 0 and 95 cycles per minute. The frequency was set by a pulley adjustment on the pump. The output from a pressure transducer, tapped into the pulse line, was displayed on a variable-speed recorder. Accurate measurements of the pulse frequencies were thus obtained from recorder charts taken at known chart speeds.

The stroke amplitude of the pulse pump was adjusted by a positioning screw on the pump driver cam. As shown in Figure 1, there was an 8-ft x 0.75-in. pulse-leg, between the

pulse pump and the column, one arm of which was clear Tygon tubing. This leg was half-filled with aqueous on the column side while the pump side was filled with organic. A visible interface was thus established for measuring the pulse height external to the column. This measured pulse height was related to pulse height in the column by the inverse ratio of the cross-sectional area of the 3/4-in. side arm to that of the 2-in. column, i.e. approximately 7:1. Thus a measured pulse height of between 3.5 and 7 in. in the side arm reflected a pulse height of between 0.5 and 1 in. in the column.

The column was operated so that the aqueous phase was continuous. The organic/aqueous interface in the column was set approximately 4 in. above the aqueous feed port. The aqueous phase was pumped into the column by a variable-speed Moyno pump. A bypass and magnetic valve on this pump, energized by electrodes, controlled the interface level. The organic flow entered the column through a port situated 8 in. above the pulse entry. It was energized by a variable-speed gear-type metering pump. The organic flow-rate was measured manually at the loaded solvent outlet. The loaded solvent overflowed from a port near the top of the upper settler, 11 in. above the top of the 7-ft x 2-in. column. The raffinate was pumped from the base of the lower settling chamber by a variable-speed Peri finger pump, the rate also being measured manually. In Set 2, the aqueous flow-rate was maintained at 0.5 1/min.

In Set 1 stainless steel sieve plates, as shown in Figure 1a, were 5/32 in. thick, had 3/16-in. openings, and were 1.84 in. in diameter. Twenty-seven of these plates were mounted on a centrally located 1/4-in. stainless steel rod, separated by 2-in. spacers, the lowest plate being 4 in. above the organic feed port. The uppermost, 27th plate was set approximately at the level of the aqueous feed port, 8 in. below the upper settling chamber. The holes through a plate accounted for 35.8 % of its horizontal surface.

In Set 2, the plate diameter was 1.92 in. and other dimensions were the same as those of the plates used in Set 1. The holes accounted for 32.7 % of a plate's horizontal area. In this set, the plate spacing was one of the independent variables. Therefore the number of plates in the effective 60 in. of column length varied. For 1-in. spacing, there were 53 plates; for 2-in., 27 plates; for 4-in., 14 plates; for 6-in., 10 plates; for 7-in., 8 plates.

Observations made during the Set 1 tests led to the only other significant difference between the two sets of tests. During Set 1, the organic-inlet pipe discharged its contents at the side of the column. This caused a poor bubble distribution around the lower plates in the column. This problem was overcome during the Set 2 tests by extending the organic-inlet pipe to approximately the centre of the column.

EXPERIMENTAL DETAILS

The procedure followed in each test was to set the design variables and then operate the column until steady-state conditions were reached. The results of some test work done prior to Set 1 indicated that it required between 4 and 5 hours for the column to reach steady state. For the 12 tests of Set 1, then, a standard operating period of 6 hours was used. In addition, the column was drained and washed thoroughly after each test. In Set 2, an operating period of 6 hours was used for the first 7 tests. For tests 17, 18, and 19 raffinate samples were taken and analyzed every half-hour for uranium, in an attempt to study extraction rates. The results showed that steady state was reached much more quickly than expected, actually within 1 to 2 hours. As a result, all the remaining tests in Set 2 were run for 3 hours. Also in Set 2, the column was not drained and washed after each test. This was done only after Tests 18 and 29, when new feed was to be prepared, and after Test 14 in which emulsification of the organic occurred in the column. In both Set 1 and Set 2, raffinate and organic flowrates were measured and adjusted to the desired levels every half-hour.

The aqueous and organic feeds were analyzed for uranium every time a new feed was prepared. In Set 1, this was done before the first and after every second test. In Set 2, the feed was prepared before tests 13, 18, and 29. The feed in both sets was a synthetic solution prepared from a uranyl carbonate source and adjusted to the desired acidity for extraction with sulphuric acid.

Samples of the raffinate and loaded solvent were taken for chemical analysis simultaneously at the end of each of the last three hours of each test. In this way sufficient analyses were available to obtain the desired agreement between the calculated and measured feeds and to check that steady-state conditions had been reached.

The per cent extractions, E, were calculated from the equation:

$$E = \frac{A_{af} - A_r}{A_{af}} \times 100 \qquad \ldots 1$$

where A_{af} = aqueous feed analysis (g/l)

A_r = raffinate analysis (g/l)

The calculated feed was obtained from the equation

$$\text{Calc. feed (g/l)} = \frac{OFR\ (A_o - A_{of}) + AFR\ (A_r)}{AFR}$$

where OFR = organic flowrate (l/min)

AFR = aqueous (raffinate) flowrate (l/min)

A_o = loaded organic analysis (g/l)

A_{of} = feed organic analysis (g/l)

In addition, samples of the aqueous feed and final raffinate were analyzed for amine losses.

