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Chemistry-Separation Processes
for Plutonium and Uranium
(TID-4500, 13th Ed.)

APPLICATION OF THE PULSE COLUMN
TO THE PUREX PROCESS*

By

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Chemical Development

Chemical Research and Development Operation

April 5, 1957

HANFORD ATOMIC PRODUCTS OPERATION
RICHLAND, WASHINGTON

Work performed under Contract No. W-31-109-Eng-52 between
the Atomic Energy Commission and General Electric Company

Printed by/for the U.S. Atomic Energy Commission

Printed in USA. Price 30 cents. Available from the
Office of Technical Services
U.S. Department of Commerce
Washington 25, D.C.

*Presented at the Aqueous Reprocessing Symposium in Brussels,
Belgium, May 1957.

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ABSTRACT

General aspects, including the effects of factors influencing performance, of pulsed solvent extraction columns are described. The original design concept, i. e. , H. T. U. requirements, column heights, cartridge geometry, and expected operable volume velocities of the pulse columns for use in the Purex process is presented. Subsequent improvements in column internals resulting from development studies directed toward extending the range of column operability by increasing amplitude-frequency limitations and/or reversing the choice of continuous phase are also included.

APPLICATION OF THE PULSE COLUMN
TO THE PUREX PROCESS

I. INTRODUCTION

The Purex process as previously described utilizes solvent extraction to separate, decontaminate, and purify uranium and plutonium from irradiated uranium fuel elements. Solvent extraction processes require equipment capable of producing the equivalent of multiple contact and separation of two liquid phases. The contacting equipment believed sufficiently developed for radioactive service includes packed columns, mixer-settlers, and pulse columns. A schematic drawing of the size (determined from development data) of each contactor type required to carry out a typical Purex separation is shown in Figure 1. The excessive height requirement of packed columns would mean an appreciably larger capital investment for plant construction. The choice between pulse columns and mixer-settlers is by no means clear cut. However, while the cost, reliability, and rangeability of pulse columns and mixer-settlers are considered about equal, pulse columns are believed more desirable because:

1. Pulse column plutonium contactors could easily be made critically safe by safe geometry.
2. The removal of solids from the contactor could be more readily accomplished from a pulse column.
3. The smaller volume per unit of capacity in a pulse column would result in a lower time requirement for detection of off-standard conditions and a restoration of steady-state operation.

II. DESCRIPTION OF PULSED COLUMN

A schematic diagram of a pulsed solvent extraction column is shown in Figure 2. The column has a contact zone, enlarged disengaging sections at both top and bottom to permit several minutes for phase disengagement, and conventional provisions for solvent and feed inlet and for raffinate and

extract withdrawal. The contact zone consists either of a series of stationary, spaced, horizontal perforated plates or Raschig ring packing. Examples of perforated plates used in Purex contactor development studies are given in Figure 3 in which d = diameter of hole in inches, FA = free area in percent, and nd = nozzle depth in inches.

In addition, and up-and-down pulsing motion is superimposed on the net countercurrent flow of the liquid phases. The pulsing motion of the column contents through the plate perforations or packing interstices results in intimate mixing of the phases. In the case of perforated-plate columns, the pulsing also provides the means for countercurrent flow of aqueous and organic phases. The specific gravity difference is usually not sufficient to cause a significant countercurrent flow through the small holes in the plates. Consequently, the net flow of light phase up and heavy phase down the column is caused almost entirely by the pulsing action and the stream pumps.

The pulsing action is imposed on the column contents by a pulse generator. Pulse generators utilizing a reciprocating piston-cylinder mechanism or a stainless steel (or Teflon) bellows actuated by an eccentric and push rod assembly have been satisfactorily demonstrated. The factors influencing the vertical location of the pulse generator and size of the pulse transmission line joining the generator to the column have been analyzed by Cooper and Groot.⁽¹⁾

III. PERFORMANCE OF A PULSE COLUMN

A. Types of Contacting

As indicated in Figure 4, which is a plot of column throughput versus pulse frequency at constant amplitude, pulse column operation can be divided into five distinct zones. These are: (1) flooding due to insufficient pulse, i. e., the pulsed volume velocity is not equal to the volume velocity of the net flows; (2) stable mixer-settler-type operation; (3) stable emulsion-type operation; (4) unstable operation; and (5) flooding due to excessive emulsification.

