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AEC RESEARCH AND DEVELOPMENT REPORT

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Chemistry-Separation Processes for Plutonium and Uranium

USE OF THE HIGGINS CONTINUOUS ION EXCHANGE CONTACTOR IN RECOVERING URANIUM FROM AQUEOUS SLURRIES

I. R. Higgins

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CHEMICAL TECHNOLOGY DIVISION

Chemical Development Section B

USE OF THE HIGGINS CONTINUOUS ION EXCHANGE CONTACTOR IN RECOVERING URANIUM FROM AQUEOUS SLURRIES

I. R. Higgins

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1.0 ABSTRACT

Flowsheets are presented for recovering uranium from unfiltered sulfuric acid-- or carbonate-leached ore pulps, at a rate of 100 tons of ore per day, in a Higgins continuous ion-exchange contactor. In the experimental work on which the flowsheets were based, approximately 5 ft of Permutit SK-20 was required to maintain a uranium loss of less than 1% with resin uranium loadings of 40-50 g/liter and feed flow rates of 300-600 gal/hr/ft^2, or with 20 g/liter and a flow rate of up to 900 gal/hr/ft^2. When the loading was 30 g/liter or more, a higher column was required as the flow rate increased, but resin loading was more important than flow rate in determining the column height. Loading column data indicated almost identical performance of the 2-, 6-, and 12-in.-dia contactors.

With the sulfate-loaded resin, product uranium concentrations were 60 g/liter with the 5 M NaCl--water elution scheme, 15 g/liter with 1 M NaCl eluant, and 20 g/liter with 1 M NH_4NO_3 eluant. Reagent consumptions were 0.5 lb of NaCl, 3.5 lb of NaCl, and 4 lb of NH_4NO_3, respectively, per pound of uranium. The elution efficiency of recycled ammonium nitrate was reduced because of sulfate accumulation. The 5 M NaCl was recovered for reuse by removing sulfate with 1.5 lb of $CaCl_2$ per pound of uranium processed. With the carbonate-loaded resin, elution with 1 M $NaHCO_3$ gave a product containing 25 g of uranium per liter and used 1.5 lb of $NaHCO_3$ per pound of uranium. With pulps containing 10% suspended solids, 10-20 mesh resin was satisfactory when less than 1% of the solids was sand greater than 200 mesh. With 5% pulps, 20-40 mesh resin was used when less than 1% was greater than 325 mesh.

2.0 INTRODUCTION

A continuous countercurrent ion-exchange flow system is expected to be more efficient and economical than the conventional fixed-bed method. Use of the Higgins continuous ion-exchange contactor, developed at ORNL, is a mechanically simple and reliable method of accomplishing countercurrent flow.[1] The particular ion-exchange process of interest for this study was the recovery of uranium from ore leach solutions. The bases for the adaptation of the Higgins contactor to this application were the standard chemical flowsheets and operating conditions used in conventional fixed beds. With modifications of these chemical flowsheets, the following advantages of continuous over batch operation are expected: (1) Desanded ore pulps may be treated directly, without being clarified; (2) the feed rate may be 3 or 4 times as fast, thus reducing equipment cost and resin inventory; (3) eluting chemicals are utilized more efficiently; (4) higher product concentrations and purity may be expected; and (5) the system is more flexible, i.e., more complex eluting systems, which may be awkward to handle with the batch method, may be used for conservation or recovery of reagents.

This report covers the initial testing of the Higgins contactor on actual ore pulps and should be considered a scouting study. Many flowsheet variations were investigated, during which, about 500 hr of successful mechanical operation was accumulated. Routine flowsheet demonstration is still lacking. Lukachukai, Utex, and Los Ochos pulps from the Grand Junction pilot plant and Mallinckrodt bomb liner slag leach were tested to determine pulp handling characteristics. One molar ammonium nitrate and sodium chloride eluting systems were demonstrated, with ultimate economy and recycle demonstrations still pending. A new and more complex eluting method using concentrated sodium chloride is emphasized, because it promises greater economy and may tie more closely into further processing steps.[2] The carbonate flowsheet was demonstrated with Mallinckrodt magnesium fluoride bomb liner leach, but would apply also to carbonate-leached ores. Loading conditions would be almost identical, and elution conditions would be identical. With scrap or ore, the amount handled would be 100 tons/day, but uranium production would be considerably higher with scrap because of its higher uranium content.

Flowsheets are presented for a mill processing 100 tons of ore per day based on runs made in a 2-in.-dia Higgins contactor. These flowsheets may be used as a reference point. Future development will be aimed at higher throughput rates, more economical eluting procedures, and adaptation to additional purification steps.

3.0 EQUIPMENT DESCRIPTION

The mechanical and operating features of the Higgins contactor are discussed in other reports.[1] Briefly, this contacting system (Fig. 3.1) claims mechanical simplicity, operating reliability, gentle and easily metered resin flow, unrestricted throughput rates, and proximity to the ideal minimum stage size. Only a few modifications (Fig. 3.2) are required in order that it may handle pulps nearly as easily as clarified solution. Distributors are designed to eliminate stagnant flow pockets and are installed with flush-out lines. A hydraulic classifier is included to separate any particles which may have been carried or filtered out by the resin bed.