RESULTS

The results of the 12 tests of Set 1 and of the 22 tests of Set 2 are shown in Tables 3 and 4 respectively. In these tables, AFR is the aqueous feed rate, PF is the pulse frequency, PH is the pulse height measured in the pulse-leg side arm and PLSP is the sieve-plate spacing. The pulse frequencies

listed and used in the statistical analyses are those measured by the high-speed recorder. The per cent extractions, EXTRACTN (PCT), for each test were calculated from the aqueous feed, AQ.FEED, and raffinate, RAFF, analyses using Equation 1. The agreement between measured and calculated feeds was better than 1.5 % in all tests.

In the lower half of Table 3 are some observations on the bubble movement and size and on the coalescence of organic and the extent of back-mixing in each test of Set 1. Table 5 shows similar observations for Set 2.

Due to difficulties in getting consistent amine loss analyses, the results of the amine loss tests are not quoted. There were some indications that higher amine losses were associated with higher pulse frequencies and pulse heights and that flow rates and plate spacing had little effect on amine losses. However these observations could not be checked statistically in these two sets of experiments.

MATHEMATICAL ANALYSES OF THE RESULTS

A multi-variable regression computer program was used to analyze the per cent extraction, E, as a function of the measured experimental variables in Sets 1 and 2 (Tables 3 and 4). For Set 1 the best fitting equation was

$$E = 29.797 + 1.8267 \,(PH) - 2.8030 \,(AFR)\,(PH) + 0.019856$$
$$(PF)(PH) \qquad \ldots \; 2$$

with a multiple correlation coefficient of 0.972[4].

For Set 2 the equation was

$$\text{Log}(E) = 2.0686 - 0.24648 \log(\text{PLSP}) - 0.30953 \log(\text{PF})$$
$$- 0.038194 \, (\text{PH}) + 0.0013935 \, (\text{PF})(\text{PH}) \quad \ldots \, 3$$

where log = logarithm to the base 10.

The multiple correlation coefficient for Equation 3 was 0.978.

As explained previously, there were two principal differences between the two sets of tests. A sieve-plate 0.92 in. in diameter was used in Set 2 yielding a plate open area of 32.7 % compared with 35.8 % for the 1.84-in.-diameter plates in Set 1. The other change was that a longer organic inlet tube was used in the second set, which would be expected to improve the distribution of organic bubbles to the lower plates. The comparative tests are Tests No. 4, 6, 8, and 11 of Set 1 having an extraction of about 35 % and Tests 15, 20, 25, and 29 of Set 2 which have an extraction of about 41 %. Because the exact variable involved in this variation could not be resolved statistically, a fifth independent variable, SET, was defined in order to fit the results of all 34 tests in both sets. SET was given the value -1 for Set 1 and +1 for Set 2.

The best-fitted equation relating all five variables (including SET) and the extraction, E, for the 34 tests of Sets 1 and 2 was as follows:

$$\text{Log}(E) = 2.21291 - 0.24770 \log(\text{PLSP}) - 0.40569 \log(\text{PF})$$
$$- 0.019010 \, (\text{PH}) - 0.039649 \, (\text{SET}) + 0.0012609 \, (\text{PF})(\text{PH})$$
$$+ 0.0014875 \, (\text{PF})(\text{SET}) - 0.031126 \, (\text{AFR})(\text{PH})$$
$$\ldots \, 4$$

It had a multiple correlation coefficient of 0.959.

Table 6 shows a comparison of the measured extractions with those predicted for each of the two sets (Equations 2 and 3) and for all 34 tests (Equation 4). Table 6 also lists again the levels of all five independent variables.

DISCUSSION AND CONCLUSIONS

The comparison of measured and predicted uranium extractions in Table 6 indicates that Equation 4 is an adequate empirical model for the 34 tests of Sets 1 and 2. It was obtained by combining the best empirical relations (Equations 2 and 3) for Sets 1 and 2 respectively. Equation 2 fits the 12 test results in Set 1 closely, where plate spacing (PLSP) and A/O ratio are fixed. The fit on Equation 3 for the results of Set 2, in which aqueous feed rate (AFR) and A/O ratio were fixed, is somewhat poorer, especially at the higher extractions - Tests 32, 33, 28, and 16. There is, however, good agreement between the measured and predicted extractions at the design centre points - Tests 27, 21, 26, and 24 and for the tests in which the centre point conditions of Set 1 were repeated - Tests 15, 20, 25, and 29.

For the combined relationship, Equation 4, the agreement between measured and predicted responses is similar to that for Set 2. This equation now relates the effects of varying all four experimental independent variables of both sets as well as the arbitrary variable, SET. There is particularly good agreement at the centre points in Set 1 - Tests 4, 6, 8, and 11 as well as those for Set 2, identified above.

There is no theoretical significance to the logarithmic

terms in Equations 3 and 4. The use of logarithmic variables simply gave a better fit. In the final model, as well as in Equations 2 and 3, the product of the pulse frequency and the pulse height "PF x PH" had a highly significant effect on uranium extraction. This has been observed by other investigators, for example, by Kayser[5].

To demonstrate these effects graphically four response surface diagrams, based on the final model, Equation 4, were prepared, in which the loci of constant extraction, E, in 5 % intervals, were plotted on graphs of pulse frequency vs pulse height throughout the experimental ranges. These are shown in Figures 2, 3, 4, and 5.