Characteristics of pulse column behavior in the three operable zones (Items 2 through 4 above) have been discussed by Sege and Woodfield⁽²⁾ and their presentation will be briefly reviewed below.

Mixer-settler-type operation (Figure 5), which occurs at low throughputs and low pulse frequencies, is characterized by phase separation into discrete layers during the quiescent portions of the pulse cycle. During upward pulse movement, the light phase initially resting under a sieve plate is forced up through the perforations and rises in fairly large globules through the heavy phase layer above the plate. Similarly during downward pulse the heavy phase moves through the light phase zone. Mixer-settler-type operation is highly stable but relatively inefficient.

Emulsion-type operation (Figure 6), occurring at higher throughputs and frequencies, is characterized by small drop size and fairly uniform dispersion of discontinuous phase with little change in dispersion during the course of the pulse cycle. The intimate interphase contact makes this the most efficient type of operation.

Unstable operation (Figure 6), occurring at still higher frequencies and throughputs, is characterized by mixtures of fine and coarse dispersed phase drops, the formation of large globs of dispersed phase by coalescence, and periodic reversals of the continuous phase in short sections of the column. The efficiency is generally lower than for emulsion-type operation and is subject to wide fluctuations.

B. Main Factors Affecting Performance

The factors affecting pulse column performance can be divided into two broad groups: (a) those which may be varied in the course of operating a column of fixed design, and (b) those which are fixed by design of the column or of the associated pulse generator.

Only the general direction and order of magnitude of the effects are to be presented.

1. Effect of Operating Variables

The important operating variables are:

- Pulse Frequency
- Volume Velocity
- Flow Ratio
- Solute Concentration
- Physical Properties of Liquids
- Temperature

Pulse Frequency. The effect of pulse frequency on pulse column capacity has been previously discussed. As shown in Figure 7, within the region of stable operation H. T. U. values generally decrease sharply with increasing amplitude times frequency product. On the threshold of unstable operation there may be a slight reversal of the trend. Experience indicates that optimum H. T. U. values generally lie between 75 and 95 per cent of the flooding frequency.

Volume Velocity. The effect of volume velocity on flooding frequency has been previously discussed. Pulse column H. T. U. values are relatively insensitive to variations in throughput rate. At constant pulsing conditions, plots of H. T. U. values against volume velocity are generally convex downward and shallow as shown in Figure 8. The increase in constant pulse H. T. U. values at low volume velocities may usually be circumvented by increasing the pulse frequency.

Flow Ratio. Although not of practical importance, both H. T. U. values and flooding volume velocities generally increase slightly with increasing continuous-to-dispersed phase flow ratio.

Solute Concentration. H. T. U. values are usually higher at the dilute end of a column than at the concentrated end.

Physical Properties of Liquids. The flooding capacity of a pulse column has been shown to be approximately proportional to:

1. The 0.7 power of the density difference between the phases.
2. The 0.4 power of the interfacial tension.
3. The minus 0.3 power of the continuous phase viscosity.

Since individual film H. T. U. values are believed to vary directly with the dimensionless Schmidt number (viscosity divided by density and diffusivity of diffusing component) raised to about the 0.6 power, low viscosity and high diffusivity favor low H. T. U. values.

Temperature. An increase in temperature generally both increases the flooding capacity and decreases the H. T. U., presumably because the increased temperature reduces the viscosities and increases the diffusivities involved.

