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COLUMN FLOTATION OF URANIUM FROM ELLIOT LAKE ORE

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COLUMN FLOTATION OF URANIUM FROM ELLIOT LAKE ORE

by

W.R. Honeywell*

SYNOPSIS

This report describes investigations using the column flotation cell on an Elliot Lake ore sample. Results obtained from conducting exploratory tests followed by a statistically designed series of tests involving six operating variables using a two-inch-diameter column cell are given.

On deslimed uranium ore, a recovery of 90 per cent with a concentration ratio of 3.0 was obtained. These results are similar to those obtained using conventional cells in previous studies. On un-deslimed ore, recoveries in the order of 80 per cent, and concentration ratios ranging from 4.7 to 8.3 were made. These concentration ratios are higher than can be obtained by conventional cells, but the recoveries are lower.

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Direction des Mines

SÉPARATION DE L'URANIUM DU MINERAI EN PROVENANCE D'ELLIOTT LAKE PAR LE PROCÉDÉ DE FLOTTATION PAR COLONNE

par

W.R. Honeywell*

RÉSUMÉ

L'auteur décrit des recherches sur l'usage de la cellule de flottation en colonne dans le traitement d'un échantillon de minerai en provenance d'Elliott Lake. Il donne les résultats obtenus d'essais d'exploration suivis d'une série de tests comportant six variables de fonctionnement, par l'emploi d'une cellule en forme de colonne de deux pouces de diamètre.

On a obtenu une récupération de 90 p. 100 en utilisant du minerai d'uranium lavé; le rapport de concentration était de 3:0. Ces résultats sont semblables à ceux qui ont été obtenus en utilisant des cellules ordinaires au cours d'expériences antérieures. On a obtenu des récupérations de l'ordre de 80 p. 100 en utilisant du minerai non lavé et les rapports de concentration variaient entre 4:7 et 8:3. Ces rapports sont plus élevés que ceux que l'on peut obtenir à l'aide des cellules ordinaires, mais les pourcentages de récupération sont moins élevés.

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INTRODUCTION

Previous work on the problem of recovery of uranium from the Elliot Lake ores by flotation (1) had shown that when the conventional type of flotation cell was used, the flotation feed had to be deslimed for efficient flotation of the uranium minerals to take place. Since the slimes contained an appreciable amount of uranium, the slime fraction had to be considered as part of the concentrate with the result that the ratio of concentration in the combined flotation concentrate and slime fraction was low, being in the order of 2.3:1 to 2.0:1 with uranium recoveries of about 90%.

With the introduction of the column flotation cell by Column Flotation of Canada, Limited, the possibility arose of treating the Elliot Lake ores by flotation without de-sliming the flotation feed, since the developers of the column cell claimed that it was capable of treating very fine particles by flotation.[2] This possibility was of interest in the treatment of the Elliot Lake ores since the elimination of the desliming step would result in both a simpler flotation process and a higher ratio of concentration.

This report describes the work done to investigate the value of using the column flotation cell on one Elliot Lake ore. Results obtained from conducting some exploratory tests followed by a statistically designed series of tests with a two-inch-diameter column flotation cell are given.

ORE SAMPLES

The tests were carried out on two ore samples from Denison Mines Limited, Elliot Lake, Ontario. The samples were the usual quartz-pebble conglomerate and the ratio of pebbles to matrix has been estimated to be 65:35.[1] The composition of the conglomerates of the Quirke Lake uranium deposits has been calculated to be as follows:

Quartz-pebbles	40-65%
Sulphides	2-8%
Sericite	5-20%
Matrix quartz	15-25%

Most of the radioactivity is present in the matrix and the radioactive minerals usually occur in the more richly pyritized areas of the matrix. Brannerite, uraninite and monazite are responsible for most of the radioactivity. The size of the grains vary from 48 to 325 mesh with an average size of about 150 mesh.