Figure 2 shows the iso-extraction lines for a small plate spacing, 2 in., a small flow rate, 0.2 l/min, and the variable, SET, equal to +1, conditions which, according to Equation 4, yield the maximum extractions. It will be recalled that the variable SET had the value +1 for the tests in which larger-diameter plates were used and the organic feed pipe was extended to the axis of the column, and had a value of -1 where smaller plates and a shorter organic inlet pipe were used. Figure 2 shows that almost complete extraction could be obtained at a frequency of 80 c/min and a pulse height of 7.35 in. Figure 3 shows the surface obtained when a larger plate spacing, 4 in., was used, Figure 4, the effect of a higher flow rate, 0.5 l/min and Figure 5, the effect of changing SET from + 1 to -1.

To make a numerical comparison between these four plots, values of E were calculated at the same three points -

(PF = 60, PH = 5.5), (PF = 70, PH = 6.5) and (PF = 80, PH = 7.35) on each of the four surfaces. The following table shows these values:

FIG.	PLSP (IN)	AFR (L/MIN)	SET	E(%)		
				PF = 60 PH = 5.5	PF = 70 PH = 6.5	PF = 80 PH = 7.35
2	2	.2	+1	55.4	73.1	100
3	4	.2	+1	46.7	61.6	84.5
4	2	.5	+1	49.3	63.6	85.7
5	2	.2	-1	44.1	54.3	69.6

Comparing the extractions at the third point for Figure 2 with that for Figure 3, where the plate spacing was increased from 2 to 4 in., shows a 15.5 % reduction in extraction. Comparing Figure 4 with Figure 2 at the same point shows a 14.3 % reduction for an increase of aqueous flow rate from 0.2 to 0.5 l/min. The largest effect is indicated in comparing Figure 5 at SET = -1 with Figure 2 at SET = +1. At the same point (PF = 80, PH = 7.35) there is a 30.4 % reduction in extraction.

It is apparent that this is an important effect the exact significance of which, as explained previously, would require further statistically-designed tests to resolve.

In addition it should be noted that, although the curves shown in Figures 2, 3, 4, and 5 were calculated from variable levels within the range of the experimentally designed variables, there is considerably less precision in the higher extraction areas. This is due to the fact that, as explained previously, test conditions which might be expected to produce complete or almost complete extractions were avoided in the design, so that

the effect of variables on the system could be assessed. Thus,
only four of the thirty four tests produced extractions 60 %
or higher.

The visual observations on the bubble movement, co-
alescence, etc., given in Tables 3 and 5 have been included since
these are the traditional ways by which column operation is
assessed visually. It should be noted, at the outset, that all
the observations reported in these tables were made by the same
operator. Whatever bias there is in estimating the extent of
bubble movement, size of bubbles, etc., can be considered constant.
In addition, all the observations arise from visual estimates;
no sophisticated measuring devices were used.

A close examination of these results and a comparison
with the extractions obtained for corresponding tests indicate
that there is little correlation. In Table 5, there is some
indication that smaller bubbles in Tests 19, 32, 33, 16, and 28
were related to higher extractions, and the converse might be
true for Tests 18 and 17. These results indicate that, as
expected, mass transfer and, hence, extraction increase with
bubble surface area, i.e., with decreased bubble size.

Backmixing seems to have a beneficial effect on
extraction since those tests in which backmixing was noted are
generally those with higher than average extractions. The other
observations - bubble rise, distribution of bubbles, and extent
of coalescence, however, don't appear to correlate with extraction.

It may be concluded, therefore, that it would be
difficult to determine the relative extractions obtainable by

sieve-plate column operations, using only observations such as those reported in Tables 3 and 5. A more accurate determination of extraction may be obtained by using the empirical mathematical model (Equation 4) based on 34 statistically designed tests by which it is shown that higher extractions are related to high values of the interaction between pulse frequency and pulse height, to lower aqueous flow rates, to larger-diameter sieve-plates and to the closeness of the organic inlet to the axis of the column.

REFERENCES

1. Ritcey, G. M., and Lucas, B. H., "Co-extraction of Uranium and Thorium from Sulphuric Acid Solutions and Recovery by Selective Stripping", Presented at the A.I.M.E. Annual Meeting, New York, February, 1971.

2. Ritcey, G. M., and Lucas, B. H., "Process for the Recovery of Cobalt from Ammoniacal Solutions Using a Carboxylic Acid", Cdn. Pat. Appl. No. 073,825,1970, Presented at the International Solvent Extraction Conference, The Hague, April, 1971.

3. Ritcey, G. M., Lucas, B. H., Price, K. T., and Chagnon, R. L., "Construction and Operation of an Experimental Sieve-Plate Pulse Column for Solvent Extraction of Metals", Mines Branch IC 259, 1970, Dept. of Energy, Mines and Resources, Ottawa, Canada.

4. Draper, N. R., and Smith, H., "Applied Regression Analysis", John Wiley, New York, 1966, p. 117.

5. Kayser, R. A., "Controlled Cycling Operation of a Pulsed Column Extractor", Ph.D. Dissertation, University of Washington, 1970.

Top Settler

Loaded Organic

Aqueous Feed Port

Sample Port "A"

Perforated Discs 2 in. apart

Port "B"

7'

Port "C"

Port "D"

Bottom Settler

Final Raffinate

Hole Dia. $\frac{3}{16}$ in.

Hole Spacing $\frac{5}{16}$ in.

Centre Mounting Hole $\frac{1}{4}$-in. Dia.