2. Effect of Design Variables

The major design variables influencing pulse column efficiency and capacity are:

Pulse Amplitude

Wetting Characteristics and Choice of Continuous Phase

Sieve Plate Geometry

Height of Plate Section

Column Diameter

Pulse Wave Shape

Pulse Amplitude. The pulse amplitude affects column performance primarily as an effect of the arithmetic product of amplitude and frequency which has been discussed above. While the amplitude-frequency product has proved to be a useful means of correlating pulse column data, two additional considerations have not been fully defined. First is the relationship between pulse amplitude and sieve plate spacing. Usually an amplitude equal to one-half the plate spacing gives optimum capacity and efficiency relationships but not always. Second, it has been observed that flooding, good emulsion-type operation, and lowest H. T. U. values occur at lower amplitude-frequency products with 0.5-inch amplitude than with a one-inch amplitude. This suggests

that the product of amplitude times frequency to the n power might be a more exact correlator. The exponent n would have a value between 1 and 2, but might not be the same for all systems.

Wetting Characteristics and Choice of Continuous Phase. It is generally advantageous from the standpoint of extraction effectiveness to make the phase with the smaller flow continuous and to disperse the phase with the larger flow. The advantage, however, does not appear fully unless the perforated plate material of construction is preferentially wetted by the continuous phase. With plates preferentially wetted by the dispersed phase, H. T. U. values are higher.

Sieve Plate Geometry. Capacity and H. T. U. achievable in a pulse column increase with increasing hole size, plate spacing, and percentage of free area of the sieve plates. A cartridge consisting of two-inch-spaced stainless steel plates with 1/8-inch diameter holes and 23 per cent free area has been designated as a "standard cartridge". It has been found that a "standard cartridge" often represents a satisfactory compromise between the conflicting functional requirements of high capacity and high efficiency.

In the neighborhood of standard cartridge geometry up to two-fold variations in capacity and H. T. U. are encountered as hole size, plate spacing, or free area is varied three- to four-fold.

An increase in the mean diametric clearance between the plates and the wall of a three-inch-diameter column from 0.015 to 0.125 inches was found to exert little or no effect on H. T. U. values.

Height of Packed Section. H. T. U. values generally increase with increasing column height. This is partly due to a general trend toward higher H. T. U. values with decreasing diffusing-component concentration. Aggravation of channeling tendencies with increasing height is also a probable contributor.

Column Diameter. As the column diameter increases, the countercurrent flowing liquid phases display an increasing tendency to channel in some portion of the column cross section rather than distribute evenly across it.

The increasing channeling tendency brings with it increasing over-all transfer unit heights as the columns become larger. The severity of this effect varies with the properties of the liquid-liquid system and with the column design.

Pulse Wave Shape. Limited experience indicates that pulse wave shapes substantially deviating from sinusoidal often give optimum frequency H. T. U. values comparable with a sine wave. It has also been demonstrated for some systems that nonsinusoidal wave shapes substantially reduce pulse column capacity from that obtained with a sine-wave pulse.

IV. PUREX PROCESS PULSE COLUMN DESIGN

Following the establishment of a firm Purex flowsheet, extensive nonradioactive pulse column development studies were conducted on a pilot plant scale in 3- and 4-inch diameter pulse columns. The objective of the studies was to define the pulse column variables that influence contactor design. The pulse columns were to permit 0.1 per cent or less uranium or plutonium loss per column at the required capacity. The uranium and plutonium yields from the pulse column battery were expected to be at least 99 per cent. The uranium and plutonium effluent streams from the pulse column battery must also be adequately decontaminated from fission products.

In all cases, minimum column heights and diameters compatible with low waste losses, adequate capacity, and the standardization of columns and pulse generators were sought.

The number of theoretical stages and transfer units required to meet the extraction criteria as outlined above was calculated from operating diagrams and is summarized in Table I.

Development study results in terms of pulse column cartridge design, pulse amplitude, choice of continuous phase, maximum operable volume velocity, and H. T. U. values are given in Table II. In most cases, several cartridge designs were tested and those listed represent the best compromise.

