**Solvent Extraction Equipment
Evaluation Study
Part 3. Summary**

January 1977

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and Development Administration
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SOLVENT EXTRACTION EQUIPMENT
EVALUATION STUDY
PART 3. SUMMARY

by

L. M. Browne

R. G. Geier^(a)

January 1977

BATTELLE
Pacific Northwest Laboratories
Richland, Washington 99352

(a) Atlantic Richfield Hanford Company, Richland, Washington

ABSTRACT

This is Part 3 of a three-part document that reviews the solvent extraction contactors available for use in radiochemical reprocessing plants. The three parts are: Part 1 - A Review of the Literature, Part 2 - Workshop Proceedings, Part 3 - A Summary. The main objective of the document is to provide an information base to aid in contactor selection and design of future reprocessing plants.

The Literature Review (Part 1) brings together scattered data on all major contactors in use today. It contains an annotated bibliography of the citations used in the review and a complete listing of all the citations screened prior to the review. These bibliographies should aid in determining which reports would be most useful if additional information is desired.

The Workshop Proceedings (Part 2) summarizes a workshop on the title subject held in mid-1976. The participants had considerable experience in the use of solvent extraction contactors in reprocessing plants. The purpose of the workshop was to bring together these people in order to collect, evaluate and document any information that would be helpful in the selection of solvent extraction contactors for nuclear fuels reprocessing plants.

The Summary (Part 3) is a compendium of the information presented in the Literature Review and the Workshop Proceedings. It was written to present the salient points of Parts 1 and 2 without going into as much detail. The Summary contains a listing of the references used in the Literature Review so the reader can either go directly to the citation or to Parts 1 and 2 for further information.

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SUMMARY -
LITERATURE REVIEW
SOLVENT EXTRACTION CONTACTORS

SUMMARY -
LITERATURE REVIEW
SOLVENT EXTRACTION CONTACTORS

1.0 INTRODUCTION

This document reviews the available literature on the types of liquid - liquid extraction contactors used to perform radiochemical separations. Also included are comparisons between the types of contactors. The summarization of each of the approximately 130 papers reviewed contains a description of the equipment tested, the chemical system used to test it, and the results obtained. Conclusions drawn by the original authors have not been altered.

A bibliography has been included which has been numbered to cross-reference the summaries to the proper references.

2.0 PULSE COLUMNS

A pulse column is a vertical counter-current contacting device containing a series of stationary plates or packing. An up-and-down pulsing motion is superimposed on the net counter-current flow of the liquid phase. In addition to providing intimate mixing of the two phases, this pulsing action also provides a means for counter-current flow through the plate perforations or packing interstices. The following subsections summarize the various types of pulse columns and list the literature from which this information was summarized.

2.1 REDOX PLANT, URANIUM RECOVERY PLANT AND PUREX PLANT WITH CARBON TETRACHLORIDE SOLVENT

A conceptual pulse column design is presented for the first extraction cycle in the Redox process and for a Purex extraction battery using TBP in carbon tetrachloride. A description of the actual extraction and stripping column internals used for the recovery of the uranium from the bismuth phosphate wastes is included. For more information see bibliographic entries 24, 86 and 105.

2.2 PUREX PLANT - HYDROCARBON SOLVENT

The dimensions, pulsing conditions, and the column internals for a nominal 16 ton/day plant operating on a Purex flowsheet are given. The influence of design variables on pulse column performance (Table 1) was reviewed by a number of authors. The performance of a variety of column internals including nozzle plates, staggered sieve plate spacing, and mixed fluorothene sieve plates - stainless steel sieve plates is discussed. In given situations each of these internals has some advantages. Some documents describe cartridges for operation with the continuous phase which reversed from that in the original design (e.g., an organic phase continuous HA column).

TABLE 1. Effect of Design Variables on Pulse Column Performance

<u>Variable Range Studied</u>	<u>Relative Importance</u>	<u>General Effect</u>
Column Diameter 3 to 24 in.	Essentially no effect on flooding volum velocity; third-order effect on efficiency, providing adequate interphase mixing is attained.	Processing capacity varies directly with the column cross-sectional area from 0.5 ft ² to 5.0 ft ² ; slight decrease in efficiency with increasing diameter from 3 in. to 24 in. for A-type columns.
Cartridge Height 6 to 13 ft	Third-order effect on capacity and HTU.	Less than 10% decrease in capacity by increasing the contactor length 50%; increase in contactor length from 9 to 13 ft increased the HTU an average of 10%.
Hole Diameter 0.06 to 0.188 in.	Second-order effect on capacity and efficiency.	An increase in capacity and HTU with increasing hole diameter; a hole diameter of 0.125 in. appears to be near optimum for most columns.
Plate Free Area 10 to 23%	First-order effect on both capacity and efficiency.	The capacity and HTU generally increases 10% or more when the free area is increased from 10 to 23%.
Plate Spacing 1.0 to 4.0 in.	Second-order effect on capacity and efficiency in the range of 1 to 4 in.	General increase in both capacity and HTU with increased spacing.
Plate Material	First-order effect on capacity, second order effect on efficiency of C-type columns.	Capacity of C-type column w. fluoroethene or nozzle plates is about 100% greater than that with stainless steel sieve plates; efficiency of C-type columns with nozzle plates is 20 to 50% higher than with fluoroethene sieve plates.
Diametral Clearance (Column ID Less Plate Diameter) Up to 0.125 in.	Third-order effect on capacity for a clearance up to 1/8 in. on a 3.00-in. diameter column; third-order effect on efficiency for a column with aqueous phase continuous; second-order effect on efficiency with organic phase continuous.	Very slight increase in capacity and HTU with increasing clearance up to 1/8 in. for aqueous phase continuous; considerable increase in HTU with increasing clearance with organic phase continuous.

Phase redistributor plates of a louver-type design for use in pulse columns over about 1-ft in diameter produced a reduction in waste losses from 6 to 0.001%. For more information see bibliographic entries 17, 43, 46, 52, 53, 56, 58, 63, 72, 81, 82, 85, 87, 88, 96, 99 and 129.

2.3 EFFECTS OF TEMPERATURE

The effects of temperature were investigated using the uranium recovery plant flowsheet. It was found that a higher temperature

- led to a better dispersion and coalescence,
- resulted in large gains in stripping column efficiency, and
- produced greater extraction efficiency and lower waste losses.

For more information see bibliographic entry 21.

2.4 PULSE GENERATORS - MECHANICALLY DRIVEN

Mechanically driven pulse generators which have been used successfully are:

- crank driven piston pulser,
- electromagnetic powered piston pulser, and
- bellows pulser.

The need for a weep hole for air bleeding in the face of a piston-type pulser was stressed. Leakage rate past a 21.2-in. diameter piston having a 3/64-in. diameter hole was about 0.2 gpm (gallons per minute).

The system can be made inoperable by cavitation which occurs when the sum of the atmospheric, hydrostatic, and acceleration pressures is less than the vapor pressure of the liquid under the piston. An equation has been developed to calculate the minimum value of acceleration pressure in terms of pulse volume, pulse frequency, pulse leg diameter and length. An equation is also available to calculate the power input to a pulse generator. Small diameter pulse column data using a wide variety of plate configurations showed little influence of the type of pulse move (sine, saw-tooth, and square move) on either capacity or efficiency. For more information see bibliographic entries 31, 41, 56, 65, 75, and 11.

2.5 PULSE GENERATORS - AIR DRIVEN

A number of investigators have examined pulsing devices using air as the motive force. It was concluded that some advantages of the air pulser are:

- no moving mechanical parts in the cell to be repaired and serviced by expensive remote systems,
- expensive cell space is conserved,

- process liquids are completely contained, whether or not the system is in operation,
- both pulse amplitude and frequency can be varied without the use of costly remote control systems.

A major disadvantage to air pulsers is the amount of control instrumentation required. For more information see bibliographic entries 7, 16, 57 and 108.

2.6 AUTOMATIC CONTROL

A control system to minimize plutonium losses from a pulsed extraction column would include magnetic flow meters for monitoring aqueous streams, electronic differential pressure cells for monitoring organic streams, and neutron counting devices for measuring plutonium concentration. For more information see bibliographic entry 3.

2.7 THEORETICAL CONSIDERATIONS

A number of authors have attempted to relate the physical properties of the phases, the geometry of the pulse column cartridge and pulsing characteristics to produce an equation from which either the capacity, the efficiency, the hold-up, or the axial distribution in a pulse column can be calculated. The equations contain complex functions of the variables and may provide rough scheming of the impact of a variable, but cannot as yet be considered a substitute for pilot plant testing. This is borne out by the wide variation in the net exponent of the individual variables between the various investigator's equations. For more information see bibliographic entries 6, 9, 10, 22, 48, 55, 74, 76, 77, 89, 92, 97, 98, 101, 102, 103, 112 and 118.

2.8 BACKMIXING

Studies using tracers have demonstrated that in a pulse column considerable backmixing of the continuous phase occurred, i.e., a portion of

the continuous phase being carried against the net flow of the continuous phase. Experiments showed that backmixing at a constant pulse amplitude was a function of the continuous phase flow rate only and was independent of pulse frequency, spacing, and discontinuous flow rate. In an extraction section having an HTU = 1.0 ft, with backmixing present, the HTU could be reduced to 0.76 ft without backmixing. For more information see bibliographic entries 106 and 107.

2.9 VALVE ACTUATED PULSE COLUMNS

A valve-actuated pulse column employs timed solenoid valves and pressurized feeds to provide pulsing action. Under Purex extraction column conditions, HETS valves of 7 to 8 in. were obtained in a 1-in. diameter column. For more information see bibliographic entries 18, 19 and 20.