Fig. I A Detail of Sieve Plate

Pulse Leg

Organic Feed Port

Diaphram Pulse Pump

Figure I: Sieve Plate Pulse Column

TABLE 1

PULSE COLUMN EXPERIMENTAL DESIGN - SET 1

RANDOM TEST NO.	AQ. FEED RATE (L/MIN)	PULSE FREQ (C/MIN)	PULSE HEIGHT (IN.)
2	0.2	35	3.5
9	0.8	35	3.5
5	0.2	55	3.5
1	0.8	55	3.5
10	0.2	35	7.5
3	0.8	35	7.5
12	0.2	55	7.5
7	0.8	55	7.5
4	0.5	45	5.5
6	0.5	45	5.5
8	0.5	45	5.5
11	0.5	45	5.5

TABLE 2

PULSE COLUMN EXPERIMENTAL DESIGN - SET 2

RANDOM TEST NO.	PLATE SPACING (IN)	PULSE FREQ (C/MIN)	PULSE HEIGHT (IN)
13	2.0	40.0	3.5
18	6.0	40.0	3.5
19	2.0	80.0	3.5
17	6.0	80.0	3.5
30	2.0	40.0	7.5
31	6.0	40.0	7.5
32	2.0	80.0	7.5
33	6.0	80.0	7.5
27	4.0	60.0	5.5
21	4.0	60.0	5.5
26	4.0	60.0	5.5
24	4.0	60.0	5.5
23	7.0	60.0	5.5
28	1.0	60.0	5.5
16	4.0	90.0	5.5
22	4.0	30.0	5.5
14	4.0	60.0	8.5
34	4.0	60.0	2.5
15	2.0	45.0	5.5
20	2.0	45.0	5.5
25	2.0	45.0	5.5
29	2.0	45.0	5.5

TABLE 3

EXTRACTION RESULTS - SET 1

(A/O RATIO = 5/1 , PLSP = 2 IN.)

TEST NO.	AFR (L/MIN)	PF (C/MIN)	PH (IN.)	URANIUM ANALYSES (G/L)				EXTRACTN (PCT)
				AQ.FEED	RAFF	ORG.FEED	ORG	
2	0.2	34.2	3.5	0.995	0.63	0.000	1.78	36.7
9	0.8	35.2	3.5	1.04	0.74	0.000	1.58	29.8
5	0.2	54.6	3.75	1.03	0.62	0.022	1.94	39.8
1	0.8	55.6	3.5	0.995	0.67	0.000	1.60	32.7
10	0.2	34.2	7.5	1.04	0.575	0.000	2.32	44.7
3	0.8	33.2	7.5	1.075	0.73	0.000	1.66	32.1
12	0.2	55.3	7.5	1.02	0.54	0.062	2.44	47.1
7	0.8	54.0	7.5	1.00	0.65	0.024	1.82	35.0
4	0.5	45.1	5.5	1.075	0.68	0.000	1.88	36.7
6	0.5	45.9	5.5	1.03	0.65	0.022	1.82	36.9
8	0.5	44.6	5.5	1.00	0.67	0.024	1.91	38.0
11	0.5	45.6	5.5	1.02	0.66	0.062	1.82	35.3

2   SLIGHT HESITATION IN BUBBLE RISE AT 2 IN., NO COALESCENCE

9   4-IN. BUBBLE RISE, COALESCING UNDER EVERY 2ND PLATE

5   3-IN. BUBBLE RISE

1   2-IN. BUBBLE RISE, COALESCING UNDER EACH PLATE

10 4 TO 5-IN. BUBBLE RISE, COALESCENCE

3   4-IN. BUBBLE RISE, COALESCING UNDER EVERY 2ND PLATE

12 3-IN. BUBBLE RISE, COALESCING, SOME BACKMIXING

7   2-IN. BUBBLE RISE, FINE BUBBLES, SOME BACKMIXING

4
6
8   } 3-IN. BUBBLE RISE, COALESCING UNDER EVERY 3RD PLATE
11

TABLE 4

EXTRACTION RESULTS - SET 2

(A/O RATIO = 5:1 , AFR = 0.5 L/MIN)

TEST NO.	PLSP (IN.)	PF (C/MIN)	PH (IN.)	AQ.FEED	RAFF	ORG.FEED	ORG	EXTRACTN (%)
				URANIUM ANALYSES (G/L)				
13	2.0	40.2	3.5	1.07	0.68	0.030	1.99	36.5
18	6.0	39.3	3.5	1.08	0.76	0.064	1.66	29.4
19	2.0	77.8	3.5	1.01	0.55	0.064	2.34	45.3
17	6.0	81.0	3.5	1.09	0.71	0.084	2.02	35.3
30	2.0	39.1	7.5	1.06	0.59	0.106	2.44	44.0
31	6.0	39.3	7.5	1.06	0.69	0.106	1.91	34.2
32	2.0	77.5	7.5	1.07	0.20	0.106	4.42	80.9
33	6.0	79.7	7.5	1.06	0.30	0.106	3.96	71.7
27	4.0	59.2	5.5	1.01	0.59	0.054	2.12	41.0
21	4.0	59.2	5.5	1.01	0.61	0.054	2.03	39.2
26	4.0	57.2	5.5	1.01	0.59	0.054	2.12	41.0
24	4.0	58.7	5.5	1.01	0.59	0.054	2.12	41.0
23	7.0	58.1	5.5	0.99	0.67	0.042	1.66	32.6
28	1.0	60.2	5.5	1.01	0.40	0.054	3.07	60.0
16	4.0	90.0	5.5	1.06	0.36	0.084	3.59	66.0
22	4.0	30.0	5.5	0.99	0.71	0.042	1.45	28.4
14	4.0	59.6	8.5	1.08	0.49	0.084	3.04	54.6
34	4.0	58.6	2.5	1.08	0.76	0.106	1.72	29.8
15	2.0	44.4	5.5	1.06	0.64	0.042	2.15	40.0
20	2.0	44.4	5.5	1.01	0.59	0.054	2.12	41.0
25	2.0	43.5	5.5	1.01	0.58	0.054	2.17	42.1
29	2.0	44.1	5.5	1.01	0.59	0.054	2.12	41.0