The data from Table II and the pulse column decontamination performance obtained during radioactive pilot plant studies at Oak Ridge permitted the formulation of preliminary pulse column heights for Purex process application. These are presented in Table III.

V. RECENT PULSE COLUMN DEVELOPMENTS

Continued development work indicated several improvements which would increase assurance of adequate performance and/or increase the versatility of a pulse column battery.

A. C-Type Column Cartridge

A cartridge consisting of fluorothene sieve plates having 3/16-inch-diameter holes, 23 per cent free area, and four-inch spacing, demonstrated adequate capacity and efficiency under C-type column conditions with the organic phase continuous. Such plates were suspect, however, because of possible changes and/or damage occurring on prolonged exposure to high level radiation. One alternative was the use of a "standard cartridge" with the aqueous phase continuous. However, neither the capacity nor the H. T. U. values for the "standard cartridge" were as favorable as those for the fluorothene cartridge. This led to the development of nozzle plates, i. e., sieve plates with each hole indented. The indentations cause each hole to act as a tiny jetting nozzle. When oriented downward (for a lighter-than-water organic phase), the nozzles permit high capacity and efficiency to be obtained with stainless steel plates and organic phase continuous operation. Figure 9 shows the appearance of the phases in two glass pulse columns operating with the organic phase continuous and with stainless steel sieve plates and nozzle plates. In the case of the sieve plates, the aqueous phase descending through the column wets the stainless steel plates and coagulates into large globules. The tendency of the aqueous phase to wet the plates is counteracted by the nozzle plates, and the resulting dispersion is fairly uniform.

It was demonstrated as shown in Figure 10 that a cartridge consisting of stainless steel nozzle plates having 0.115-inch-diameter holes, 8.5 per cent free area, and a nozzle depth of 0.04 inch, and 4-inch spacing has appreciably higher capacity than fluorothene plates for organic phase continuous C-type column operation. In addition, the nozzle plates exhibit higher capacity than a "standard cartridge" for aqueous phase continuous operation. Limited experiments using fluorothene plates for aqueous continuous operation and a "standard cartridge" for organic phase continuous operation indicate neither to be practical. Therefore, since H. T. U. values for a nozzle plate cartridge are at least as good as those for a fluorothene plate cartridge, the versatility of a C-type column is considerably enhanced by using nozzle plates.

B. Graded Plate A-Type Extraction Cartridge

Table II indicates that the maximum operable volume velocities for the dual-purpose Purex A-type column extraction and scrub sections are widely different. This is compensated for to some extent by utilizing a scrub-section-diameter to extraction-section-diameter ratio of 4 to 3. For a given uranium capacity, a scrub section volume velocity of 500 is equivalent to an extraction section volume velocity of 1000 gal/hr - sq ft. It is apparent from Figure 11, which is presented on the basis of comparable uranium capacity in a 4-to-3 dual-diameter column, that the two sections have radically different flooding characteristics. The two curves for the extraction section indicate cyclic local flooding and complete flooding. While the column is operable at conditions lying between the curves, such operation is unstable and not desirable.

The scrub section flooding curve cannot be established with the same degree of confidence as the extraction section. However, the curve as drawn represents the most probable flooding condition.

At extraction section volume velocities below 1600 gal/hr - sq ft, the extraction section controls the flooding conditions. In the range of 500 to 1300 gal/hr - sq ft, the maximum operable pulse frequency varies from 50

to 80 per cent of the scrub section flooding frequency. This is below the 80 to 90 per cent of flooding frequency generally regarded as optimum, and it appeared desirable to provide for operation of the A-type column scrub sections at pulse frequencies nearer optimum.