2.10 CONCATENATED PULSE COLUMN

A concatenated pulse column can provide the equivalent height of a tall column by connecting two or three short columns in series and using one pulse generator. Another method of achieving concatenation relies on the column interconnections being filled with check valves. The principle conclusions which resulted from the work on this type of concatenation were:

- A concatenated column offers not only equal but sometimes greater efficiency than a tall column.
- Pulse power requirements are usually lower than the power required for a tall column.

For more information see bibliographic entries 66 and 73.

2.11 OTHER PULSE COLUMN APPLICATIONS AND DESIGNS

The pulse column battery for the Eurochemic Separations Plant, at Mal, Belgium is described. Data obtained in the plant on several off-standard first-cycle pulse column operating conditions showed the time for detection as listed in Table 2.

TABLE 2. Time Needed to Detect Off-Standard Conditions

<u>Incident</u>	<u>Time to Detect, min</u>
Sudden increase of 15% in HA column feed rate	15
Sudden decrease of 10% in HA column extractant rate	15
Sudden decrease of 20% in HS column scrub flow	50
Sudden 25% decrease in pulse amplitude	Difficult to detect
Sudden 50% decrease in pulse amplitude	15
Temperature increase 50 to 70°C	40

An investigation of the reextraction of uranium from the solvent phase in a Purex system made with pulse column internals yielded the results listed in Table 3. A number of other pulse column studies include their use in:

- the separation of hafnium from zirconium,
- the removal of thorium from uranium in a scrub section,
- the processing of STR and SIR fuel, and
- the recovery of uranium from solutions containing 60 to 80 ppm uranium.

TABLE 3. Reextraction of Uranium from Solvent

<u>Plate Type</u>	<u>Maximum Throughput, gal/hr-ft²</u>	<u>Uranium Conc. in Raffinate, g/l</u>	<u>Stage Efficiency, %</u>
Sieve	1550	0.02	79 to 91
Nozzle	1880	0.3	75 to 83
Dual-Faced ^(a)	1510	0.2	82 to 91

(a) Fluorothene coated stainless steel, one side only.

The use of pulsed-packed and pulsed-sieve plate columns was also investigated, and it was concluded that: 1) for packed columns pulsation is a practical way to improve efficiency, and 2) sieve plate columns have higher throughputs than packed columns and smaller plate perforations increase column efficiency. Solvent extraction column (1-in. diameter by 12 in. high) having a rotating paddle between sieve plates produced HTU values in the range of 0.6 in. for uranium extraction. For more information see bibliographic entries 8, 25, 26, 40, 42, 47, 49, 50, 64, 69, and 84.

3.0 MIXER-SETTLERS

The mixer-settler is a countercurrent contacting device consisting of a series of stages in which mixing is accomplished by the mechanical action of a variable speed impeller and the phases are separated by gravity.

3.1 SAVANNAH RIVER CONTACTORS

Using a heat balance to measure the mixing capability of a mixer settler unit, it was found that:

- mixing efficiency increased with paddle speed,
- the suction head increased with an increase in the number of blades or an increase in blade height,
- stage efficiencies as high as 99% were obtained,
- with no head, capacity is proportional to impeller speed,
- with no flow, head is proportional to the impeller speed squared,
- head and flow increase with impeller speed for a given size recirculation hole, and
- head-capacity characteristics of the impeller are independent of recirculation ratio.

In a three-stage mixer-settler using a uranium TBP system and an aqueous-to-organic flow ratio of 1.5, extraction was increased from 35 to 90% by increasing the impeller speed from 200 to 500 rpm. The pressure drop of the light phase was found to be 1.3 in./stage at a flow rate of 45 gpm. A critically safe mixer-settler 3 in. high by 8 in. wide by 5 ft long used a 4-1/2 in. diameter flat impeller paddle capable of speeds up to 700 fpm, had six stages and showed an extraction efficiency of 80%.

Heat transfer between water and ultrasene was used to determine mixing efficiency in a three-stage mixer-settler unit in which each stage had a 3-in. wide by 1-ft high mixing zone. The heat transfer could be correlated by the following equation:

$$UA = 0.32 V_m (\pi NL)^{1.8} \quad (1)$$

in which

UA = heat flow, Btu/min-°F

L = paddle diameter, ft

N = paddle speed, rpm

V_m = mixing volume, in.³

Mixing devices were tested in a single stage of a pump-mix mixer-settler. The effectiveness of various impellers was compared at constant tip speed in a single-stage of a mixer-settler. A comparison of impellers shows that higher efficiencies were produced by open impellers (paddles and propellers) than by closed impellers (centrifugal and disk impellers) at the same tip speeds. At those speeds approximately the same amount of dispersion was produced by all the impellers. For more information see bibliographic entries 27, 28, 37, 79, 80 and 125.

3.2 KAPL-TYPE MIXER-SETTLERS FOR RADIOACTIVE USE

Tests were conducted in a 16-stage mini-mixer-settler using the acetic acid - methylisobutyl ketone - water system. The throughput of the unit was 0.2 to 0.5 gpm which resulted in a residence time of 1 to 2 min. Using an impeller with four 1/4-in. long and 3/16-in. high blades fastened to the top disk, an extraction stage efficiency of 83% was obtained. When a light phase baffle was incorporated into the design, stage efficiencies increased to 99%. The size capacity characteristic is one of the bases for comparison of the relative effectiveness of different types of extraction equipment. Assuming the volume occupied by the apparatus is considered the important size variable, a quantitative measure of the effectiveness of mixer-settlers was developed.

Transfer efficiency in a 16-stage mixer settler unit was found to be a function of both rotor speed and direction of transfer. As an example, at a rotor speed of 550 rpm 100% efficiency was obtained when transfer was from aqueous to organic. The efficiency dropped to 95% for organic to aqueous transfer.

A scale-up procedure for pump-mix mixer-settlers was developed. For the settling zone scale-up was proportional to residence time. In the mixing section, if the horizontal cross-section is assumed to remain square, the impeller diameter is scaled-up proportionally as the one-third power of the capacity ratio. The scale-up of the impeller speed involves a relatively complex equation. For more information see bibliographic entries 32, 34, 35 and 60.

3.3 THE EFFECTS OF ENTRAINMENT

A model of a mixer-settler based on a given set of assumptions was made. Using the model as a calculational base, it was concluded that high entrainment rates have little effect on the efficiency of mixer-settler extractors. For more information see bibliographic entry 100.

3.4 SOLVENT EXTRACTION ECONOMICS

Equations have been developed for determining extractor cost, cost of solvent in the raffinate, cost of recovered solvent, and cost of lost solvent. A method for calculating an economic scale-up index has also been described as well as a short cut method to find the most economic value of volumetric flow rates. For more information see bibliographic entry 116.

3.5 DESIGN CONSIDERATIONS FOR MIXER-SETTLER EXTRACTORS

The following areas of mixer-settler design are considered:

- The use of a common shaft for all stages versus an individual shaft for each stage.
- A vertical versus a horizontal arrangement of the stages.
- Concurrent or countercurrent settling within each stage.
- Control of the ratio of phases in the mixing chamber.
- Design of stirring motors and shaft seals, agitator flow and design, and accessory equipment.

For more information see bibliographic entries 38 and 39.

3.6 DESIGN REVIEW - MIXER SETTLERS

A review of mixer design, settler design, mixer-settler scale-up and a comparison of pump mix and gravity flow mixer settlers has been made. The salient points developed include:

- The design of a mixer follows the principles used for a continuously stirred tank.
- For a given mixer design, the residence time in the mixing chamber determines the efficiency of mixing.
- The size and shape of the settling chamber are determined by the depth of the emulsion, the rate of emulsion coalescence, and by the depth of liquid above and below the band required to minimize entrainment.
- The presence of "picket-fence" baffles in the settler enhance coalescence.
- The linear velocity of the phases down the settler is of major importance.
- The reliability of the settler is affected by the accumulation of "crud" at the interface.
- Mixers may be scaled-up by geometric similitude at constant power per unit volume.
- Settlers may be scaled-up on the basis of constant flow rate per unit of horizontal cross-sectional areas.
- The maximum throughput of pump-mix units, was lower than that of similarly sized gravity flow units.
- The interface levels in the pump-mix unit increase rapidly with increase in flow rate whereas the gravity flow unit maintained fixed levels independent of flow rate.

It was concluded that the pump-mix mixer-settler concept gives independent control of each settler interface and reduces the need for interstage pumps in large units. However, these units are usually designed to operate over a limited range of flow rates. The gravity flow design allows each stage to be hydraulically independent; a bank of units can continue to

operate with one or more mixers defective, the design can deal with large ranges of flow rates, and the overall construction of a unit is relatively simple. For more information see bibliographic entry 91.

3.7 ADDITIONAL MIXER-SETTLER TYPES

Using a four-stage mixer-settler unit at mixer speeds between 1200 and 2500 rpm and throughputs between 10 and 150 ml/min, the effect of baffling, pumping, paddle arrangement, and their affect on efficiency was determined.

The use of three small-scale ten-stage mixer-settler units in series to simulate extraction-scrub-strip cycles for thorium purification with 30% TBP in diluent 3-1/2 in. wide, 4 in. long and 6 in. deep produced stage efficiencies of 80% for extraction (Table 4). Studies results in the following design recommendations for mixer-settler units.

- mixed phase port height: 1/4 to 1/2 in. above interface,
- mixed phase baffle: 1-1/2 in. wide and not less than 1 in. high,
- mode of heavy phase: entry to mixing compartment - false bottom with a 3/4 in. diameter hole,
- effect of paddle type impeller position: best mixing with tube 1/2-in. above mixer base and impeller 1/8-in. above tube, and
- effect of blades: for blades 1/4-in. wide by 1/2-in. high on a 1/4-in. diameter shaft, the optimum speed is 400 rpm.