PROCEDURE

The column used was a 2-inch glass column, 26 feet high. The ore was fed as a slurry, of from 30 to 55 per cent solids, by a Moyno pump. The flotation products from each test were sampled over a 90-minute period of continuous operation. The slurry entered the column about 6 1/2 feet from the top of the column. Air was fed into the bottom of the column through a stainless steel diffuser thus producing a rising column of bubbles which carried the concentrate off at the top of the column. The tailings were pumped out at the bottom with a Moyno pump at a density of 15 to 25 per cent solids. Wash water was fed into the top of the froth column. Figure 1 shows a diagram of the system.

Oxidation of the ore prior to flotation was minimized by obtaining from the mine only 4 to 6-inch mine ore, each piece being washed to remove the fines before drying and storing. These pieces were subsequently crushed to minus 4 mesh in lots of 400 to 500 pounds and then ground in a 10-inch by 30-inch ball mill to 65 to 70 per cent minus 200 mesh.

Main variables in conventional flotation are type of water, ore fraction, i.e. whether deslimed or whole ore, pulp solids, pH, air quantity, promoter-reagent concentration and pulp temperature. A preliminary series of column flotation tests using these variables was carried out. The results were incomplete and it was difficult to determine the relative importance of these variables.

It was then decided that a second series of tests should be done according to a statistically designed plan with the aim of determining the relative importance of the operating variables. This was done using a design described by Plackett and Burman (3) as being a useful one for ranking the importance of a number of process variables with a limited number of tests. Table 2 shows the conditions of the eight tests required by the Plackett-Burman design. In these tests six variables were investigated each at two levels designated by either a +ve or -ve sign as listed below.

Variable Identification	Variable	+ve level	-ve level
A	Type of water	Distilled	Tap
B	Ore fraction	Deslimed	Whole ore
C	Pulp solids	30%	55%
E	Air	1.5 cfm	3.0 cfm
F	Reagent Conc.(Acintol)	2.0 lb/ton	3.0 lb/ton
G	Pulp temperature	51° C	75° C