4.0 PROCESS FLOWSHEETS

The flowsheets presented are scaled up to 100 tons of ore per day, based on laboratory data from runs on a 2-in.-dia contactor. Since loading conditions are similar, even for sulfuric acid and carbonate leaches, the flowsheets are designated by the elution method used.

The leach pulps used in the 2-in.-dia column runs were about 10% in suspended solids and contained about 0.75 g of uranium per liter. The ore tonnage was calculated by considering it to be 25% pulp. Most runs were made at feed rates of 450 gal/hr/ft^2, although higher rates are feasible. With a uranium loading of 40 g/liter on Permutit SK-20, recoveries were greater than 99% with 4-5 ft of bed height. Eight feet was considered adequate to include a safety factor. The elution chemical consumptions were scaled up directly from the results on the 2-in.-dia contactor and do not necessarily represent the minimum possible. Eluting

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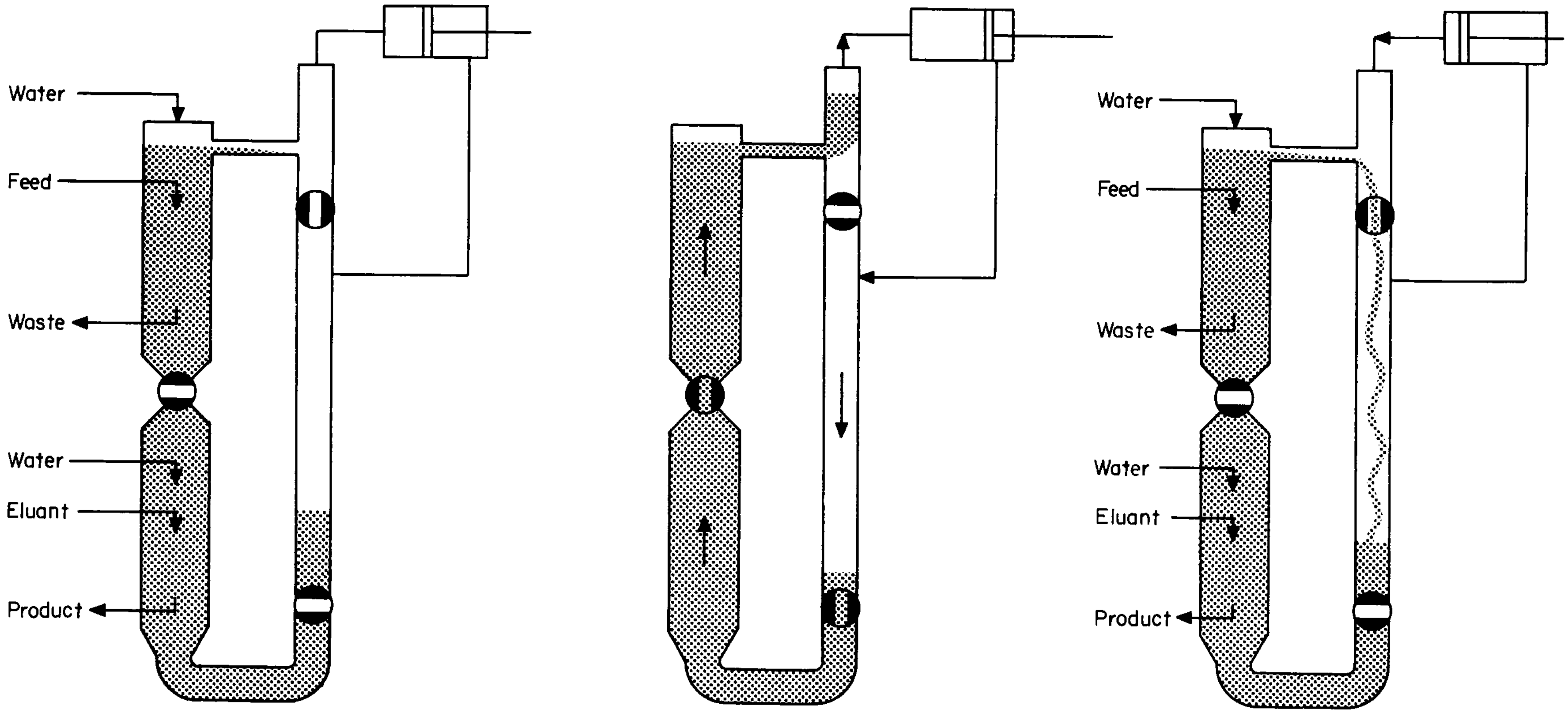

Solution Pumping Period (several minutes)
Pump Stopped

Resin Movement Period (3-5 sec)
Pump Running

Solution Pumping Period (several minutes)
Pump Stopped

Fig. 3.1. Schematic Diagram of Higgins Continuous Ion Exchange Contactor, Showing Mechanism of Countercurrent Solid-Liquid Flow.