TABLE 4. Stage Efficiency in a 10-Stage Mixer-Settler

<u>Operation</u>	<u>Stage Efficiency, %</u>
Extraction	80
Scrubbing	80% near feed point to 20% at product end and 50% for stripping

A 10-stage critically safe mixer-settler was tested and the effects of operating variables were found to be:

- Three-fold increase in the aqueous flow rate caused a rise in interface height of less than 0.4 in. for each stage.

- Impeller speeds between 250 and 350 rpm had no effect on interface level. Operation was poor above and below the above values.
- Capacity was very sensitive to minor changes in impeller height.

The use of a 6-in. diameter mixer in a barrel to determine the effectiveness of the extraction of uranium from a 1-g/ℓ solution by a 0.1M solution of a long chain amine showed that greater than 90% stage efficiency was obtained with a power input of 6 hp/1000 gal and a residence time of up to 1.5 min.

A number of radioactive runs were made in a miniature mixer-settler unit using both the Purex and Thorex flowsheet. The Purex runs showed a uranium loss of 0.007%. Stage efficiencies of 65% for extraction and 77% for stripping were obtained. The waste losses in the Thorex runs were 0.19% for uranium and 0.07% for thorium.

A conventional mixer-settler unit was tested to determine its effectiveness in recovering copper from a 0.05 to 0.1 g copper/ℓ solution by extraction with 5 to 11% ion exchange resin dissolved in kerosene. An impeller of double-shrouded backward-swept vane design was located in the center of the mixing compartment. A correlation of $N^3 D^2$ where N is the impeller speed in revolutions per second and D is the impeller diameter in feet showed that stage efficiencies approached 95% at $N^3 D^2$ values above 80.

The system used was 45 g copper/ℓ plus 0.5 g sulfuric acid/ℓ-40 vol% LIX 73 in kerosene. Organic-to-aqueous flow ratios were 11.25 for extraction and 3.0 for stripping. Under these conditions, extraction and stripping efficiencies were 75 to 85, and 85 to 95%, respectively. Under organic continuous mixer conditions, there is an increase in efficiency when the organic/aqueous ratio was decreased from 1:1 to 1:4. Under aqueous continuous conditions, efficiency increased when the organic/aqueous ratio was raised from 1:1 to 3:1. Under organic continuous mixer conditions, the amount of organic entrainment in the aqueous phase was independent of the operating organic-to-aqueous flow ratio (O/A). With the aqueous phase

continuous conditions, organic entrainment in the aqueous phase is constant from an O/A value of 4:1 to an O/A value of 1:1, but then increased very sharply. By contrast, aqueous entrainment in the organic phase does not appear to be strongly affected by the O/A ratio with the aqueous phase continuous. For more information see bibliographic entries 4, 5, 15, 23, 71, 90, 94, 104, 122 and 128.

4.0 CENTRIFUGAL CONTACTORS

The centrifugal extractor is a horizontal countercurrent liquid-liquid contacting device consisting of a series of concentric stages in which both mixing and settling are accelerated by a variable centrifugal force field.

4.1 SAVANNAH RIVER DEVELOPMENT

A 5-in. centrifugal extractor was tested with 1.2 M $\text{Al}(\text{NO}_3)_3$ - 6% TBP system in ultrasene. Several conclusions were drawn.

- The volume of entrained air in the liquid increases with liquid discharge rate up to values of 40% air, but has little effect on efficiency.
- Between 600 and 1800 rpm the capacity of the unit varies with the 0.8 power of the rotor speed.
- At a rotor speed of 1800 rpm, the unit had a capacity of 6.5 gpm at an A/O ratio of 1.5 and a capacity of 11 gpm at an A/O ratio of 6.
- Interface solids had little effect on capacity.

The major operating characteristics of a versatile 16-state centrifugal contactor are: residence time, mixing intensity, and centrifugal force in the settler. The residence time varies with throughput and organic-to-aqueous flow ratio. Mixing intensity varies with the agitator speed, throughput, and flow ratio.

The first Purex extraction cycle was adapted to short-residence contactors. Performance with an organic-phase residence time of 4 sec/stage was equivalent to performance normally obtained with conventional mixer-settlers. Purification of uranium and plutonium was excellent (gamma decontamination factor greater than 10^4), and cross-contamination of uranium and plutonium was negligible. The tests included a demonstration of satisfactory performance with solvent that had been exposed to typical levels of radiation for about 300 hr. The following characteristics of the process were also observed:

- Zirconium-niobium decontamination increased almost linearly with increases in the irradiation level of the fuel.

- Excessive dibutyl phosphate did not form at elevated temperatures.
- Maximum solvent saturation at the feed stage of the 1A bank gave the highest decontamination.

The factors affecting decontamination of the product are listed below.

- Irradiation Level. Decontamination from zirconium-niobium increased almost linearly, as the irradiation level of the uranium increased; decontamination from ruthenium was independent of the irradiation level.
- Temperature. The marked improvement in ruthenium decontamination at elevated temperatures is consistent with previous studies using miniature mixer-settlers.
- Solvent Saturation. Decontamination with two to three saturated stages was as good as that with more than three saturated stages, but decontamination was poor when only the feed stage was saturated.
- Solvent Quality. Decontamination was satisfactory with solvent that had been exposed about 300 hr to acid and radiation fields typical of the 1A bank and an additional 600 hr to acid alone.

The capacity and mass transfer obtained in a five-stage bank of 10-in. diameter centrifugal contactors having a rotor speed of 1745 rpm and using the system 0.5 M nitric acid-30.5 vol% TBP in ultrasene demonstrated that at a throughput of 70 gpm entrainment was essentially constant at 2% between an A/O of 0.2 and 2 and then increases. The contactor was also tested for extraction and stripping efficiency on a Purex flowsheet. Under extraction conditions, the uranium loss was 0.0008%, and under stripping conditions 89 to 94% stage efficiency was obtained. It was also shown that the addition of 5000 ppm manganese dioxide to the feed showed no detectable effect on the separating characteristics of the feed.

Capacity tests were made under simulated ²⁴⁴Cm process conditions for batch extraction, stripping, and solvent washing. In each test, the two

liquid phases were mixed for 30 min in the feed tank with agitation, and the mixed-phase feed was jetted immediately to the centrifugal separator at 40 to 50 gpm.

- Feed tests with a pump showed that the capacity of the centrifuge exit line to the waste tank is about 60 gpm. The capacity of the exit line to the product tank is more than 65 gpm.
- Delivery of the separated organic liquid to the collection tank was equally satisfactory through either the open line or the sealed dip leg with a 1/4-in. diameter vent hole above the solution level.
- The extraction, stripping, and solvent washing solutions were centrifuged as thoroughly mixed (>4.2 hp/1000 gal) emulsions to determine the liquid entrainment in each endstream. To maintain $<0.5\%$ liquid entrainment in both endstreams, the feed rate should be <25 gpm at 25°C , and <30 gpm at 45°C . A clear stream at higher rates can only be obtained by increasing air pressure on the centrifuge weir.

It was concluded from the performance of an 18-stage bank of centrifugal mixer-settlers that the units would have the following advantages over pump-mix mixer-settlers:

- reduced exposure of solvent to radiation,
- reduced aqueous and solvent inventories,
- reduced space requirements,
- easier flushing for process changes,
- greater safety in handling fissionable materials, and
- accommodation to a wide variety of process solutions with varying densities and viscosities.

Other conclusion are listed below.

- The hydraulic capacity of centrifugal mixer-settlers is not adversely affected by aqueous-phase acid concentrations as low as 0.01 M HNO_3 .
- The method for detecting a rotor failure and the procedure for flushing a unit containing an inoperable stage are satisfactory.

- The air-weir pressures required to control the location of the emulsions can be predicted for any system.
- The centrifugal mixer-settler performance is not impaired by 5000 ppm of solids in feed solution.

Tests with nonradioactive low uranium concentrations (waste end of the Purex extraction bank) showed satisfactory operation at rates equivalent to 8 to 27 tons of uranium/day. More concentrated feed, tested under Purex extraction - scrub conditions, showed that at rates between 8 and 16 tons of uranium/day:

- higher air pressures were required on the weirs,
 - cocurrent stage efficiencies approached 100%
 - less than 0.03% of the uranium remained in the waste stream,
 - less than 0.3% entrainment occurred in each end stream,
 - mechanical reliability has been excellent,
 - the automatic control system performs well,
 - the total shut down time is one hour per use versus 5 to 6 hr for a pump-mix mixer-settler,
 - steady-state operation can be obtained in 20 min versus 16 hr for a pump-mix mixer-settler, and
 - retention of fission products in the solvent was markedly reduced.
- For more information see bibliographic entries 54, 70, 95, 124 and 125.

4.2 ARGONNE NATIONAL LABORATORY DEVELOPMENT

The capacity of a long-rotor centrifugal contactor can be correlated by the equation:

$$\text{Capacity} \propto \frac{N_C^2 D_b^3 L}{10^5 N_m D_m} \quad (2)$$

where N_C = rotor speed, rpm
 N_m = mixing speed, rpm
 D_b = rotor I.D., in.
 D_m = mixing paddle diameter, in.
 L = settling length in rotor, in.

Tests were carried out with an aqueous phase of 0.5 M nitric acid and an organic phase of 30 vol% TBP Ultrasene. Capacities at an A/O ratio between 1 and 2 were 5 and 8 gpm at rotor speeds of 2000 and 3500 rpm, respectively. At an A/O ratio of 4, the capacity increased to 9 and 17 gpm at the above rotor speeds. Entrainment was 1% or less under all conditions. With 0.46 M uranium and 0.68 M nitric acid as the aqueous feed and 30 vol% TBP in ultrasene as the organic feed, an A/O = 1, a rotor speed of 3000 to 3500 rpm, and a feed rate of 4 to 7 gpm (sum of phases) a staged efficiency of 96 to 100% was obtained.