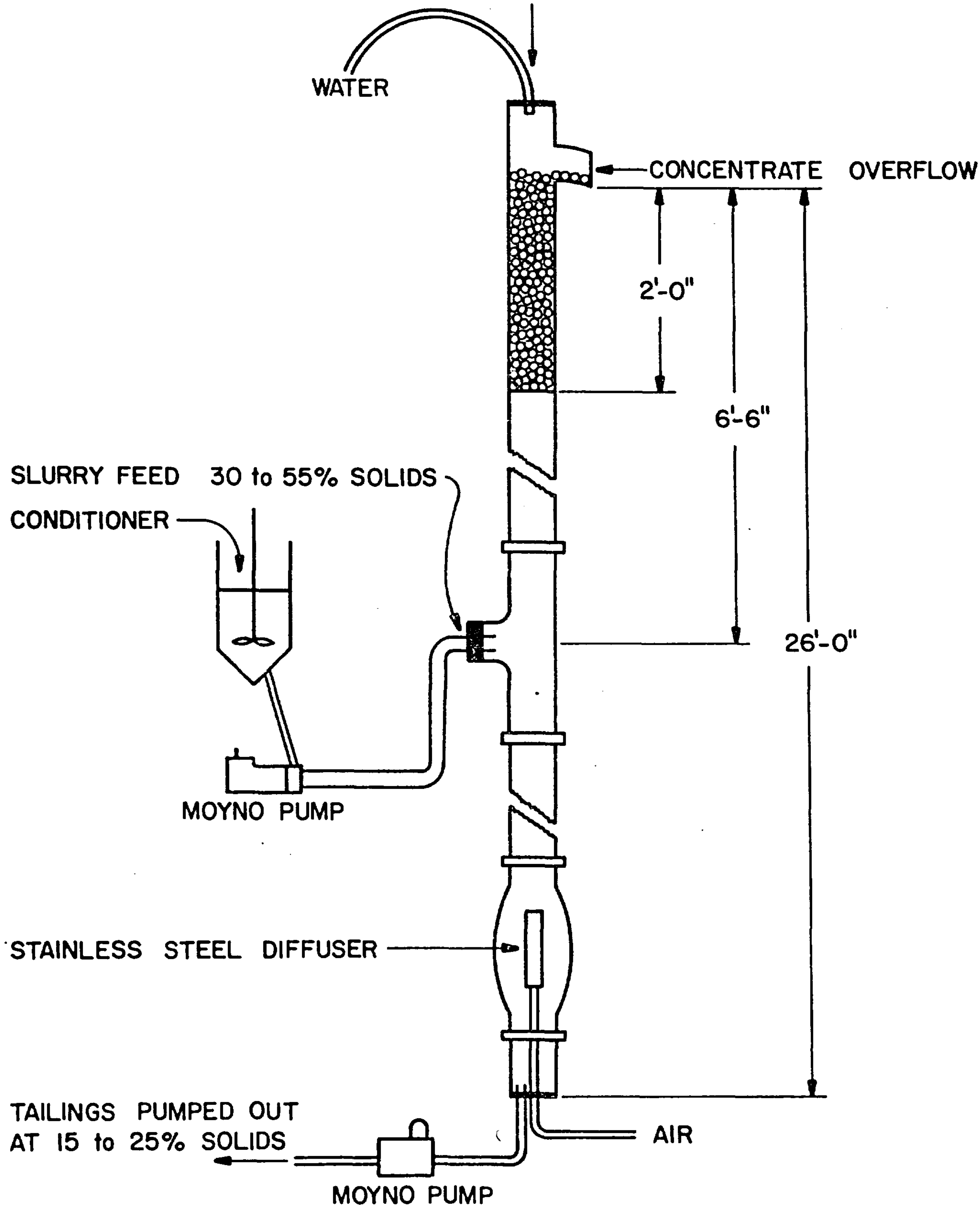

Figure 1. Column Flotation

The selectivity index was chosen as the test result for comparing the effects of the variables. The reason for this choice is that the selectivity index reflects both recovery and ratio of concentration, both of which are of interest in this study. The selectivity index as defined by A.M. Gaudin[4] is equal to $\sqrt{\frac{M}{m} \cdot \frac{n}{N}}$, where M and m are the analyses of valuable component in the concentrate and tailing respectively, and N and n are the analyses of waste material (gangue) in the same products. In this work the percentage of gangue (i.e. minerals other than uranium) in both the concentrate and the tailing was always nearly 100% so that n/N is for all practical purposes equal to unity in calculating the selectivity indices shown in Table 2.

The Plackett-Burman method of analysis (3) was used in the examination of the selectivity indices obtained. In the Plackett-Burman technique, the block of experiments is designed so that each variable occurs four times at its positive level and four times at its negative level (Table 2). In addition it can be seen from Table 2 that when variable A (for example) is at its positive level, variable B is positive two times and negative two times. This is also true for B when A is at its negative level and consequently the net effect of changes in B cancel out when the net effect of A is calculated. Since this is true of all the other variables, when the effect of A is calculated in the proper manner the effect of all variables except A cancel out.

The calculations involved are very simple. The net effect of a variable is simply the average value of the four results obtained with the variable at the positive level less the average value of the four results with the variable at the negative level. For example, the net effect of variable C using the selectivity index as the result is simply

$$\frac{2.10 + 3.60 + 2.40 + 2.37}{4} - \frac{2.67 + 2.60 + 5.10 + 4.08}{4} = - 0.995.$$

This net effect of C along with the net effects of all the other variables on the selectivity index are given in Table 3.

An estimate of the experimental error is obtained by calculating the net effect of the pH adjustment. (Table 2, D). Since this condition was not varied during the tests any net effect observed is due to random experimental error. The significance of each variable is then determined by calculating the ratio

$$\frac{\text{net effect of a variable}}{\text{net effect due to experimental error}} = t$$

The value of t is then compared with the tabulated values of t (5) to determine the relative significance of the variable's effect. The t-table is entered at one degree of freedom since we have only one estimate of experimental error provided by the net effect of dummy variable D (Table 2). The calculated relative significances of the effects of the variables are given in Table 3.