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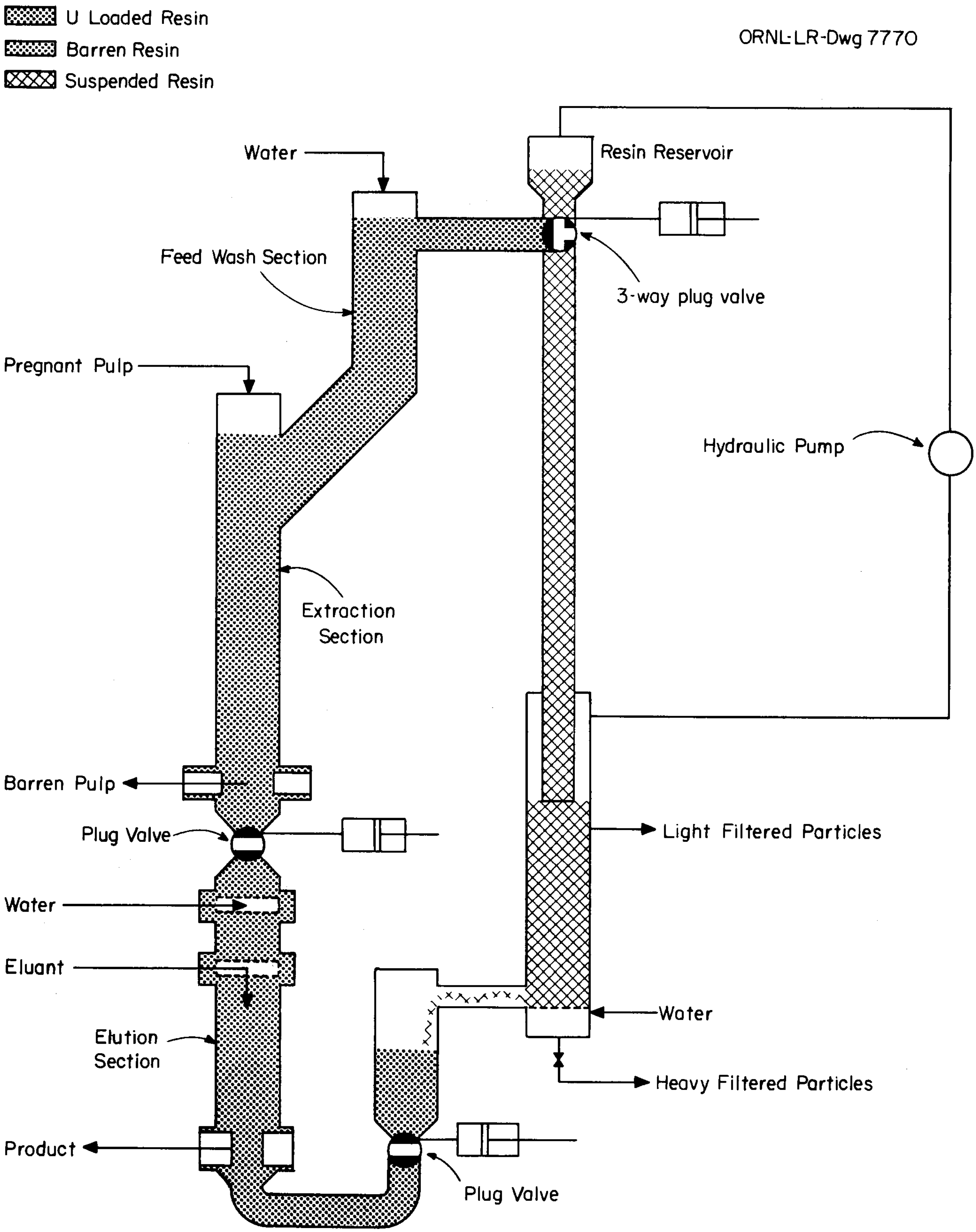

Fig. 3.2. Diagram of Contactor System for Use with Unfiltered Uranium Ore Leach Slurry.

chemicals were used only once, and recycle steps were not thoroughly demonstrated.

4.1 Concentrated Sodium Chloride--Water Elution

Emphasis is placed on the elution of uranium by the concentrated NaCl-water method (Fig. 4.1). The uranyl chloride product is obtained in high concentration and contains very little sodium chloride. With the 2-in.-dia contactor a continuous product was obtained which contained 60 g of uranium per liter and was 0.3 M in sodium chloride. With more refined operational control, the product concentration may have been higher and the sodium chloride even lower. This elution method is especially attractive because of the possibility of final purification without intermediate precipitation.[2] Metal equipment may be used.

In this elution method uranyl sulfate--loaded resin countercurrently contacts 5 M NaCl. In the presence of high chloride concentrations, sulfate ions are eluted efficiently and the uranyl sulfate anion complex is converted to uranyl chloride anion complex, which remains on the resin. The uranyl chloride complex remains anionic only because of the high chloride concentration, and therefore may be eluted with water. The waste sodium chloride, containing sulfate, is regenerated by adding calcium chloride to precipitate calcium sulfate.* No sodium chloride is consumed except the small amount which goes with the product or is not separated from the waste calcium sulfate. The calcium chloride consumed is stoichiometric with the amount of sulfate on the resin. The higher the resin loading, the smaller the calcium chloride consumption per pound of uranium. However, the resin loading does not affect the final product concentration. Since the quantity of water required for elution is only slightly greater than a resin void volume, the product solution may have twice as high a uranium concentration as the maximum resin loading in 5 M NaCl.