A Savannah River model centrifugal contactor was modified to operate in the annular mixing mode by: 1) removing the mixing chamber, paddle, radial baffle and nozzle plate, 2) attaching a bottom section having a baffled plate, and 3) attaching the organic and aqueous ports to side inlet. These changes result in mixing occurring as the solutions flow downward through the annulus between the rotor and the casing. Capacity tests using the 0.5 M nitric acid:30 vol% TBP system in ultrasene were conducted at A/O ratios of 0.25 to 4 and rotor speeds of 2500 to 3500. The capacity was about the same as for the unmodified unit except that the minimum capacity occurs at a higher A/O ratio. Efficiency tests with a rotor speed of 200 to 3500 rpm, and A/O of 1, and a flow rate of 4 to 7 gpm showed a stage efficiency between 97 and 100%. The annular design retains all the desirable features of the Savannah River design plus:

- being more adaptable to remote maintenance
- having a simpler rotary seal for interface control
- having a motor, spindle, and rotor assembly which can be removed as an integral unit.

For more information see bibliographic entries 12 and 13.

4.3 MULTISTAGE CENTRIFUGAL CONTACTORS

The Robatel contactor consists of a series of fixed, circular plates that are fitted perpendicular to the axis to form a vertical train of compartments. An eight-stage device having maximum flow rate of 100 l/hr showed

about seven theoretical stages for extraction and five to six stages for stripping when tested with cold uranium. At rotor speeds above 2500 rpm operation was generally poor. During extraction-type operation waste losses ranged between 0.1 to 0.5 mg uranium/l. Waste losses during the stripping runs were 4 to 16 mg uranium/l.

Radioactive runs carried out at a rotor speed of 1500 rpm gave the following results:

- extraction waste loss: 0.2 mg uranium/l, 0.0- mg plutonium/l (A/O = 1.3),
- extraction stage: 6 for uranium, 7 for plutonium,
- stripping waste loss: 1 mg uranium/l (A/O = 1), and
- overall decontamination (β, γ)-extraction plus scrub: 5000.

An industrial scale unit (5500 lb/hr total throughput which is equivalent to 8 tons of uranium processed per day) was also tested. It was found that efficiency is relatively insensitive to flow rate but that it is dependent on the uranium content of the feed. For more information see bibliographic entry 11.

4.4 MISCELLANEOUS CENTRIFUGAL CONTACTOR DEVELOPMENT

LuWesta, DeLaval, and Podbielniak contactors vary in size from a 16 to 60 in. diameter and can handle throughputs of from 0.06 to 600 gpm.

A quadronic centrifuge (i.e., a horizontal shaft device) is capable of operation with feeds of 250 to 365 gpm, flow ratios (A/O) from 100/1 to 1/100, and rotor speeds from 500 to 5000 rpm. In order for the unit to accommodate varying feed conditions, the adjustments needed are shown in Table 5.

TABLE 5. Adjustments Necessary for Variable Feed Conditions

<u>Feed Variable</u>	<u>Operational Variable</u>
Δ Specific gravity	Rotor speed
Viscosity	Orifice adjustment
Surface tension	Orifice adjustment
Emulsifiable liquids	Use of gradient orifices
Capacity	Change in rotor speed; orifices or clarification zone

An equation to define the inlet pressure requirements for a centrifugal contactor is:

$$P_{LLI} = P_{HLD} = (0.5) 10^{-6} (R_{LLI})^2 N^2 (\Delta G) \quad (3)$$

where

P_{LLI} = pressure of light liquid in

P_{HLO} = pressure of light liquid out

R_{LLI} = radius from shaft centerline, in.

N = rotor speed, rpm

ΔG = specific gravity difference.

A laboratory-size Podbielniak extractor was used as a Purex IC contactor. The unit had a capacity of about 300 ml/min and 450 ml/min at rotor speeds of 3000 and 5000 rpm, respectively. When the aqueous-to-organic phase flow ratio was decreased from 1.5 to 1.0, the uranium loss increased from 0.1 to 2%. The uranium loss was also sensitive to rotor speed and choice of continuous phase.

A similar unit was tested under Purex extraction conditions. Uranium in the raffinate and holdup were found to be a function of $\Delta p/w^2$ where Δp is the pressure. At values of $\Delta p/w^2 = (2 \times 10^{-6} \text{ to } 5 \times 10^{-4}) \text{ [lb force/in.}^2 \text{] [min/sec]}^2$ no flooding occurred. The unit showed 0.5 transfer units (1.5 theoretical stages). Extraction was found to improve as: 1) $\Delta p/w^2$ decreases, 2) flow rate decreases, and 3) rotor speed decreases. The lowest uranium loss was 0.05% at a flow rate of 200 ml/min, 3500 rpm rotor speed and a $\Delta p/w^2 = 2.5 \times 10^{-6}$.

The third investigator used the system of acid-isoamyl alcohol-water to test a Podbielniak "PuP" unit which had a capacity of 450 ml/min sum of the phases. With a heavy phase flow of 100 ml/min, and a light phase flow of 100 ml/min, 2.5 stages were obtained, and there was no dependence on rotor speed in the range of 3000 to 5000 rpm. With a heavy phase flow of 100 ml/min and a light phase flow of 200 ml/min, 4.5 stages were obtained at the above rotor speeds.

Flooding of centrifugal contactors can occur when the throughput is excessive or by movement of the principal interface to either the inlet or the outlet points. The flooding limits can be predicted by the following equations:

$$(P_{Lo})_{\text{heavy phase flooding}} = 3.86 \times 10^{-6} w^2 \text{ lb force/in.}^2 \quad (4)$$

$$(P_{Lo})_{\text{light phase flooding}} = 0.447 \times 10^{-6} w^2 \text{ lb/in.}^2 \quad (5)$$

Extraction studies demonstrated that for $P_{Lo} = 20$ to 80 psig, a flow ratio $O/A = 1.5$ to 2 and a total flow equal to 250 to $300 \text{ cm}^3/\text{min}$, 2 to 3 theoretical stages were achieved in the contactor. The advantages of centrifugal contactors are indicated to be that they can operate with a low specific gravity difference, have a low holdup and a high throughput. These combine to permit a very rapid approach to equilibrium. For more information see bibliographic entries 14, 29, 44, 45, 61, 78, 113 and 114.

5.0 MISCELLANEOUS CONTACTORS

A wide variety of contacting devices are available in addition to those mentioned in the preceding sections. Inasmuch as they have never been used in radioactive service and experience has been limited to a very small diameter column, only a brief description of the devices will be given.

- An extraction column compartmented by horizontal plates, agitated by mixing impellers on a vertical shaft, and baffled by vertical members.
- A column containing eight stainless steel or polyethylene plates. Each plate had 59 1/8-in. diameter holes which gave a free area of 6%. An upcomer, extending either 2 or 4 1/2 in. above the plate, accounts for an additional 5% free area.
- Tests were conducted using: extraction column packings of 1/2-in. diameter spheres, 3/4-in. diameter spheres, 0.25-in. Raschig rings, 0.25-in. polyethylene pellets, 0.75-in. spheres randomly packed in an orthorhombic arrangement and in a rhombohedral arrangement.
- Column hold-up was determined and correlated for Raschig ring and Intalox saddle packing.
- A column utilizing uniformly spaced, horizontal tubular jetting and intake rings at the center and periphery of several cross-sections involves a large amount of rotating equipment.
- The effect of pulsing on a rotating disc contactor showed that the maximum efficiency is greater than for pulsing alone.

For more information see bibliographic entries 2, 51, 62, 68, 83 and 119.

6.0 COMPARISON OF CONTACTORS

A number of studies have been made on viable contacting devices. They indicate that pulse columns, mixer-settlers, and centrifugal contactors are the contactor types to be considered in the design of a nuclear separations plant based on solvent extraction technology. Each type may be considered proven, and each type has some advantages and disadvantages with respect to the other. Therefore, the choice to be made is by no means clear-cut. It must be made with a high degree of dependence on the background and particular needs of the user.

An in-depth comparison has been made of packed columns, pulse columns, mixer-settlers and centrifugal contactors as the contactor for the first cycle in the Purex Process. As shown in Table 6, contactor operation, maintenance and design considerations were addressed. In the opinion of the authors, columns appear to be favored in several categories, but mixer-settlers or centrifugal contactors are favored in others. Thus, no clear-cut choice is indicated.

During considerations of the contactor type to be used in the Hanford Purex Plant, it appeared that a mixer-settler type contactor is slower to recover from an operating upset, therefore producing larger quantities of off-specification material for a given upset. Also, there are certain conditions under which a mixer-settler could be operated to give rise to criticality problems. Additional test work would be required to furnish full process information on a mixer-settler unit sized for the proposed plant. A memorandum presented the comparison of mixer-settlers and pulse columns from the standpoint of operability and maintenance. These considerations are given in Table 7.