RESULTS

The results of the first series of flotation tests, which were of an exploratory nature, are given in Table 1. Although these results give indications as to the desirable levels of the operating variables involved in the column flotation of the Elliot Lake uranium ores, they do not provide a basis for determining the relative importance of the variables. The data in Table 1 show that when using the selectivity index as the criterion of successful flotation, good results were obtained with distilled water and either deslimed or whole ore (Tests 2, 4 and 6). There is no indication that pulp solids is an important factor when the ore is deslimed (Tests 2, 4 and 6). It is not possible to determine the importance of air flow and fatty-acid promoter from these results.

Table 2 shows the specific variables used in the Plackett-Burman design and the results obtained, while Table 3 shows the results of the statistical calculations made from the data on Table 2. An examination of the relative significance of the selectivity indices (Table 3) shows that variable B (deslimed or whole ore), and variable C, the pulp solids content, are the two most significant variables, while the type of water, reagent concentration, and pulp temperature (variables A, F and G respectively) are only slightly less significant. The amount of air added (variable E) is of little significance as long as there is a minimum of 1.5 cu ft per hour.

The experimental error was small as indicated by the calculated effect of pH which was not in fact varied. The accuracy of the experimental error estimate is of low degree as it is based on only one set of data. On the other hand, because there is only one set of data used in estimating the experimental error, the t - table (5) is entered at the level of one degree of freedom where the value of t must be relatively high before the effect of the variable is considered to be significant. This in effect means that the effect of the variable must be large compared to the experimental error, a situation which compensates for an error on the low side in the estimate of the experimental error.

It can be seen from the way in which the selectivity index is calculated that the higher the value of the index, the more efficient is the flotation procedure, since the selectivity index increases with both recovery and ratio of concentration. With this in mind and considering the way in which the net effect (Table 3) is calculated, it can be seen that the sign associated with the net effect indicates the direction in which the variable should be changed in order to improve the selectivity index. Consequently, the results of the Plackett-Burman series show that the efficiency obtained in the flotation of the ore investigated, as indicated by the selectivity index, can be improved by decreasing the soluble salt concentration of the water used, by operating at pulp densities of at least 55% solids, by decreasing the Acintol F.A. 1 added to at least 2.0 lb/ton, by increasing the pulp temperature to at least 75°C, and by floating the whole ore with no desliming step. These condition levels are those used for Test 13 where the highest selectivity index was in fact obtained.

TABLE 1

Column Flotation Results

Test No.	Type of Water	Ore Fraction	Pulp Solids %	pH Adjustment	Air cu ft/hr	Acintol FA 1 lb/ton	Na_2SiO_2 lb/ton	Na_2CO_3 lb/ton	Recovery %	Ratio of Conc	Selectivity Index
2	distilled	deslimed	55	8.8	1.5	3.0	0.75	1.0	92.6	2.36	4.47
3	"	"	40	8.6	1.5	3.0	0.75	1.0	86.1	3.06	3.58
4	"	"	40	8.9	3.0	3.0	0.75	1.0	91.0	3.15	4.71
5	tap water	"	40	8.5	1.5	3.0	0.75	1.0	48.0	2.50	1.19
6	distilled	whole ore	30	8.7	1.5	3.0	0.50	1.0	83.8	4.67	4.36

Common conditions

Pulp temperature - 70°F approx
Cresylic acid, lb/ton - 0.1
Xanthate 301, lb/ton - 0.2

TABLE 2

Plackett-Burman Matrix Design

Test No.	A	B	C	D	E	F	G	Recovery %	Ratio of Conc.	Selectivity Index, *
	Type of Water	Ore Fraction	Pulp Solids	pH Adjustment	Air cu ft/hr	Reagent Conc. lb/ton	Pulp Temp. °F			
	(+) Distilled (-) Ottawa City	(+) Deslimed (-) Whole Ore	(+) 30% (-) 55%	* dummy	(+) 1.5 (-) 3.0	(+) 2.0 (-) 3.0	(+) 51 (-) 75			
9	+	+	+	-	+	-	-	82.6	1.9	2.10
10	+	+	-	+	-	-	+	44.5	9.9	2.67
11	+	-	+	-	-	+	+	82.8	3.6	3.60
12	-	+	-	-	+	+	+	89.1	1.8	2.60
13	+	-	-	+	+	+	-	78.8	8.3	5.10
14	-	-	+	+	+	-	+	66.3	3.9	2.40
15	-	+	+	+	-	+	-	76.4	2.7	2.37
16	-	-	-	-	-	-	-	70.9	7.8	4.08