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*Development work has started which makes use of the 5 M NaCl (or 8 M HCl) only once at a much lower flow rate, thus eliminating the precipitation with $CaCl_2$ (or distillation of HCl). Preliminary indications are that sulfate may be displaced by chloride 100% excess over stoichiometric in 3 ft of column.

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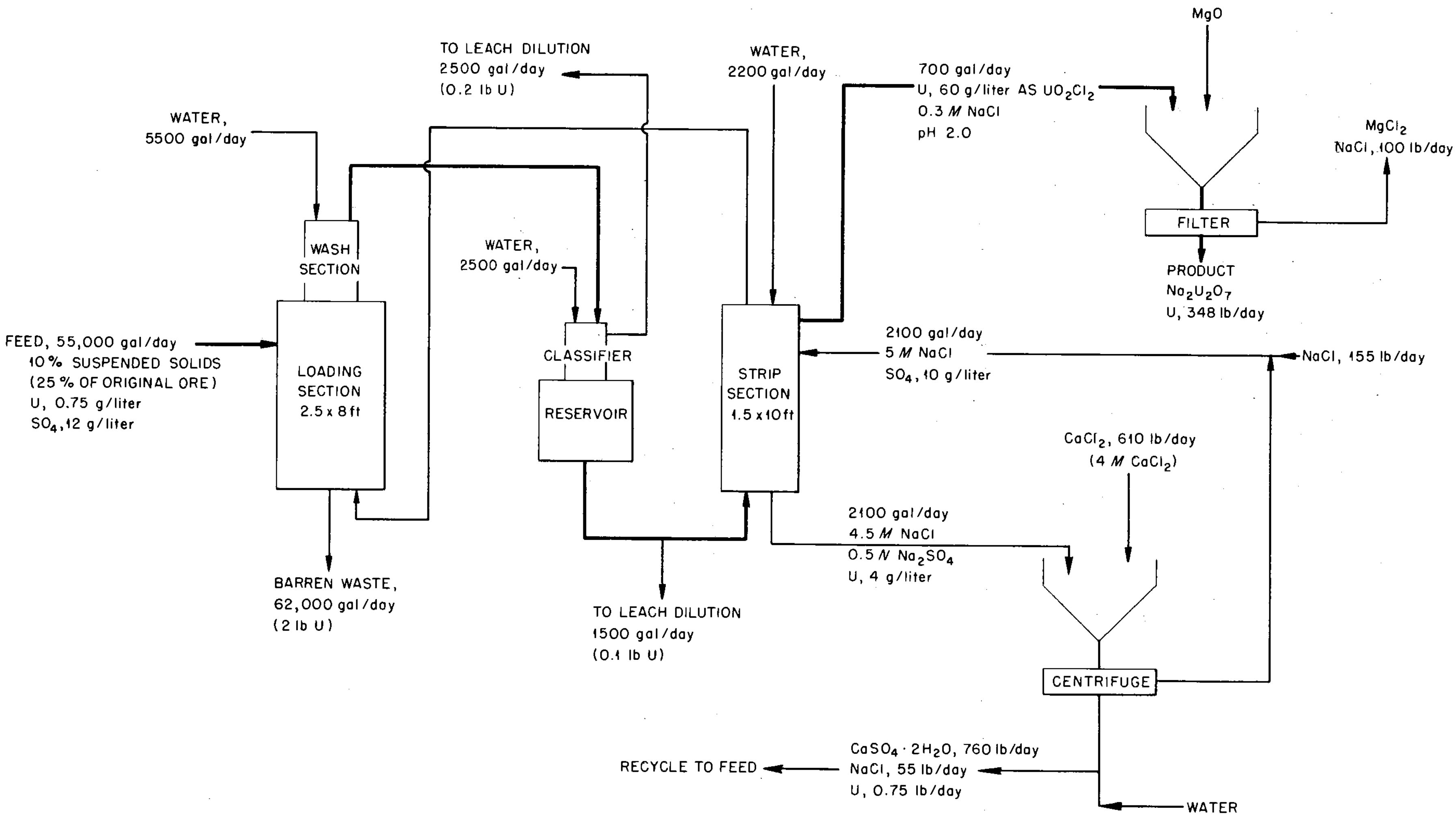

Fig. 4.1. Ore Pulp Processing in the Higgins Ion Exchange Contactor by the Concentrated Sodium Chloride–Water Elution Scheme. Ore processing rate, 100 tons/day; resin inventory, 74 ft^3; resin flow rate, 1050 gal/day; resin uranium loading, 40 g/liter.

The calcium sulfate cake is granular and easily filtered or centrifuged off. A cake has been filtered and washed to 0.03% uranium, but a preferred method is to use a less stringent solid-liquid separation and recycle the calcium sulfate with fresh leach pulp. Traces of chloride will not interfere with uranium sorption in a sulfate system. Traces of uranium carried by the calcium sulfate cake, will be sorbed as is the uranium from the original leach. An alternate procedure, which avoids the handling of calcium sulfate, is to use 8 M HCl instead of 5 M NaCl for the conversion step. The sulfuric and hydrochloric acids are then separated by distillation. However, acid-resistant equipment must be used throughout, whereas the sodium chloride system has an acidity no lower than pH 2.