Efficiency and capacity studies were carried out in a 4-in. diameter pulse column packed with 1/2-in. ceramic Raschig rings using the uranyl nitrate:20% TBP system. Pulsing improved the efficiency of the column by about 5-fold. Capacity studies utilized the water-20% TBP system in the

TABLE 6. Comparison of Liquid-Liquid Extraction Contactor Types

A. OPERATION

Operation	Packed Column	Pulsed Column	M/S	C-C
1. Start-up - Shut Down	4 Volume Changes Pulse Columns Slightly Favored			
2. Mechanical	1 Interface	1 IF Columns Favored	Multiple IF	Rotor speed and back pressure controlled
3. Difficulty of start-up after shut-down of short duration		Procedures adequate, no waste loss increase. Equilibrium easily recovered		Rapid start-up, no waste loss
4. Extended Shut-Down		Radiation Damage Minimal	Radiation damage may be appreciable	Minimal radiation damage
Steady-State Operation				
1. Types of Maladjustment not common to all	Variation of interface position	Variation of interface position. Loss of pulse generator	Variation of interface position and agitator speed	Variation of rotor speed and back pressure
2. Mechanical control and adjustment required	One IF control	One IF control and simple instrumentation for pulse generator	Several IF position. Simple instrumentation required for agitator	Simple instrumentation for rotor drive and back-pressure
Packed Column Slightly Favored				

B. MAINTENANCE

1. Plugging	No problem	?	?	May require flushing
2. Moving Parts	None	Comparison Incomplete		
3. Electrical Service	None	Pulse generator	Multiple agitator and seals	Seals rotor bearings
4. Total Replacement	50'H. Replacement possibly by existing technology	Pulse generator	Multiple circuits for agitator mechanism	Simple circuit for prime mover
		Maximum height 27'. No problem	Bulk and number of contractors. Multiple	Simple and easy
5. Ease of decontamination	Packed column expendable. Package hard to decontaminate.	Column expendable plates easy to decontaminate	Unit not expendable, flushing difficult, torturous	Low volume flushing adequate. Unit inexpensive

TABLE 6. (contd)

	Packed Column	Pulsed Column	M/S	C-C
	Rating: 1 Pulse Column, 2 Packed Column, 3 M/S			
	0.1	0.05		
	In The Pures Process, the Chemical Condition for the Optimum Are Met by All			
	16"D x 50'H	16"D x 27'H	10' x 4' x 16' (20 stages)	6' x 2' x 2'
1. Lower limits of density difference				
2. Size and geometry				
3. Holdup volume	500 gallons	280 gallons	425 gallons	3 gallons
		MS Do Not Require Deep Canyon		
		Small Holdup Advantageous for Short Downtimes		
4. End section design		Methods Demonstrated	None	Seals demonstrated
5. Capacity		Demonstrated at 1.5 TU/day	Not demonstrated at 1.5 TU/day	Capacity to 10,000 gal. per minute available
6. Phase separation		Satisfactory emulsion at small density eff.	Pulsing enhancer phase set, and minimizes flooding from foreign material	Centrifugal source will break emulsion
7. Pressure requirements	25 psi	Unknown due to flow reserve	Low	75 psi
8. Flexibility	Limited by Flooding Rates, Number of Stages and Stage Height. Modified Readily. Flow is inefficient	Column Length Can Be	Stages can be added or removed. Limited by flooding rates at agitator speed	Variation of motor speed and pack pressure will accommodate 10 fold change in density differential

**TABLE 7. Comparison of Pulse Columns and Mixer-Settlers -
The Effect on Operability and Maintenance**

1. Reliability of Equipment

1a. Pulse Mechanism versus agitators (mechanical)

As many as 15 to 20 fractional H.P. agitators per contactor. These are direct drive and over-powered several times. Spare stages provided so that loss of agitators would not cause process difficulty and would allow for a planned shutdown for repair or replacement. All agitators will be in "not" zone.

Only one mechanical unit per contactor, however, unit contains wearing parts such as reduction gear box, gear and rack, and reciprocating piston with rings. Unless pulse generator is spared in place, which involves remote valving problems, failure of unit causes immediate shutdown for replacement. Location in a cold zone would allow for a preventative maintenance program.

Agitators are simple mechanically with bearings and rotating shaft being the only revolving parts.

Comment: There has as yet been no operating experience at Hanford to determine the life and reliability of pulse generators, although several thousand trouble-free hours have been accumulated on an experimental unit. Similarly there is little life experience on pump mix agitator units. However, they are made from standard designs which have been proven to be reliable in industry for many years.

Mixer-settlers are more simple and rugged mechanically and should prove more reliable based on the above points.

1b. Pulse mechanism versus agitators (electrical)

Agitator motor speed control is achieved by use of variable frequency AC current. The speed of all agitators of any one contactor can be varied.

Pulse generator frequency is controlled by a variable frequency AC current supplied by a suitable generator.

Comment: No appreciable difference is apparent.

1c. Columns versus mixer-settler boxes (mechanical)

Mixer-settler is a baffled box about 20 ft long x 6 ft wide x 1 ft deep. No difficulties are anticipated.

Pulse column is a maximum of 20 in. in diam x 40 ft high with perforated plates. Mechanically no difficulties are anticipated.

Comment: No difference is apparent here.

1d. Rangeability of throughput of the contactor.

No data are available regarding the range over which this equipment may be operated; however, other factors being equal, reasonably wide (2 or 3 to 1) operating ranges are required. No appreciable differences are anticipated between the mixer-settler and pulse column contactors.

1e. Ease of start-up and shut-down

Mixer-settler has about 1/3 greater volume; thus, longer start-up and shut-down periods are anticipated.

Pulse columns have less hold up.

Comment: Smaller hold-up is of advantage on extended shut-downs and also for changes in process conditions. Pulse columns are slightly favored here.

1f. Columns versus mixer-settler (quantity of equipment)

Each mixer-settler contactor is an integral unit.

1B pulse column is split into two sections, because of height considerations, with additional pump tank required.

Comment: Mixer-settler favored by this consideration.

TABLE 7. (contd)

2. Maintenance

2a. Effect of canyon height	Mixer-settlers are low units and will have no effect as such on canyon height and may result in canyon height reductions.	Pulse columns are long units requiring cell depth to accommodate them and a high crane for placement and removal. Cell bottom to crane rail distances in excess of 60 ft are regarded unfavorably.
Comment: Unfavorable canyon heights in case of pulse columns is a big point favoring mixer settlers. Excessive cell flow to crane rail distance cannot be accepted.		
2b. Accessibility and replaceability	Relatively compact unit - because of length must be well braced however. Removal of contactor box expected to be very infrequent.	Compact unit main problem in height as above. Pulse generator must be removed first. Removal expected to be very infrequent.
2c. Effect of pulse mechanism on a cold zone.	Not applicable.	Advantages: Allows contact and preventative maintenance to prolong life and enhance reliability of operations. Disadvantages: a) Without installed spare, failure of pulser would still cause shut-down until repaired or replaced, b) location in a "cold" zone would subject that zone to SWP conditions during maintenance, and such a zone would probably end up contaminated.
Comment: Unless all pulsed streams were "cold" streams, the removal of the pulsers from the canyon to a "cold SWP" gallery loses some of its attractiveness.		
2d. Build up of solids in contactor unit.	As currently conceived, mixer-settler units are not flushable or drainable. While the presence of appreciable quantities of solids in the system is questionable at present, flushing and clean-out periodically will be required for accountability reasons.	These units are flushable and drainable. Plugging of the sieve plate holes is not anticipated in light of experimental operations.
Comment: Pulse columns are favored by this point.		
2c. Flushing and decontamination.	Not flushable and drainable, thus not readily subject to decontamination especially with many corners, pockets, etc.	Flushable and drainable but question how successful decontamination would be beyond this. Corners of plates and settling chambers would be impossible to clear.
Comment: Slight advantage to pulse columns; however, in general, decontamination and contact maintenance for repairs is not contemplated for any type of contactor. Vessel failure nil to date. Replacement cost would be only on a comparison basis.		

column packed with stainless steel Raschig rings. It was found that the column had 140% of the capacity of an unpulsed column at an amplitude-frequency product of 30 in./min.

Twenty-five contactor types were divided into the following categories:

Class 1A - Vertical column shells. Phases flow counter-current, one dispersed in the other by a concentric rotating device.

Class 1B - Dispersion produced by reciprocating or pulsing device.

Class 11A - Variants of mixer-settlers except DeLawal and Luwesta which are centrifugal contactors.

Class 11B - Mixer-settlers except that mechanically driven impellers are replaced by ejectors.

The contactors believed applicable to radioactive service are shown in Table 8 and are rated according to their suitability. The more important contactors were judged to be pulsed and rotary columns and KAPL-type mixer-settlers.

TABLE 8. Contactor Comparison

Design/Geometrical Requirements	α, β Activity Only		γ Activity	
	Moderate Number Stages Required	Large Number Stages Required	Moderate Number Stages Required	Large Number Stages Required
	Types 11A or 11B	Type 11B	Types 11A or 11B (w/o mech. seals)	Type 11B
Headroom limited	Air pulsed mixer-settler(a)	Air pulsed mixer-settler(a)	Air pulsed mixer-settler(a)	Air pulsed mixer-settler(a)
	Mechanically pulsed mixer-settler(b)	Mechanically pulsed mixer-settler(b)	K.A.P.L. mixer-settler(b)	
	K.A.P.L. mixer-settler			
	Mensing			
	Edeleanu			
Floor area limited	Gordon Zeigler			
	Holley-Mott			
	Pump-settler(c)			
	Types 1A or 1B	Type 1B	Type 1B	Type 1B
	Air pulsed column(a)	Air pulsed column(a)	Air pulsed column(a)	Air pulsed column(a)
	Mechanically pulsed column(b)	Mechanically pulsed column(b)		
	Rotary disc			
	Oldshue-Rushton			
	Rotary annular(c)			

- (a) Refers to the most suitable type of contactor for a given duty.
 (b) Refers to alternative contactors.
 (c) Refers to other possible alternatives which might prove to be suitable subject to experimental confirmation.

Contactors have been compared on the basis of effectiveness using a size-capacity relationship. The basic assumption is made that space requirements and fabrication costs are approximately proportional to the volume of the contactor. An equation relating contactor effectiveness to number of theoretical stages, residence time, flow rate, and contactor volume was developed. A comparison of contactors is given in Table 9.