* Used to obtain an estimate of the variance in the mathematical analysis of the results. Since pH was not varied, any variation in the test result indicated as being due to D is, in fact, due to experimental error.

TABLE 3

Statistical Data Calculated From The
Plackett-Burman Design Given in Table 2

Variable Identification	Variable	Variable Range		Net Effect	Value of t	t, test Significance, %
		+ ve	- ve			
A	Type of water	Distilled	tap	+0.504	12.6	94
B	Ore fraction	Deslimed	whole ore	-1.360	34.0	98
C	Pulp solids	30%	55%	-0.995	24.8	97
D	pH	9.2 (not varied)		+0.040[1]	-	-
E	Air	1.5 cfm	3.0 cfm	-0.13	3.2	80
F	Reagent Conc.(Acintol)	2.0 lb/ton	3.0 lb/ton	+0.605	15.1	95
G	Pulp temperature	51°C	75°C	-0.595	14.9	95

(1) Experimental error estimate.

Based on these observations, some additional tests were run in which the variables were changed to values outside the ranges shown in Table 3 and in the direction indicated by the Plackett-Burman calculation. The selectivity indices obtained in these tests were not significantly better than those obtained in Test 13, Table 3.

DISCUSSION

The results of this work show that the column flotation cell is capable of treating both deslimed and un-deslimed Elliot Lake uranium ore, whereas previous work (1) has shown that conventional flotation cells are only useful for floating deslimed ore. Both the conventional cells and the column cell produce from deslimed ore a concentrate representing a uranium recovery of about 90% with a ratio of concentration of about 3:1. With undeslimed ore, the use of conventional cells results in completely unsatisfactory flotation, but the column cell will produce a concentrate representing about 80% recovery with concentration ratios in the range of 5:1 to 8:1 (Table 2, Test 6, and Table 3, Test 13) from similar un-deslimed feed.

The uranium recoveries obtained in this work using column flotation on undeslimed ore are economically unacceptable, but the relatively high ratios of concentration attained are of interest. It is possible that better recoveries could be made using finer grinds and fresh unoxidized ore as feed, and the results are sufficiently encouraging to warrant such work being done. Because previous experience has shown that the Elliot Lake ores oxidize rapidly, any further studies should be done in an operating plant on a part of the process stream.

In the Plackett-Burman design used where six variables were investigated at two levels with only eight tests, the effect, indicated by the analysis, as being due to any one of the main variables could, in fact, be due to interaction of the other variables involved. Table 4 shows the interactions associated with the main variables. This table indicates that the effect of temperature (variable G) could be due to the interactions of water type and air (A and E), ore fraction and pulp solids (B and C) and pH and reagent concentration (D and F). To distinguish between the main effect and the interactions more tests would be required, but it was thought that these could be part of any future study that might be done on fresh ore.

TABLE 4

Interactions Associated With The Main Variables

Main Variable	Interactions		
A	BF	CD	EG
B	AF	CG	DF
C	AD	BG	EF
D	AC	BE	FG
E	AG	BD	CF
F	AB	CE	DG
G	AE	BC	DF

CONCLUSIONS

On the basis of this work the following conclusions can be made:

(a) The use of the column flotation cell for the flotation of uranium from a deslimed Elliot Lake ore would give results similar to those that would be obtained in conventional cells;

(b) the use of the column flotation cell for the flotation of uranium from an un-deslimed Elliot Lake ore would result in a relatively high ratio of concentration (up to 8:1), and a recovery of about 80%;

(c) the results obtained are sufficiently encouraging to warrant the column flotation cell being tested further in an operating plant.

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