4.2 Dilute Sodium Chloride Elution

The standard uranium eluting agent for sulfate-loaded anion-exchange resin is acidified 1 M NaCl solution. Sodium chloride is popular because of its availability at very low cost (Fig. 4.2). One molar NaCl is not so efficient as 5 M for eluting sulfate, and it is not concentrated enough to leave uranyl chloride anion complex on the resin. Sulfate and chloride are eluted together, and with the 2-in.-dia contactor about 3.5 lb of sodium chloride is consumed per pound of uranium. The product solution contains about 16 g of uranium per liter and all the salt. An intermediate diuranate precipitation is required to remove the uranium from the bulk salt. The cost of the sodium chloride is low enough that recycle need not be considered.

The 1 M NaCl elution has the advantage of combining low elution cost with simplicity in equipment and operation. It has the disadvantage of being highly corrosive to metals, and rubber- or plastic-lined equipment is recommended.

4.3 Ammonium Nitrate Elution

The 1 M NH_4NO_3 elution method (Fig. 4.3) is almost identical with the 1 M NaCl system just mentioned. One molar ammonium nitrate is

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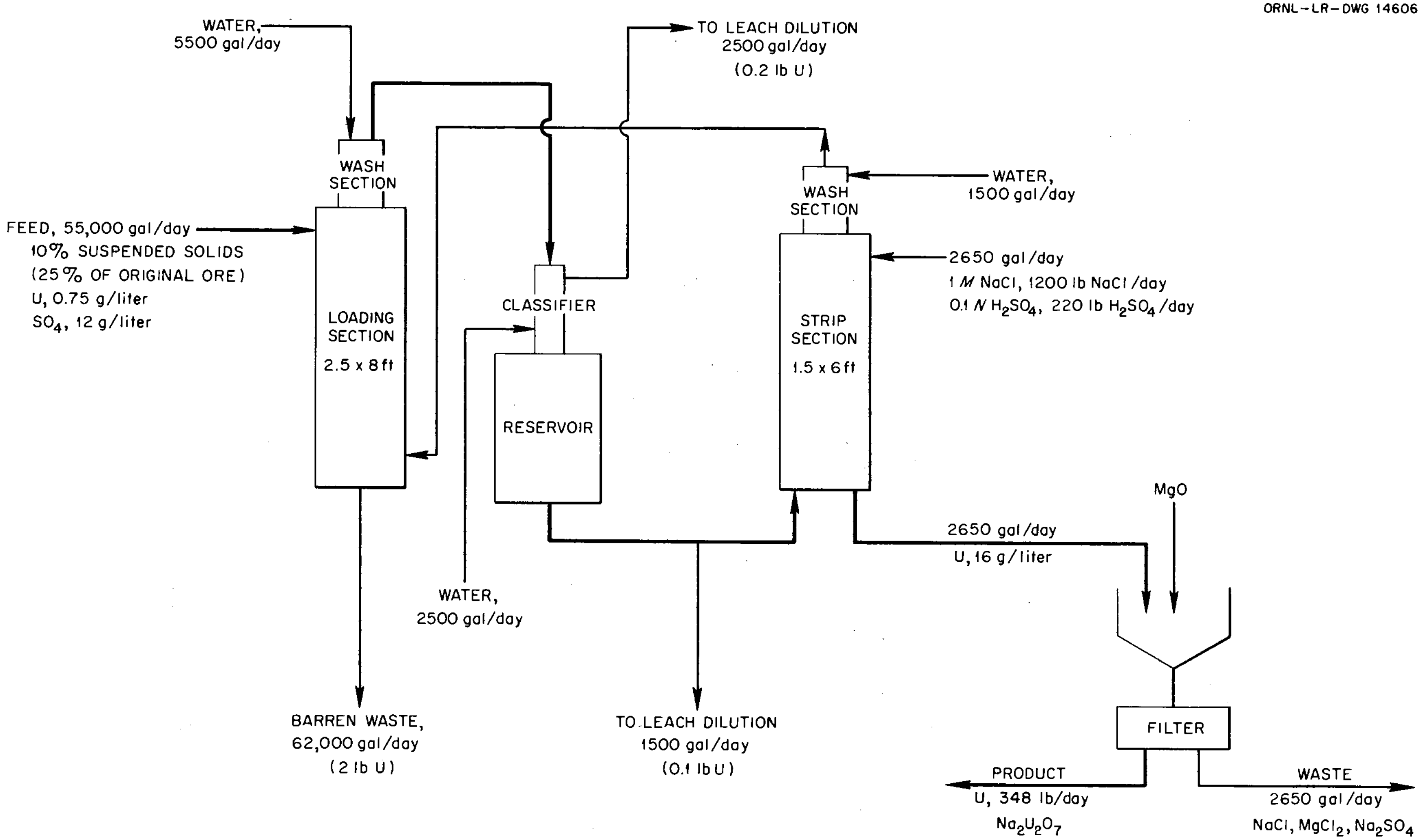

Fig. 4.2. Ore Pulp Processing in the Higgins Ion Exchange Contactor by the Dilute Chloride Elution Scheme. Ore processing rate, 100 tons/day; resin flow rate, 1050 gal/day; resin uranium loading, 40 g/liter; resin inventory, 67 ft^3.