TABLE 5

TEST OBSERVATIONS FOR SET 2

TEST NO.	BUBBLE RISE(IN)	BUBBLE DIA(MM)	BUBBLE DSTN	COALESCING UNDER PLATES	BACKMIXING	OTHER REMARKS
13	3-3.5	3-4				
18		>3				ORG CLINGING UNDER PLATES
19	1.5-1.75	1-2		SOME		NORMAL OPERATION
17	3	>3			NO	
30	3.5-4	<3		EVERY 2ND	SOME	
31	5	2-3				
32		1-2	GOOD			ALMOST EMULSIFICATION
33	1.5	1-2	GOOD		STRONG	ALMOST EMULSIFICATION
27	2.5-3	1-4	GOOD			
21	3-4	2-3			SOME	
26	2.5-3	1-4	GOOD			
24	2	1-3			SOME	
23	2-2.5	3-4				
28	2	1-3		EVERY 2ND	SOME	
16	1-1.5	1-2			SOME	
22	4	3-4		SOME		
14	2-2.5	2-3		NO		
34	3-3.5	2-3	POOR	SOME		
15	3	4		SOME		
20	3	2-3		EVERY 2ND		
25	3		GOOD	EVERY 2ND		TOP PLATES DIRTY
29	3	2-4		EVERY 2ND	NONE	

TABLE 6

COMPARISON OF MEASURED AND PREDICTED EXTRACTIONS FOR THE MODELS
OBTAINED FOR EACH SET (EQ. 2 AND 3) AND THAT FOR ALL 34 TESTS (EQ.4)