The dispersion in an A-type extraction column varies sharply throughout the height of the column. Near the top of the column there is a loose dispersion of large drops; lower, there is a tight dispersion of small drops; and below this there is a loose dispersion of larger drops. The reason for this is believed to be related to mass transfer, i. e., a high rate of mass transfer tends to stabilize the formation of large drops. The large uranium transfer at the top of the column, the relatively large nitric acid transfer in the lower half of the column, and the low net transfer in the intermediate regions would thus account for the disparity in dispersion throughout the column.

Flooding in the extraction section usually originates in the region of tight dispersion. One way of increasing flooding frequency would be to "open" the cartridge in the region of tight dispersion, that is, increase the sieve plate hole size, free area, and/or spacing. Such a cartridge has been designated as a "graded cartridge".

A cartridge constituted as indicated in Table IV was found to:

1. Increase the flooding frequency 30 to 40 cycles/minute at 1000 gal/hr - sq ft and 5 to 20 cycles/minute at 500 gal/hr - sq ft.
2. Eliminate cyclic local flooding.
3. Be at least equal in extraction efficiency to an equivalent height of "standard cartridge".

The flooding curve of the "graded cartridge" has been included in Figure 11. Its use with a "standard cartridge" scrub section increases the maximum stable operating frequency from 50 to 75 per cent of the scrub section flooding frequency at 500 gal/hr - sq ft and from 60 to 100 per cent of scrub section flooding frequency at 1000 gal/hr - sq ft.

C. Organic Continuous A-Type Columns

Table II indicates that at the time of preliminary Purex process pulse column specification a cartridge composed of stainless steel sieve plates and aqueous phase continuous operation was thought to be the best choice for the A-type columns. Utilizing the graded cartridge in the extraction section, as discussed above, does not alter the choice of continuous phase.

The interface in a solvent extraction column always accumulates foreign solid materials. It has been found in pilot plant and in development studies that this accumulation builds up a high level of radioactivity. When A-type columns are operated with the aqueous phase continuous, the interface with its high level of radioactive material is in contact with the effluent product stream. Such a condition might jeopardize decontamination performance. The obvious solution would be to move the interface to the bottom, or waste end, of the column. It was found, however, that the stainless steel sieve plates were not well suited to organic phase continuous operation.

The results of a program for the development of a pulse column cartridge suitable for Purex A-type columns are summarized below:

Extraction Section. A satisfactory extraction section cartridge was composed of stainless steel nozzle plates having 3/16-inch-diameter holes, 23 per cent free area, 0.04-inch-deep nozzles pointing downward, and 2-inch spacing. It appeared to be the equal of the graded plate cartridge both from the standpoint of capacity and efficiency.

The flooding frequencies of the nozzle plate cartridge are 105 and 95 cycles/minute at volume velocities of 500 and 100 gal/hr - sq ft, respectively. The graded plate cartridge (aqueous phase continuous) has flooding frequencies of 115 and 105 cycles/minute at the above throughputs.

The uranium extraction behavior of the two cartridges was also similar. They both gave H. T. U. values between 0.6 and 1.0 foot at pulse frequencies ranging from 60 to 100 cycles/minute and volume velocities of 500 to 1000 gal/hr - sq ft. It is also of interest to note that the nozzle plate cartridge operated just as efficiently with the aqueous phase continuous.

Scrub Section. The most promising scrub section cartridge found was a mixed cartridge containing alternate pairs of fluorothene and stainless steel sieve plates. The fluorothene plates had 3/16-inch-diameter holes and 23 per cent free area. The stainless steel plates had 0.08-inch-diameter holes and 21 per cent free area. A one-inch plate spacing was used throughout.

The mixed cartridge had flooding pulse frequencies of 125 and 105 cycles/minute at volume velocities of 250 and 500* gal/hr - sq ft respectively. For comparison, a "standard cartridge" scrub section (aqueous phase continuous) showed flooding frequencies of 125 and 85 cycles/minute at similar throughputs.

The extraction section controlled the flooding only at lower throughputs for the aqueous phase continuous case. However, extraction section controlled the flooding at all throughputs studied for the organic phase continuous case.