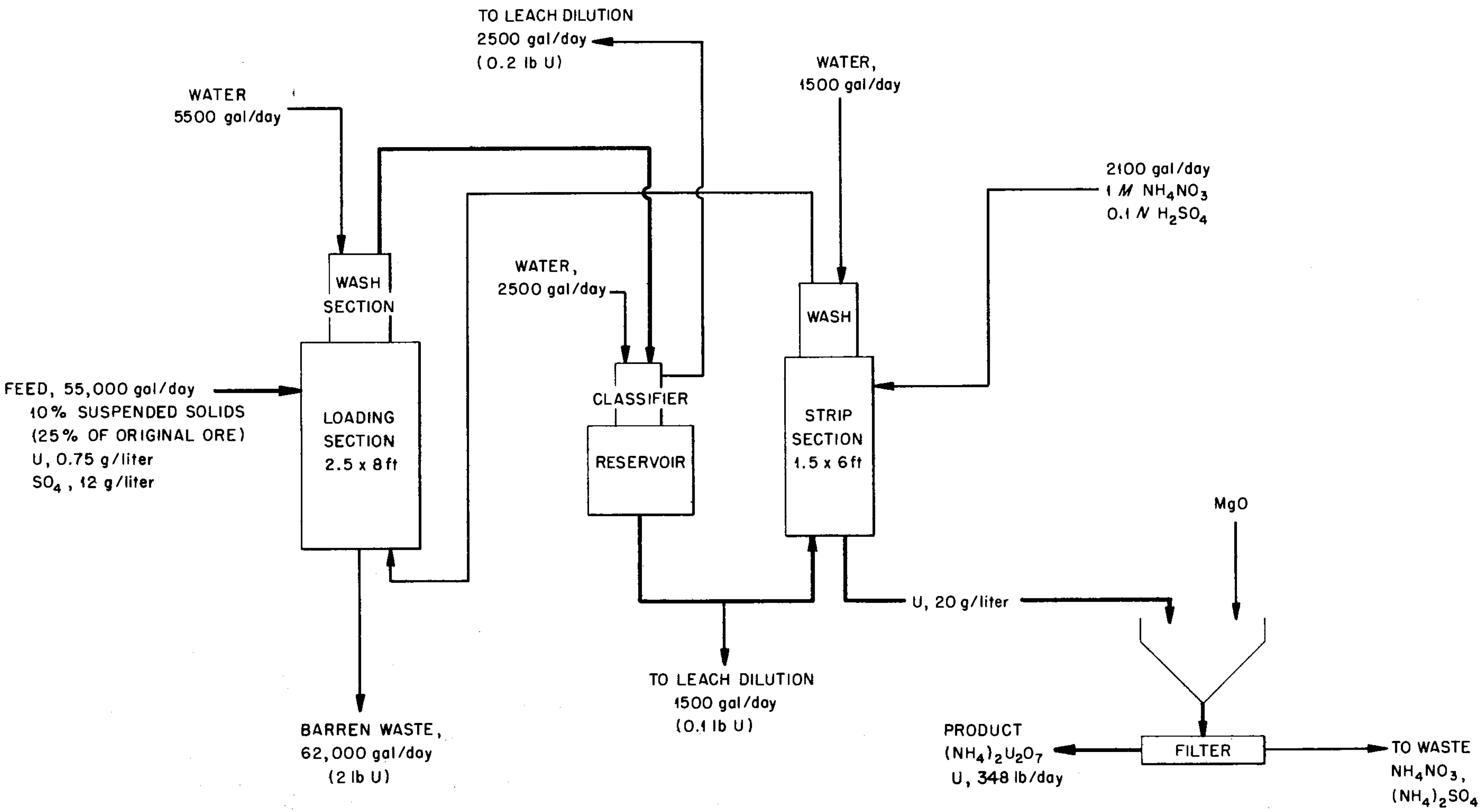

Fig. 4.3. Ore Pulp Processing in the Higgins Ion Exchange Contactor by the Ammonium Nitrate Elution Scheme. Ore processing rate, 100 tons/day; resin inventory, 67 ft^3; resin flow rate, 1050 gal/day; resin uranium loading, 40 g/liter.

slightly more efficient, mole for mole, than 1 M NaCl, but its chief advantage is that stainless steel construction may be used throughout. With the 2-in.-dia contactor about 4 lb of ammonium nitrate was consumed per pound of uranium, with no recycle, and a product solution of about 20 g of uranium per liter was obtained. Ammonium nitrate is sufficiently expensive that maximum recycle and recovery steps should be considered. This approach is discussed in Sec. 5.4, but continuous demonstration tests have not been completed.