TABLE 9. Comparison of Contactors for the System
Acetic Acid - Methylisobutyl Ketone - Water

Contactor	Contactor Effectiveness, hr ⁻¹
Pump mixer-settler ^(a)	43-54
Vertical-stacked extractor ^(b) (Fenske)	114
Turbine contactor ^(c)	~45
Packed towers	
1) Pulsed	33
2) Not pulsed	11.5
Pulse columns (perforated plate)	65
Scheibel column	59
^(a) Second figure based on hydraulic data only. Efficiency data taken only at lower flowrates (first figure).	
^(b) Pilot plant unit	
^(c) Estimated	

A comparison of pulse columns and KAPL-type mixer-settlers was made on radioactive feed to determine their relative performance with respect to decontamination, partitioning and waste losses. It was found that the waste losses from the mixer-settler banks was lower, and the decontamination was slightly higher than provided by the pulse columns. However, the pulse columns produced lower uranium contamination in plutonium and plutonium in uranium.

A collection of scattered data to give a very rough comparison of the general characteristics of some of the contacting devices produced the following generalizations.

- Efficiency increases (reductions in overall column heights) can be obtained in columns that use mechanical techniques to produce dispersion approaching a factor of 3 over nonmechanical input columns such as packed columns can be obtained.
- Mechanical input columns such as pulse, sieve and rotating disc can approach a capacity advantage of at least 2, while maintaining efficiency.
- Although dependent on the particular design, the hold-up or contact times (sum of both phases) are generally under 1 min/stage for mechanical energy input columns while nonmechanical input columns approach 2 min/stage with some as high as 5 to 10 min.
- The wider efficient operating range, approaching a factor of 2 for pulse and certain agitated columns, offers some advantage as well as mechanical simplicity over mixer-settlers.
- Other comparisons and choices are apparently made on the bases of solids content, holdup and kinetics. The final choice, to a large extent, appears to be controlled by familiarity and individual preference.

A survey of the advantages and disadvantages of a variety of contacting units produced the results listed in Table 10.

A comparison of mixer-settlers, packed towers and perforated plate towers, concludes that:

- Mixer-settlers are free of back-mixing and can produce stage efficiencies of greater than 90%.
- Packed towers are intractable devices which suffer from end effects and back-mixing.
- Perforated plate columns are not subject to back-mixing. Extraction occurs during drop formation, the passage of the drops through the continuous phase, and drop coalescence. For best results, neither the trays or the column wall should be wetted by the continuous phase.

TABLE 10. Survey of Contactor Comparisons

Mixer-Settlers

Advantages

1. Good contacting
2. Handles wide flow ratio
3. Low headroom
4. High efficiency
5. Many stages
6. Reliable scale-up

Disadvantages

1. Large holdup
2. High power costs
3. High investment
4. Large floor space
5. Interstage pumping may be required

Differential Contactors (Packed or Sieve Plate Columns Not Mechanically Aided)

Advantages

1. Low initial cost
2. Low operating cost
3. Simplest construction

Disadvantages

1. Limited throughput with small density difference
2. Cannot handle wide flow ratio
3. High headroom
4. Sometimes low efficiency
5. Difficult scale-up

Differential Contactors (Mechanically Aided)

Advantages

1. Good dispersion
2. Reasonable cost
3. Many stages possible
4. Relatively easy scale-up

Disadvantages

1. Limited throughput with small gravity difference
2. Cannot handle emulsifying systems
3. Cannot handle high flow ratio

Centrifugal Extractors

Advantages

1. Handle low gravity difference
2. Low holdup volume
3. Short holdup time
4. Low space requirements
5. Small inventory of solvent

Disadvantages

1. High initial costs
2. High operating costs
3. High maintenance costs
4. Limited number of stages in single unit

Characteristics of contactor types are:

- a mixer-settler which can be easily sized and accepts high flow rates. Liquid holdup is high and one mechanical unit per stage is required.
- pulse columns which are easily built, have a low holdup, and reach equilibrium rapidly. The extrapolation from laboratory data to large scale is difficult.
- a centrifugal contactor which has a short residence time, low holdup, and can be started up or shut down rapidly.

Estimated relative construction costs for a plant to process 5 tons of uranium/day would be:

- Mixer-settler 1.10
- Pulse column 1.05
- Centrifugal contactor 1.0

Irradiation tests on TBP resulted in the conclusion that because of the relatively long residence time, mixer-settler units were not suitable for irradiated fuel processing due to degradation of the TBP. On the other hand, the shorter residence time in pulse columns and centrifugal contactors make such contactors a more favorable choice. For more information see bibliographic entries 1, 11, 30, 33, 34, 36, 59, 67, 93, 109, 110, 115, 117, 120, 121 and 127.

SUMMARY

WORKSHOP--EVALUATION OF SOLVENT EXTRACTION EQUIPMENT

SUMMARY
WORKSHOP--EVALUATION OF SOLVENT EXTRACTION EQUIPMENT

INTRODUCTION

On August 5 and 6, 1976 a workshop on solvent extraction equipment was held in Seattle, Washington, at the Battelle Seattle Research Center. The overall purpose of the Workshop was to bring together people of diverse background and experience to collect, evaluate, and document data on solvent extraction process equipment, control, and operation as applied to the nuclear industry. Thirteen of the 16 participants had worked in a nuclear fuels reprocessing plant at some time.

OBJECTIVES

The group developed the following list of objectives.

- Assess the current state of the technology; its main issues, problems, and deficiencies.
- Determine the potential of each contactor type and develop criteria for contactor selection according to flowsheet variations.
- Compare actual production plant experience (largely undocumented) with documented pilot plant experience to determine if product plants operate as predicted by pilot plant data.
- Identify design and operational failures since these have not been documented as extensively as the successes.
- Enable participants to learn from the experiences of others by providing an opportunity for improved communication among the various ERDA (Energy Research and Development Administration) contractors, each of which is working on a different aspect of the fuel recycle program.
- Obtain feedback on the literature search document and identify articles and other sources that should be included.

ISSUES

A list of the issues of importance in radiochemical processing was developed and the items were roughly grouped into three categories: design, performance, and auxiliary systems. Those judged most significant included:

1. Performance issues
 - a. Solids handling: tolerance for solids, handling of interfacial crud, bases for deciding which phase should be continuous.
 - b. Solvent damage
 - c. Application of pilot plant work to production plant operation
2. Design issues
 - a. Remote maintenance
 - b. Criticality
 - c. Criteria for selection of different contactor types including equipment availability
 - d. Instrumentation for process control and for safeguards
3. Auxiliary systems issues
 - a. Feed clarification
 - b. Solvent washing
 - c. Phosphate (TBP, DBP) removal

INTRODUCTORY PRESENTATIONS

Several participants gave introductory presentations about current projects dealing with some of the issues of concern listed on Page . These presentations are summarized in the following subsections.

LWR RECYCLE PROGRAM (A. Jennings, DuPont)

ERDA has recently begun putting together a program to help industry close the fuel cycle. E. I. DuPont's Savannah River Laboratory (SRL) has been selected as the lead laboratory in the R&D effort for light water reactors (LWR). The approach will be to involve all of the ERDA facilities and to have the work done where the expertise is located.

To consolidate the work, the DuPont study team will translate the data it collects into a conceptual design study for closing the fuel cycle. The study itself will not involve new R&D; rather it will develop a conceptual design based on existing technology. However, a conceptual design study is a highly effective way of pinpointing areas that need additional R&D.

Members of the study team hope that the present workshop will provide them with documentation of actual production plant experience. Information on process requirements is available from the R&D currently being done; data on equipment design, however, must be obtained primarily from experience. Although some design information is available, it is at least 15 years old. DuPont has had no experience with pulse columns, and all available documentation represents pilot plant experience. Therefore, information is needed about how the equipment works in a production plant.

A prime factor to be considered in the conceptual design study is equipment reliability. Unreliable equipment can greatly increase the cost of building and operating a fuel reprocessing plant, as it results in the need for redundancy to keep the plant operating. Since DuPont's Engineering Department estimates the current cost of building a remotely maintained and operated canyon as \$1 million/linear foot, equipment design must take

all cost-influencing factors into account. The efficiency of the equipment, on the other hand, does not seem to affect cost much, at least with respect to mixer-settlers. The difference between 75% and 95% processing efficiency does not seem to be important.

LMFBR RECYCLE PROGRAM (B. Vondra, ORNL)

The LMFBR (liquid-metal fast breeder reactor) program deals with those areas in which LMFBR fuels differ from LWR fuels: higher burnups, larger quantities of plutonium and different types of cladding. Since constraints on containment will probably be far more stringent by the time an LMFBR plant is in operation, the program is also concerned with the complete containment of off-gases and all other effluents.

The program schedule is as follows: component development and scaled-up equipment tests are currently underway; cold integrated prototype equipment testing is scheduled for startup in 1979, with a completion date of 1981; and the hot pilot plant is scheduled for startup in 1988.

The differences between LMFBR and LWR fuel reprocessing are principally a matter of degree, i.e., the quantity of fission products, the amount of radiation, the quantity of insolubles, and the separation of plutonium. Related issues include: 1) the storage, transportation, and other head-end operations involving leaking fuel rods, 2) whether flowsheet will be required to yield plutonium-free uranium or uranium-free plutonium, or whether a combined product will be acceptable, and 3) the importance of dealing with the fuel cycle as a whole rather than just a segment of it.

EVALUATION OF SOLVENT EXTRACTION EQUIPMENT (D. Lester, PNL)

A project on evaluation of solvent extraction equipment was begun in April 1976. The current phase of the project will conclude in November of this year, at which time a report will be published. The main objective of the project is to provide an information base to aid in contactor selection and design. Other objectives include:

- gathering and summarizing the relevant literature,
- critiquing, interpreting, and adapting the information in the literature,
- developing unpublished sources--letters, verbal comments, and experience,
- identifying needs for more information, and
- combining all of the above and presenting the information in a single, usable source.

The workshop is expected to contribute to attaining these goals.