| TEST NO.	PLSP (IN)	PF (C/MIN)	PH (IN)	AFR (L/MIN)	SET	PERCENT EXTRACTIONS			
						MEASD	PREDICTED (EQ.2)	(EQ.3)	(EQ.4)
2	2.0	34.2	3.5	0.2	-1	36.7	36.6		36.9
9	2.0	35.2	3.5	0.8	-1	29.8	30.8		31.6
5	2.0	54.6	3.75	0.2	-1	39.8	38.6		35.9
1	2.0	55.6	3.5	0.8	-1	32.7	32.2		30.1
10	2.0	34.2	7.5	0.2	-1	44.7	44.4		43.5
3	2.0	33.2	7.5	0.8	-1	32.1	31.6		31.3
12	2.0	55.3	7.5	0.2	-1	47.1	47.5		52.8
7	2.0	54.0	7.5	0.8	-1	35.0	34.7		37.7
4	2.0	45.1	5.5	0.5	-1	36.7	37.1		36.5
6	2.0	45.9	5.5	0.5	-1	36.9	37.1		36.6
8	2.0	44.6	5.5	0.5	-1	38.0	37.0		36.4
11	2.0	45.6	5.5	0.5	-1	35.3	37.1		36.6
13	2.0	40.2	3.5	0.5	1	36.5		36.3	36.6
18	6.0	39.3	3.5	0.5	1	29.4		27.6	27.8
19	2.0	77.8	3.5	0.5	1	45.3		45.2	46.7
17	6.0	81.0	3.5	0.5	1	35.3		35.3	36.6
30	2.0	39.1	7.5	0.5	1	44.0		42.0	41.8
31	6.0	39.3	7.5	0.5	1	34.2		32.2	32.0
32	2.0	77.5	7.5	0.5	1	80.9		85.7	83.4
33	6.0	79.7	7.5	0.5	1	71.7		68.4	66.4
27	4.0	59.2	5.5	0.5	1	41.0		41.2	41.1
21	4.0	59.2	5.5	0.5	1	39.2		41.2	41.1
26	4.0	57.2	5.5	0.5	1	41.0		40.2	40.1
24	4.0	58.7	5.5	0.5	1	41.0		41.0	40.8
23	7.0	58.1	5.5	0.5	1	32.6		35.4	35.3
28	1.0	60.2	5.5	0.5	1	60.0		58.8	58.6
16	4.0	90.0	5.5	0.5	1	66.0		62.4	63.0
22	4.0	30.0	5.5	0.5	1	28.4		30.4	30.7
14	4.0	59.6	8.5	0.5	1	54.6		56.5	54.6
34	4.0	58.6	2.5	0.5	1	29.8		30.3	31.1
15	2.0	44.4	5.5	0.5	1	40.0		41.2	41.1
20	2.0	44.4	5.5	0.5	1	41.0		41.2	41.1
25	2.0	43.5	5.5	0.5	1	42.1		40.8	40.8
29	2.0	44.1	5.5	0.5	1	41.0		41.0	41.0
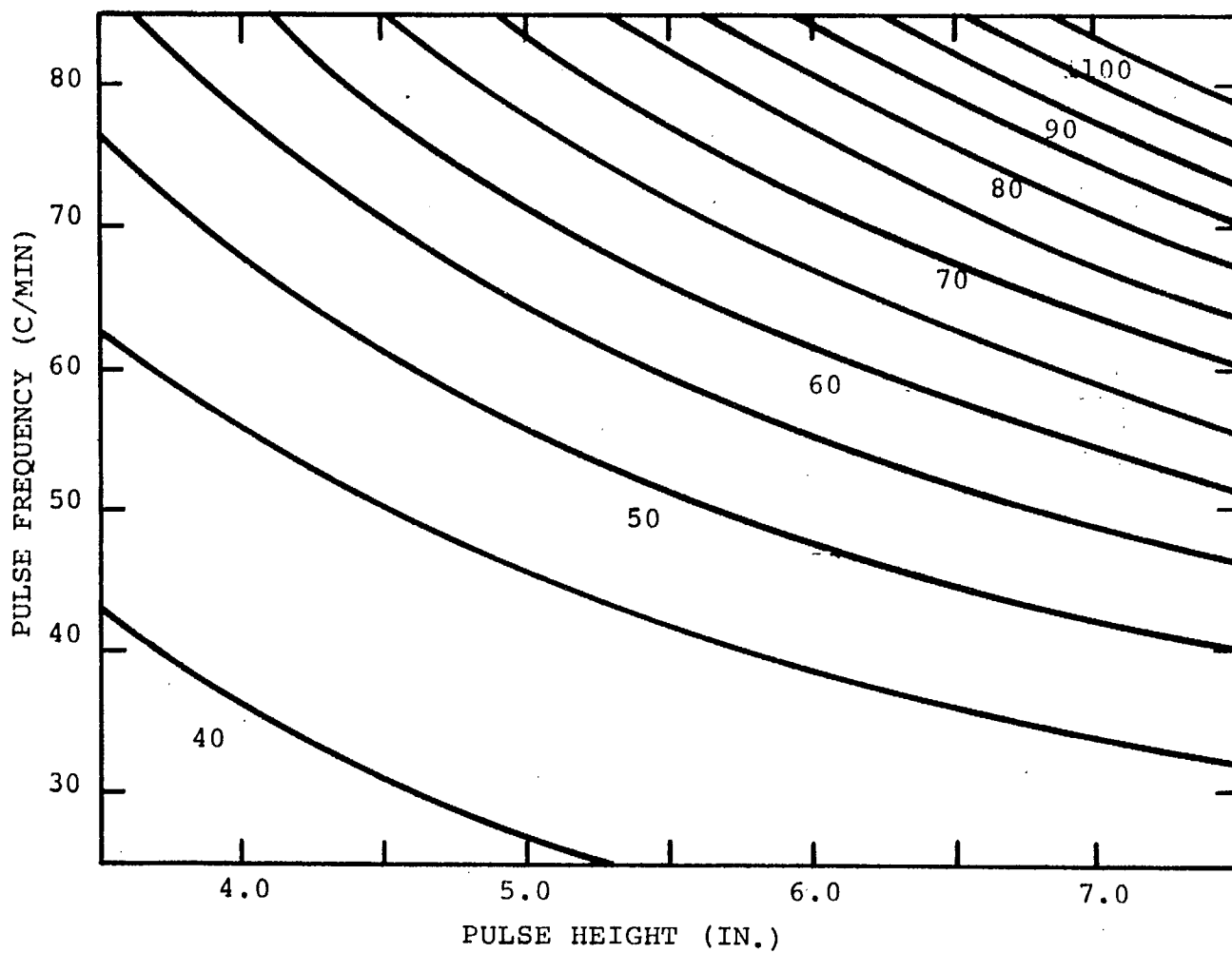
FIGURE 2: Iso-Extraction Curves of Pulse Frequency
vs. Pulse Height from Equation 4.