Scrub section efficiency studies were based on the transfer of chloride ion which has an organic-to-aqueous distribution ratio between 0.12 and 0.13. This is about the same order-of-magnitude as might be expected of some fission product distribution ratios.

Tests made in a scrub section containing a "standard cartridge" indicated that the efficiency was sharply frequency sensitive. H. T. U. values ranged from 3.2 to 1.8 feet at pulse frequencies of 60 and 100 cycles/minute, respectively (volume velocities = 250 to 500 gal/hr - sq ft).

*A scrub section volume velocity of 500 gal/hr - sq ft is equivalent in uranium capacity to an extraction section volume velocity of 1000 gal/hr - sq ft for a dual-diameter column with a scrub-to-extraction-diameter ratio of 4 to 3.

The efficiency was found to be closely related to the holdup of dispersed phase, and the best efficiencies were obtained when the column was maintained at a flooded condition by continuous adjustment of the pulse frequency. The efficiencies obtained with the mixed cartridge at volume velocities of 250 and 500 gal/hr - sq ft were considerably better with the H. T. U. values ranging from 2.9 to 1.2 feet at pulse frequencies of 50 to 100 cycles/minute, respectively.

The good efficiencies of the mixed cartridge are due to coalescence of the aqueous phase at the stainless steel plates. The optimum condition was that in which the coalescence had reached a point of complete phase inversion in the region of the stainless steel plates. The column then consisted of alternate layers of organic phase continuous and aqueous phase continuous dispersion.

The efficiencies of both standard and mixed cartridges are adversely affected by dirty plates. In both cases, the unfavorable effects arose from the fact that dirty stainless steel plates are partially wetted by the organic phase. In the case of the standard cartridge, this resulted in an increased organic drop size, a looser dispersion, and a lower dispersed phase holdup with a consequent loss of efficiency. With the mixed cartridge, the partially preferentially organic wet plates decrease the degree of phase inversion attained and result in decreased efficiency.

VI. CONCLUSION

The development work carried out at HAPO has indicated that the pulsed solvent extraction column would be a very attractive contactor for Purex process application. The columns comprising the battery would be of reasonable height, be easily capable of meeting the process requirements, and provide sufficient versatility to encompass flowsheet modifications if necessary.

REFERENCES

- (1) Cooper, V. R. and C. Groot, Design Considerations for a Pulse Column System, March 9, 1950, HW-20305.
- (2) Sege, G. and F. W. Woodfield, "Chemical Engineering Progress", pages 396 - 402, Vol. 50, No. 8, August 1954. Pulse Column Variables.

TABLE I

Theoretical Stage and Transfer Unit Requirements
for Purex Solvent Extraction Columns

Basis: Loss of 0.1 per cent of U or Pu in feed

<u>Column</u>	<u>No. of Theor. Stages</u>		<u>No. of Transfer Units</u>	
	<u>U</u>	<u>Pu</u>	<u>U</u>	<u>Pu</u>
HA Extraction	2.0	2.6	7.0	7.2
HC	3.5	2.3	7.7	7.2
1A Extraction	2.0	2.6	7.0	7.2
1B Extraction	---	6 ^(a)	---	10 ^(a)
1B Scrub	2.7 ^(b)	---	10.0 ^(b)	---
1C	4.1	---	8.1	---
2A	---	3.8	---	7.1
2B	---	2.1	---	7.0
2D	2.0	---	7.0	---
2E	3.5	---	7.7	---

(a) Distribution ratio (E_A^0) assumed equal to 0.02.

(b) For waste loss of 5.7×10^{-5} per cent.

TABLE IIPurex Process Pulse Column Operability

Pulse Frequency = 35 to 110 Cycles/Min.