The literature search and organization of the workshop have been completed. The initial production of the search was somewhere between 1,000 and 2,000 citations. These sources were then screened by a review of abstracts and/or the citations themselves to eliminate duplications and material irrelevant to solvent extraction equipment. The screening reduced the number of citations to the 128 discussed in the literature search document.

The document that will be the product of the current phase of the project will have two major parts: 1) a core document that includes some introductory background material, and 2) a summary and critique that contains the salient supporting information and addresses R&D needs. The core document will be written so that it can be used alone. The second part will provide the backup information and will include an annotated bibliography, a listing of the original 1,000 to 2,000 citations that were originally gathered, the proceedings of this workshop, and the literature review document mentioned above.

LITERATURE SEARCH (R. Geier, ARHCO)

The purpose of the literature review was to provide a compendium of what has been done, to be used by those planning additional work in the field. Following the selection and screening process described by D. H. Lester, a summary was written for each entry, describing the equipment or system that

was tested and the test results. No interpretation of the data was provided other than that of the author, and no attempt was made to evaluate authors' interpretations.

Several questions were raised as to why certain entries were or were not included. The omission of the Purex Technical Manual⁽¹⁾ was of particular concern to some participants. Other concerns were that: 1) the document gives the same weight to purely academic treatises as to those that are applicable specifically to radioactive processing, and 2) some statements that are now considered invalid may have been included in the document due to the lack of critical review.

DISCUSSION OF ISSUES

CONTACTOR TYPES

Pulse Columns

Pulse columns for radiochemical separations range up to 40 ft high, depending upon the operation to be performed. Column diameters up to 34 in. have been used.

Design Standards

The question was raised as to whether pulse column design was still an art, or whether it could now be considered a science. Although participants agreed that it was generally preferable to be able to make at least a limited number of small scale runs, they felt that some standard criteria could be specified. The relationship between plate spacing hole diameter, free area, pulse frequency and pulse amplitude were debated by the group. It was observed that established designs are available for pulse columns, and that there have been no significant new design changes for some time.

Design Problems

One problem that can occur with pulse columns is that, after a period of time, plates can become dispersed-phase wet and decrease performance. One solution is to keep the plates wet all the time. Another is to flush the columns periodically.

The diameter of the line connecting the pulse generator to the column can also be a critical factor in pulse column operation. For a mechanical pulser, if the line is too small, cavitation can result. For an air pulser, however, this is no problem.

CENTRIFUGAL CONTACTORS--ROBATEL TYPE

The Robatel centrifugal contactor is capable of driving 8 to 10 stages with a single motor. It has a low tolerance for solids, a high cost (\$1,000), and a relatively high holdup time (1.6 min). Furthermore, when it is run at

high speed with low flow, it will overheat, possibly to the point of exceeding the flash point of the solvent. It cannot be used at all at less than one-half its rated capacity and, for best results, it should not be run below its rated capacity.

CENTRIFUGAL CONTACTORS--SAVANNAH RIVER TYPE

DuPont designed centrifugal contactors that are currently in use at SRL have discrete mixing and settling stages. The contactors are installed in groups of six. In the extraction process, the aqueous and organic phases first mix then separate as they travel upward, each discharging into separate annular rings.

Removability

Each motor is independently removable, and the flange, air seal, and hollow shaft come out. The bowl, paddle, and fixed shaft remain in the contactor.

Interface Control

Interface control is achieved through air pressurization of a weir chamber which makes it possible for the unit to handle a wide range of TBP concentrations. The pressure variations can be measured at each individual stage, so that if, for example, a seal leaks it can be detected.

Seals

If the units are not sealed at the top, they pump air. The resulting surges and air bubbles can create serious operational problems.

Reliability and Repair

The contactors have been in service since October 1966 for primary decontamination of the Purex feed. During this time, they have accumulated around 1,000 hot-feed operating days. There have been about 27 mechanical failures, primarily of the mechanical seals and bearings, with a few motor failures. Of the 18 stages in use, no one stage has had more than four failures, and the three most radioactive have never failed at all.

Insulation failures have occurred on both power supply jumpers and wiring harnesses for all three six-packs; in all cases, repair and replacement has been successful. The two major failures which have occurred stemmed from cracks that had developed in the piping as a result of fatigue and vibration.

Use as Only Contactor Type in Plant

There are both pros and cons to using these units as the only contactors in a plant. Cost is a negative factor: pump mixer-settlers, for example, are far cheaper. On the other hand, quick startup is a definite plus. With respect to the failure rate, opinions are mixed.

Design Improvements

It was pointed out that this contactor was intended to be an experimental unit, and many design improvements are still possible.

CENTRIFUGAL CONTACTORS--ARGONNE TYPE

Argonne developed several modifications for the Savannah River centrifugal contactors in order to both increase their capacity and make them critically safe. The first objective was accomplished by increasing the bowl length and the speed; the second, by decreasing the bowl diameter.

Annular Design

Argonne National Laboratory (ANL) decided that one way to simplify both construction and operation would be to eliminate the mixing chamber. Side inlets were added to the unit to feed the aqueous and organic phases directly into the annulus between the rotor and the casing. After making these and other changes, the unit was run at as high as 15 to 17 gpm (gallons per minute); however, this rate was achieved at a phase flow ratio which is not realistic for the Purex process. The design changes led both to simplified maintenance and steadier hydraulic operation.

Organic Holdup Time

At a rate of 10 gpm, the residence time for both phases would be about 3 sec/stage. Normally, equal volumes of organic and aqueous phase were used. The interface location can wander especially if the unit is operating below maximum capacity. As long as the interface stays between the organic overflow weir and the aqueous underflow weir, the output streams will not be contaminated.

SOLIDS HANDLING

Redox Plant Experience

When built, the Hanford Redox plant was capable of processing 3 to 4 tons of uranium/day. The disengaging section of the packed extraction columns had a diameter twice that of the 6-in. packed section. An overall decontamination factor of 6.5 was achieved. In 1954, extra capacity was needed and the column diameter was enlarged to 8 in. To achieve a higher residence time for the organic phase, the disengaging section was enlarged; however, because of space constraints, it was enlarged eccentrically. This change in the geometry of the disengaging section resulted in the overall decontamination factor dropping to 5.8.

The poor decontamination resulted from the location of the interface. With the concentric configuration, the fission product bearing solids which accumulate at the interface were forced downward so that there was very little entrainment in the organic stream. The bathtub shape, however, created a nonuniform hydraulic condition that caused the solids to accumulate in the end section along with a pocket of stagnant scrub solution, and the stagnant scrub solution precontaminated the fresh scrub solution. Lowering the interface 3 ft produced an overall decontamination factor of 7.1.

Purex Plant Experience

In the Purex plant, the 2D extraction column (final uranium cycle) was run first with a top interface and then with a bottom interface. It

was found that a top interface caused a reflux of solids, resulting in lower decontamination factors. Good decontamination factors were achieved when the column was run with the organic phase continuous allowing the solids to go out the bottom with the waste.

Thorex Plant Experience

At the General Atomic Thorex pilot plant, extraction pulse columns are run with a bottom interface and solids, consisting of finely divided silicon carbide and carbon, present no problems.

Interfacial Crud Formation

No matter how clear the feed streams appear to be, solids will always appear at the interface, presumably from siliceous materials in the water supply and/or fuel impurities. In a reprocessing facility where the condensate is recycled, interfacial accumulations may never be a problem. However, recycling poses a problem of its own: if the condensate treatment system is not adequate, impurities will be fed back into the contactor, perhaps causing a variety of difficulties, not the least of which may be inadequate decontamination.

Mistron

A technique developed at Hanford for use in the Plutonium Reclamation Facility was the use of Mistron, a finely powdered talc, to counteract the lowering of capacity that tends to occur with the buildup of interfacial scum. In an organic-continuous column, the addition of Mistron to the aqueous scrub stream will raise the capacity significantly. A layer of Mistron emulsion forms at the interface, but eventually works its way out in the aqueous raffinate.

Mixed Plates

A mixed-plate pulse column cartridge consists of alternating stainless steel and plastic sieve plates. Its effect on solids is to trap the particles, move them up, and hold them at the top plate. The usefulness of a mixed-plate cartridge is not universally accepted since mechanisms exist to partially negate its effectiveness and stainless steel nozzle plates offer a potential alternative.

Plastic Plates

Linear polyethylene, selected specifically because of its radiation resistance, was found to become brittle after prolonged use, even in cold pilot plant testing. Since a capability for plate flexing is mandatory, this form of plastic had to be abandoned. Fluorothene has also been used with some success. It has less radiation resistance than some forms of plastic, and tends to develop crud deposits, but it does stay intact.

Interfacial Slurpers

Various techniques have been developed for removing interfacial scum. One, an interface "slurper", was developed in The Hanford Plutonium Reclamation Pilot Plant Facility. This device made use of a filter and coalescer to remove the solids. Afterwards, the phases were separated and directed back into the column.

Flushing

In mixer-settlers, interfacial buildup will form in spite of feed clarification, but will not affect performance. After about 1.5 years of operations, however, the accumulation of solids may begin to cause plugging problems. At this point, the system must be exhaustively flushed.

Solids and Safeguards

It was pointed out that, even if a particular contactor type can handle solids, safeguards regulations may permit no solids in the process because of the potential plutonium content of such solids.

FEED CLARIFICATION

The general consensus was that feed clarification using removable equipment is desirable although preferences were expressed for different types of equipment.

Centrifugal

Three types of equipment are used for feed clarification:

- a solid-bowl, batch centrifuge,

- a Robatel remotable batch centrifuge, and
- a Sharples continuous-flow vertical centrifuge.

The plutonium reclamation facility at Hanford had several centrifuges, but they all have to be stopped, dismantled, and scraped out by hand. A commercial continuous centrifuge is also available that does not have to be shut down for sludge removal. The centrifuge opens periodically and, using hydraulic pressure, pushes the sludge out. The unit then closes and begins collection of another batch.