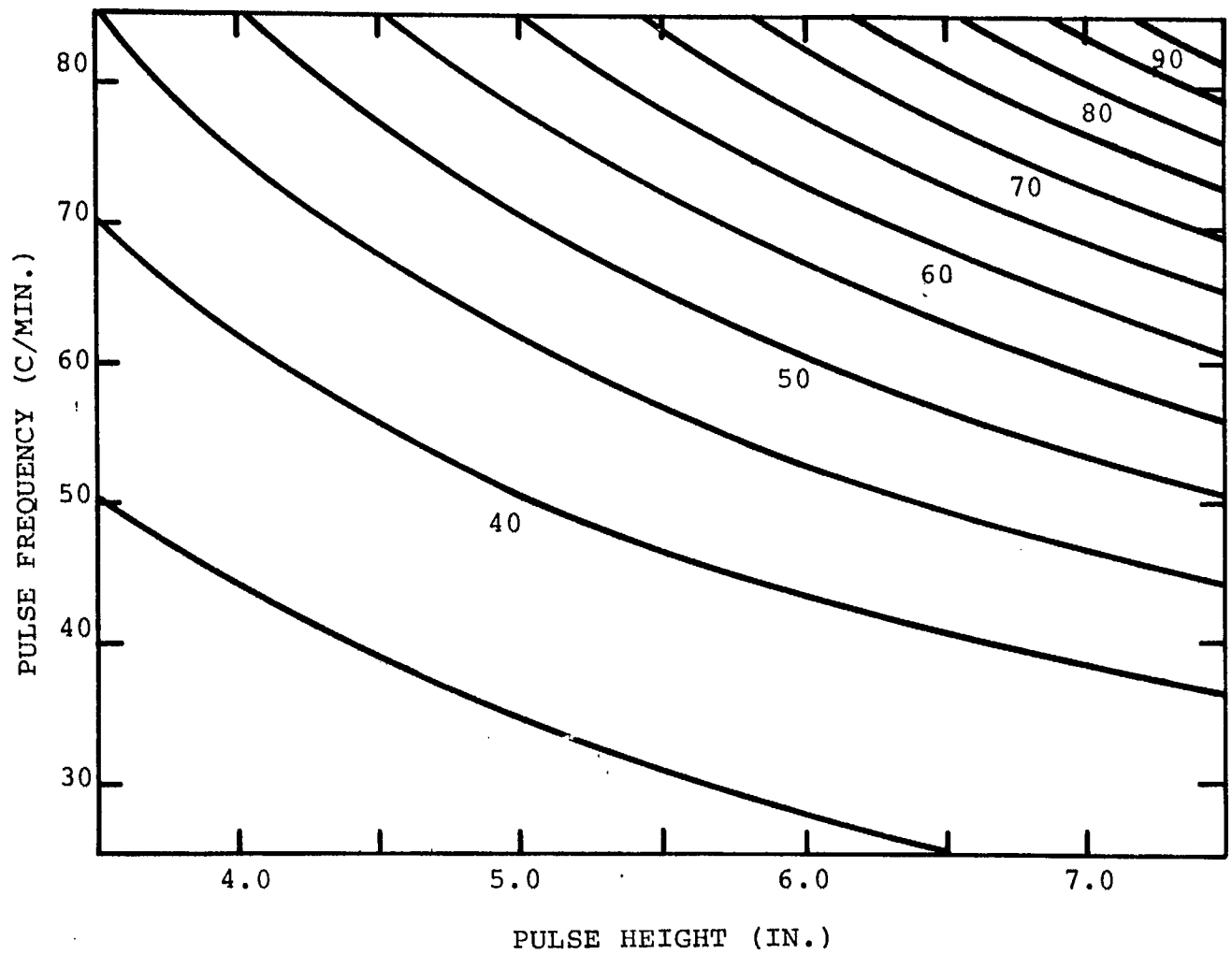PLSP = 2 in., AFR = 0.2 l/min, SET = +1

FIGURE 3: Iso-Extraction Curves of Pulse Frequency vs.
Pulse Height From Equation 4.