4.4 Carbonate Flowsheet

The carbonate flowsheet (Fig. 4.4) was developed with magnesium fluoride bomb liner leach solutions shipped from Mallinckrodt. A close comparison of sorption from carbonate versus sulfuric acid leach solution was not made, but indications were that loadings were similar. The carbonate flowsheet is presented to show that the same advantages——handling of pulp and overall efficiency——apply in the alkaline as in the acid system. The carbonate leach system is attractive because mild steel equipment may be used. A thorough investigation was not made of elution methods, but 1 M $NaHCO_3$ was found to be effective. About 1.5 lb of sodium bicarbonate was consumed per pound of uranium processed, and a product solution containing 26 g of uranium per liter was obtained, with the 2-in.-dia contactor. The uranium may be precipitated from the bicarbonate solution by caustic soda, and the filtrate regenerated with carbon dioxide for further leaching or elution. Another method of recovering the uranium is destruction of the bicarbonate with acid followed by precipitation of the diuranate as in the acid leach.

5.0 PRELIMINARY EXPERIMENTS

The flowsheets are presented to indicate the general ideas of contactor size, production rate, chemical consumption, losses, and yields. Many variables, such as pulp quality, resin mesh, resin loading, column height, flow rate, and eluting agent, affect each other and the overall contactor design. The final objective is to adjust each variable to the

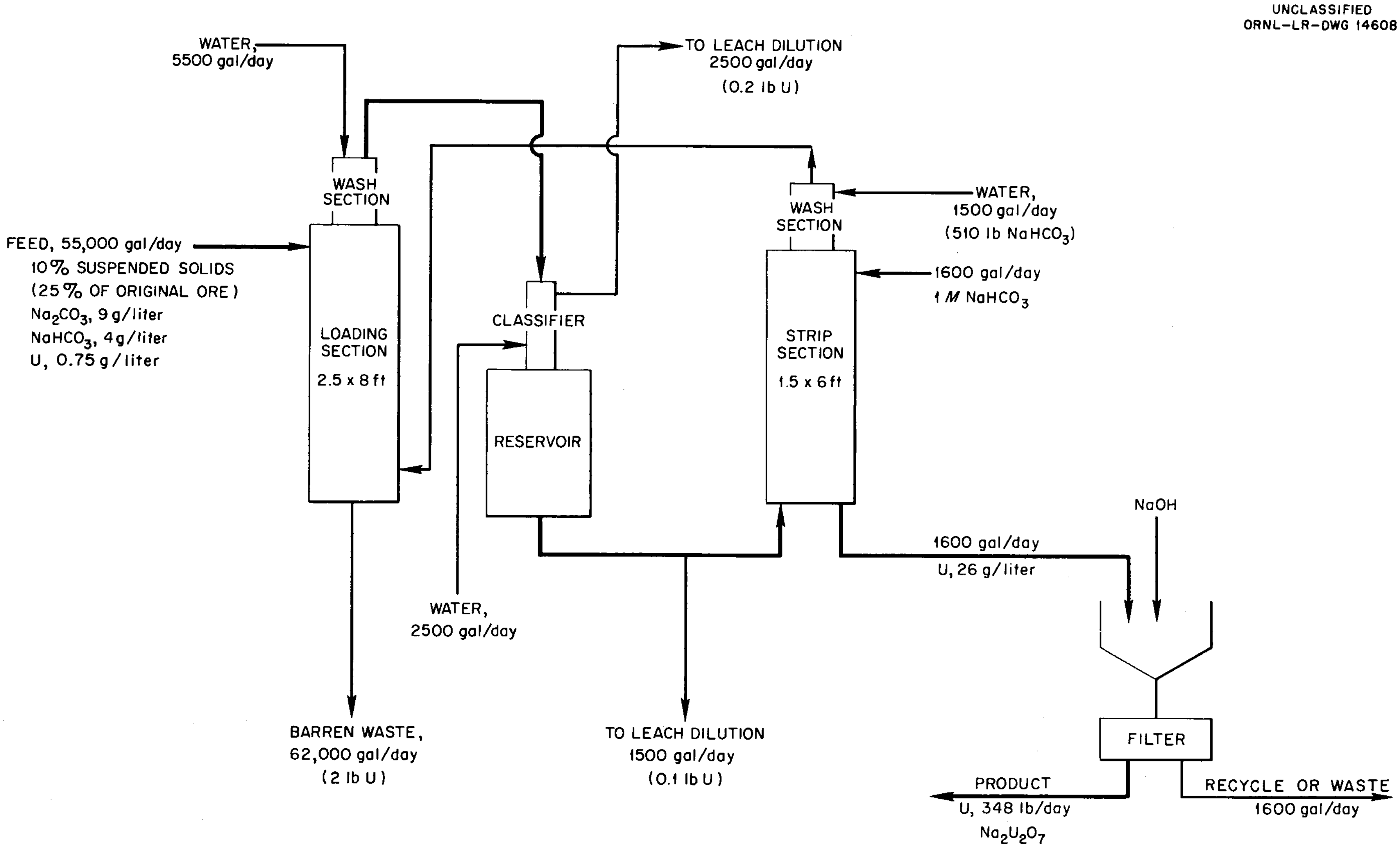

Fig. 4.4. Ore Pulp Processing in the Higgins Ion Exchange Contactor by the Carbonate Elution Scheme. Ore processing rate, 100 tons/day; resin inventory, 67 ft^3; resin flow rate, 1050 gal/day; resin uranium loading, 40 g/liter.

point that it contributes about equally to the cost of the overall operation.