<u>Column</u>	<u>Plate or Packing Type</u>	<u>Pulse Amplitude In. (a)</u>	<u>Contin- uous Phase</u>	<u>Max. Operable Volume Velocity, Gal/Hr - Sq Ft (Sum of Both Phases)</u>	<u>H. T. U., Ft.</u>
Ha,1A,2D	(b)	1.1 0.6	Aqueous	2000 (Ext.) 750 (Scrub)	0.7 to 1.2 (Ext.)
HC,1C,2E	(c)	0.53	Organic	1100	0.8 to 1.4
1BX	(b)	0.84	Aqueous	600	1.8 to 2.7
1BS	(b)	0.84	Aqueous	1700	0.8 to 1.3
2A	(d)	1.1	Organic	2300	1.3 to 2.2 (Ext.)
2B	(b)	1.1	Aqueous	800	1.2 to 2.0
10, 20	(c)	0.53	Organic	1100	-----

(a) Measured from one extreme position to another.

(b) Stainless steel plates having 1/8-inch-diameter holes, 23 per cent free area, and 2-inch spacing.

(c) Fluorothene plates having 3/16-inch-diameter holes, 23 per cent free area, and 4-inch spacing.

(d) Fluorothene Raschig rings, 1-inch-diameter by 1-inch long.

TABLE III
Preliminary Pulse Column Heights
For Purex Process Application

<u>Column</u>	<u>Packed Section Height, Ft.</u>
HA, 1A, 2D	13.5 Extraction 13.2 Scrub
HC, 1C, 2E	18.0
1BX	28.0
1BS	13.3
2A	20.9 Extraction 9.8 Scrub
2B	21.0
10, 20	26.3

TABLE IV
Graded Plate Cartridge
For A-Type Column Extraction Section

<u>In. of Cartridge Height</u>	<u>Hole Diameter, In.</u>	<u>Sieve Plates</u>	
		<u>Per Cent Free Area</u>	<u>Spacing In.</u>
18	0.125	23	2
8	0.188	33	2
20	0.188	33	4
32	0.125	23	4
28	0.125	23	2

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CHOICE OF SOLVENT - EXTRACTION CONTACTOR

FIGURE 1

**SCHEMATIC SKETCH
OF A PULSE COLUMN**

FIGURE 2

TYPICAL SIEVE PLATES USED IN PUREX PULSE COLUMN STUDIES

**FLUOROTHENE
SIEVE PLATE**

$d = 0.188$ in.,
FA = 23 %

**STAINLESS STEEL
LOUVER-TYPE
REDISTRIBUTOR
PLATE** FA = 25 %

**STAINLESS STEEL
SIEVE PLATE**

$d = 0.188$ in., FA = 33 %

**STAINLESS STEEL
NOZZLE PLATE**

$d = 0.125$ in., $n_d = 0.06$ in., FA = 7.5 %

FIGURE 3

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MIXER-SETTLER TYPE OPERATION

FIGURE 5

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**EMULSION - TYPE
OPERATION**

**COALESCENCE,
UNSTABLE
OPERATION**

FIGURE 6

EFFECT OF PULSE FREQUENCY ON PULSE COLUMN EFFICIENCY

FIGURE 7

EFFECT OF VOLUME VELOCITY ON PULSE COLUMN EFFICIENCY

FIGURE 8

NOZZLE PLATE CARTRIDGE DISPERSION IMPROVEMENT

FIGURE 9

FIGURE 10
COMPLETE FLOODING CURVES FOR
PUREX C-TYPE PULSE COLUMNS

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VOLUME
VELOCITY
GAL./HR. -SQ. FT.

— STANDARD CARTRIDGE EXT. SECT. INSTABILITY THRESHOLD
 ---- STANDARD CARTRIDGE EXT. SECT. FLOODING
 -.- GRADED CARTRIDGE EXT. SECT. FLOODING
 --- SCRUB SECTION FLOODING

FIGURE 11
FLOODING CHARACTERISTICS
OF PUREX A-TYPE PULSE COLUMNS

UNCLASSIFIED

-33-

HW-49542 A

AEC-GE RICHLAND, WASH.

UNCLASSIFIED