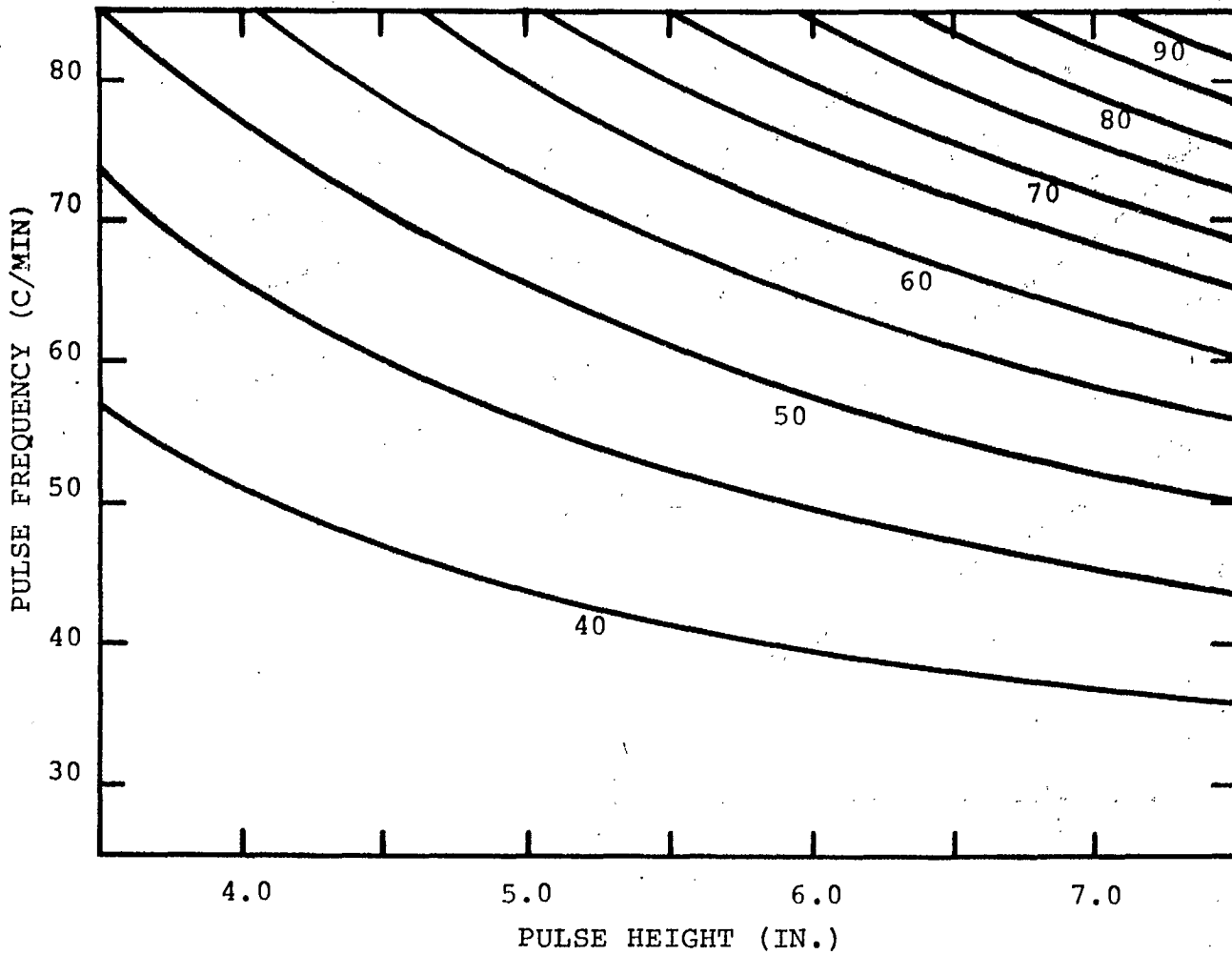PLSP = 4 in., AFR = 0.2 l/min, SET = +1

FIGURE 4: Iso-Extraction Curves of Pulse Frequency vs.
Pulse Height from Equation 4.
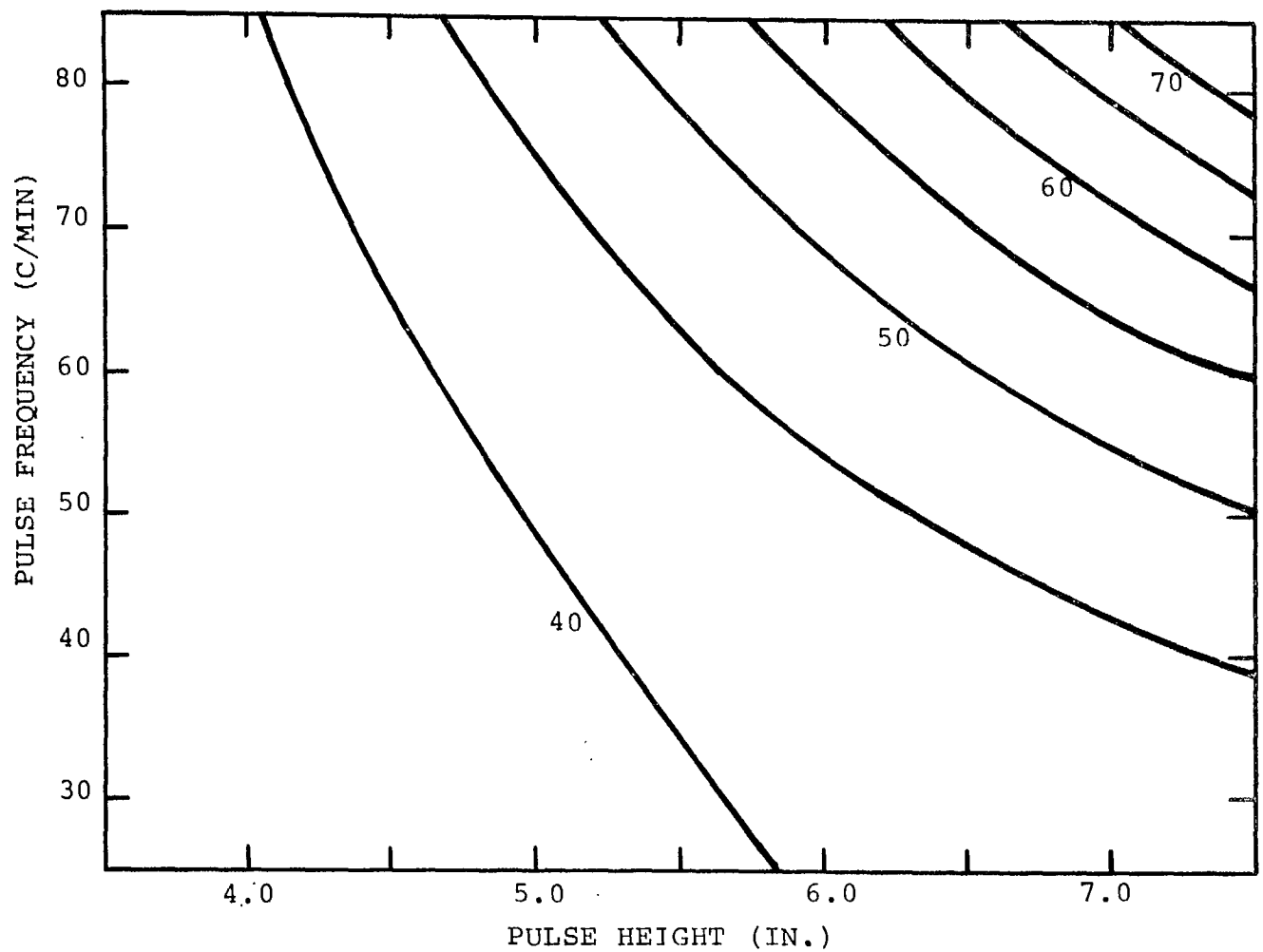
PLSP = 2 in., AFR = 0.5 l/min, SET = +1

FIGURE 5: Iso-Extraction Curves of Pulse Frequency vs. Pulse Height from Equation 4.

PLSP = 2 in., AFR = 0.2 l/min., SET = +1