Filters

It was felt that filters would not work well for feed clarification because of the high radiation levels and because of the remotability requirement.

SOLVENT DAMAGE

Solvent damage is frequently cited as a reason for using lower residence time contactors, e.g., centrifugals. One possible reason is that the kinetics of formation of DBP and other solvent-damaging complexes may be such that they do not have time to form when residence times are kept short. Droplet size, which varies among contactor types, may affect the amount of radiation damage that occurs.

At Hanford, a comparison was made between centrifugal contactors and other types. The study showed no significant difference in decontamination loss or solvent damage in one extraction cycle when using feed prepared from either LWR or LMFBR fuel.

At Oak Ridge, solvent damage studies were done on the Thorex process. More solvent damage occurs in a thorium system than in a plutonium system, due to the higher radiation levels involved.

Two questions on the solvent damage issue must be resolved.

1. Will short residence time reduce solvent damage?
2. To what extent is solvent damage a problem with respect to plant operation?

SOLVENT WASHING

A good basic solvent wash (for example a carbonate wash) will dissolve DBP, breakup the metal complexes, and take out the unfixed iodine. However, removal of the fixed portion of the iodine is almost impossible. The washing solution may either be used until all the carbonate is gone (bicarbonate being ineffective), and then be replaced on a batch basis; or a constant pH can be maintained by a feed and bleed method.

Macroreticular Resin

Macroreticular resin is an excellent cleaning agent, although a substantial amount of waste is generated. If a carbonate-washed solvent is given additional treatment, the solvent will come out as good as (or better than) a new batch.

Caustic Washes

A combination of carbonate and caustic washing can be used. It is important that the carbonate be used first to avoid precipitation of the uranium. Mixed carbonate-caustic washing has not proved to be effective.

Type of Contactor Used

Solvent washing can be performed in a variety of types of equipment.

SOLVENT NITRATION

It appears that there is more than one kind of red oil. General Atomic made a type with the use of an NPH diluent that is a highly explosive, concentrated nitrate that detonates at 135°C. Savannah River has made successfully a TBP-uranium complex concentrate as a third phase. The product is yellow when pure, but turns red when it is put in solution with TBP and heated.

VALIDITY OF DEVELOPMENT WORK FOR PLANT OPERATION

Mixer-Settlers

With rotating equipment, where the stages are well mixed, scale-up is relatively easy. DuPont has been successful in going from miniature-scale testing to full plant operation with both pump mixer-settlers and centrifugal mixer-settlers.

Pulse Columns

Presumably, knowledge of pulse columns is such that a pulse column can be designed, and its characteristics known with a great deal of accuracy. Nevertheless, pulse columns are not as easily scaled up as are mixer-settlers.

When a 16-in. diameter pulse column system was scaled up to 20 in., high waste losses occurred. The problem, which stemmed from channeling, was solved by the installation of swirlplate mixers at 3 to 4 ft intervals.

The production plant results with organic continuous pulse column agreed almost exactly with what was predicted in the laboratory concerning solids handling, capacity, operating characteristics, etc.

Solids Tolerance

Many of the problems that occur in the translation of laboratory work to full-scale production plant operation have to do with solids tolerance characteristics, which tend to change with variations in equipment size.

Temperature

It was generally agreed that laboratory work on temperature applies very well to full-scale operation. The production plant results are either the same as or better than the pilot plant predictions.

Need for Cold Testing of Equipment

Difficulties arise in taking a design directly from the laboratory to a full-scale production plant without cold-cell testing. If there is no intermediate step to develop the necessary devices for achieving flow control (adequate agitation, etc.) it is very likely that the equipment will

have to be reinvented after the building of the production plant. This is particularly true if the flowsheet specifies results that are difficult to obtain.

INSTRUMENTATION

In any plant, the proper instrumentation is important to smooth operation. Some of the types of instruments available, as well as those that are still needed, are described below.

Pneumatic Versus Electronic Instrumentation

Idaho Falls currently uses pneumatic equipment for controlling flow, levels, etc. The plant is now planning to convert to electronic equipment, and hopes at some point in the future to computerize. Savannah River has been using a computer for contactor flow control, although tank depletion is still the primary method.

Ratio Control

The Hanford Purex plant was built for ratio control, but the system was never used because there were too many problems with it. At Savannah River, however, the centrifugal contactors use an all-pneumatic system and have no problem with ratio control.

Flow Meters

At Idaho Falls, the low flow rates and the relatively large amount of undissolved solids have led to difficulties in finding good flow-measuring devices. The feed rate to a column is metered by a device in the feed tank which automatically takes the derivation of the liquid level and converts it into a flow rate.

Neutron Monitors

At Hanford, neutron monitors have been installed on the IBX column and on the feed makeup tank to keep track of plutonium concentration. They work well and are very sensitive; however, their primary use is to indicate change rather than to indicate a particular plutonium concentration. Savannah River uses neutron monitors in a similar manner.

Safeguards

Safeguard regulations can affect instrumentation in two ways: 1) they can eliminate certain types of instrumentation that are not sufficiently tamper-resistant, and 2) they can create the need for additional instrumentation. For example, bubbler tubes might be ruled out as a means of measuring density or they might have to be equipped with alarms that are activated by a change in density.

Current Status of Instrumentation

Most of the new instrumentation available today has not been tested in radiochemical service. There is a great need for applications development for all new instruments, particularly for testing their performance in a radioactive zone. Specific interest was expressed in devices for measuring density and for in-line chemical analysis.

COMPARISONS AMONG CONTACTOR TYPES

Contactor characteristics were compared on the basis of the subjects that had been discussed.

Rangeability

For pulse columns, there was some disagreement as to rangeability, although a factor of about four seemed reasonable. Centrifugal contactors are able to handle 20 tons or more, rangeability being limited only by the flow meter. Low flows can be a problem with the Robatel which tends to overheat in such conditions. This problem does not exist with the other types of centrifugal contactors.

It can be said that, between pulse column contactors and centrifugal contactors, there is no significant difference in rangeability.

Residence Time

Pulse column organic holdup on a theoretical-stage basis is under 2 min/stage on the average, and can be as low as 1 min/stage. The range for pump mixer-settlers is about the same (1 to 2 min/stage).

In the centrifugal mixer-settlers, there is a total organic phase holdup of 30 sec. The Robatel controller has a total holdup time of about 1.6 min. When the flow rate of the organic phase is pushed to the maximum (well over the recommended flow rate), the holdup has actually been below 1 min, but never as low as 30 sec.

Solids Tolerance

It was agreed that regardless of contactor type some form of feed clarification is required.

Remotability

Mixer-settlers are fully removable. In the Savannah River centrifugal contactors, the motor, flange, air seal, and hollow shaft are all removable. The Argonne design is similar, but the lower section of the paddle and shaft are removable as well. In the commercial-size Robatels, the internals (rotor and bowl) can be lifted out and replaced remotely.

Maintenance

Of the three contactor types, maintenance costs are probably highest for the existing Savannah River centrifugal mixer-settlers. However, a much simpler unit could be designed without too much difficulty which would be far less likely to have high maintenance costs.

Operation with a Third Phase

Pulse columns have no trouble handling a third phase. This is one area in which this form of contactor may have an advantage over the centrifugal type. The Argonne centrifugal contactor will not work with a third phase. The Robatel can do so, but not without problems.

Diluent or TBP Losses

In a pulse column plant, the TBP concentration tends to decline and has to be added periodically to keep the TBP-diluent ratio correct. When Savannah River centrifugal contactors are used, solvent tends to evaporate and needs to be added from time to time.

Cost

Studies have indicated that the cost of the equipment going into the plant is a very small fraction of the cost of the plant. However, the selection of the contactor type can influence the cost of the cell; for instance, a cell for equipment requiring high head room will cost more than one for equipment that is more compact.

Performance

In general, there appears to be no major performance differences between the various contactor types--they all do the job equally well.

CONCLUSIONS

The consensus was that all of the contactor types work, and that a plant can operate successfully with all pulse columns, all centrifugal contactors, or all mixer-settlers.

CRITERIA RANKING FOR CONTACTOR TYPES

The following list of criteria and their categorization was generally accepted.

Must Be Considered

- Criticality control
- Safeguards control (if mandated by NRC)
- Capacity
- Performance
- Cold testing capability

Very Important

- Impact of contactor choice on total plant cost
- Reliability (maintenance and operating costs)
- Maintenance philosophy/mandate regarding radiation dose

Important

- Cost of contactor plus auxiliary equipment
- Development and engineering effort needed (solvent extraction equipment is generally in good shape; auxiliary equipment needs work)
- Tolerance for solids
- Rangeability, residence time
- Availability of equipment
- Solvent damage, solvent washing (may be a "must"; R&D will tell)

It was pointed out that for a given plant in a given set of circumstances, certain criteria could change category; that is, a criterion that in general is only "important" might, for a particular plant, be a "must".

However, it was felt that the list provides a good starting point for thinking about design considerations in new plants.

NEED FOR MORE RESEARCH AND DEVELOPMENT

There is a need not only for development work, but also for gaining basic process understanding through research. Although most research stopped several years ago, needs still exist regarding many aspects of the solvent extraction process. The solution to a particular problem may be known, but there may be no understanding of why the solution works, or what caused the problem in the first place.

The group outlined the following areas in which R&D is particularly needed:

- In-line analytical equipment for chemical analysis
- Further development of centrifugal contactors
- Feed clarification equipment
- Pulse column capacity (including criticality control)
- Solvent damage
- Applications development of commercial instruments
- Phosphate removal

Between the LWR and LMFBR programs, research is already underway on all of these except pulse column capacity and instrumentation development, and a proposal to do work in these areas is currently under consideration.

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