5.1 Pulp Quality and Resin Mesh

Lukachukai, Utex, and Los Ochos sulfuric acid—leached pulps were shipped from Grand Junction, Colorado, and carbonate-leached magnesium fluoride bomb-liner slurries were shipped from Mallinckrodt for preliminary tests with the laboratory contactor. The Colorado ore pulps were about 10% in suspended solids and were processed without difficulty on 10-20 mesh resin when less than 1% of the solids was sand greater than 200 mesh. The magnesium fluoride carbonate pulps, about 5% in suspended solids and with less than 1% of the solids greater than 325 mesh, were processed with 20-40 mesh resin without plugging. Large low-density particles, such as wood fibers, were filtered out on the resin bed, traveled with the resin, and were separated by backwashing in the contactor classifier section. Intermediate-sized particles, which neither were filtered nor flowed freely through, accumulated in the resin bed and eventually caused plugging (Table 5.1).

A less serious type of plugging was caused by particles deposited in stagnant flow areas. This would be prevented by proper design to eliminate stagnant flow pockets and by providing flush-out lines at critical points, such as feed and takeoff distributors (Fig. 3.2).

5.2 Resin Loading, Feed Rate, and Sorption Column Height

Uranium losses of less than 1% were obtained in 4.5 ft of extraction column height with resin uranium loadings of 40 g/liter at feed flow rates of 300-470 gal/hr/ft^2 on Permutit SK, 10-20 mesh, resin. It is necessary to list all these conditions since each affects the others. However, the most significant variable for extraction is the percentage utilization of the total resin capacity. The Permutit SK resin used in most experiments had an ultimate uranium capacity with sulfate-leach slurries of about 70 g/liter. To use the full capacity of the resin would mean great sacrifice in feed rate or holdup time, but the higher the resin loading, the cheaper the elution costs. With low resin loading the

Table 5.1 Effect of Slurry Particle Size on Resin Plugging in the 2-in.-dia Continuous Contactor

Resin: Permutit SK

Slurry	Run Time (hr)	Resin Size (mesh)	Feed Rate (gal/hr/ft^2)	Plugging
Lukachukai sulfate ore leach pulp				
9% total solids 0.4% > 100 mesh 2.4% > 170 mesh 3.8% > 325 mesh Specific gravity, 1.08	29	10-20	350	On verge of plugging with 5 psi pressure on feed
6-8% total solids 1.2% > 325 mesh Specific gravity, 1.06	63	10-20	430	No indication of plugging
6.8% total solids 3% >325 mesh Specific gravity, 1.06	5	20-40	220	Finally plugged with 6-12 psi pressure on feed
Utex sulfate ore leach pulp 12% total solids 0.6% >325 mesh	18	10-20	400	No indication of plugging
Los Ochos sulfate ore leach pulp 11% total solids Negligible amount >325 mesh Specific gravity, 1.08 (wood fibers removed with 100-200 mesh screen)	50	10-20	300-450	No indication of plugging
Mallinckrodt carbonate slag leach 4.5% suspended solids Negligible amount <325 mesh ~50-50 MgF_2 and MnO_2	48	20-40	280	No indication of plugging

exchange potential is high, and high throughput is therefore permissible. As a greater percentage of the ultimate capacity is utilized, the exchange potential decreases, so that the flow rate must be decreased or the column height increased to maintain a negligible loss. The most desirable balance of loading, feed rate, and column height was not determined, but their effects on column height were investigated. As the loading was increased the profile became nearly horizontal at the feed end of the loading section. This may be considered a practical upper limit, since column height is sacrificed to make a small gain in loading (Fig. 5.1). When the resin loading was very low, there was almost no difference when the feed rate was increased considerably (Fig. 5.2). This is significant in increasing production rate if the eluting costs are low. Fortunately, both high resin loading and high throughput may be had by increasing column height, but at higher flow rates, uranium losses increase with higher resin loading (Fig. 5.3).

5.3 Contactor Scaleup

An important question that must be answered before a plant installation is started is: How dependable are run data from a 2-in.-dia column when applied to a 3- or 4-ft-dia column? Since this type of information is intermingled with other studies, it is assembled here for comparison. The first scaleup of the 2-in.-dia contactor was a 6-in.-dia unit operated at ORNL. Next a 12-in.-dia contactor was operated at Grand Junction, Colorado.* Feed conditions were not identical for the separate operations, but the loading profiles on the extraction sections were so nearly the same that the scaleup was considered very good. Resin uranium loadings varied from 35 to 45 g/liter, flow rates from 390 to 640 gal/hr/ft^2, and the feeds were synthetic, Utex pulp, and White Canyon pulp. However, about 5 ft was required in each case for greater than 99% recovery (Fig. 5.4).

5.4 1 M NH_4NO_3 Elution

Ammonium nitrate is an effective eluting agent for uranyl sulfate—

*Unpublished information. The 12-in.-dia contactor was run at Grand Junction by C. W. Hancher, T. A. Arehart, and I. R. Higgins.

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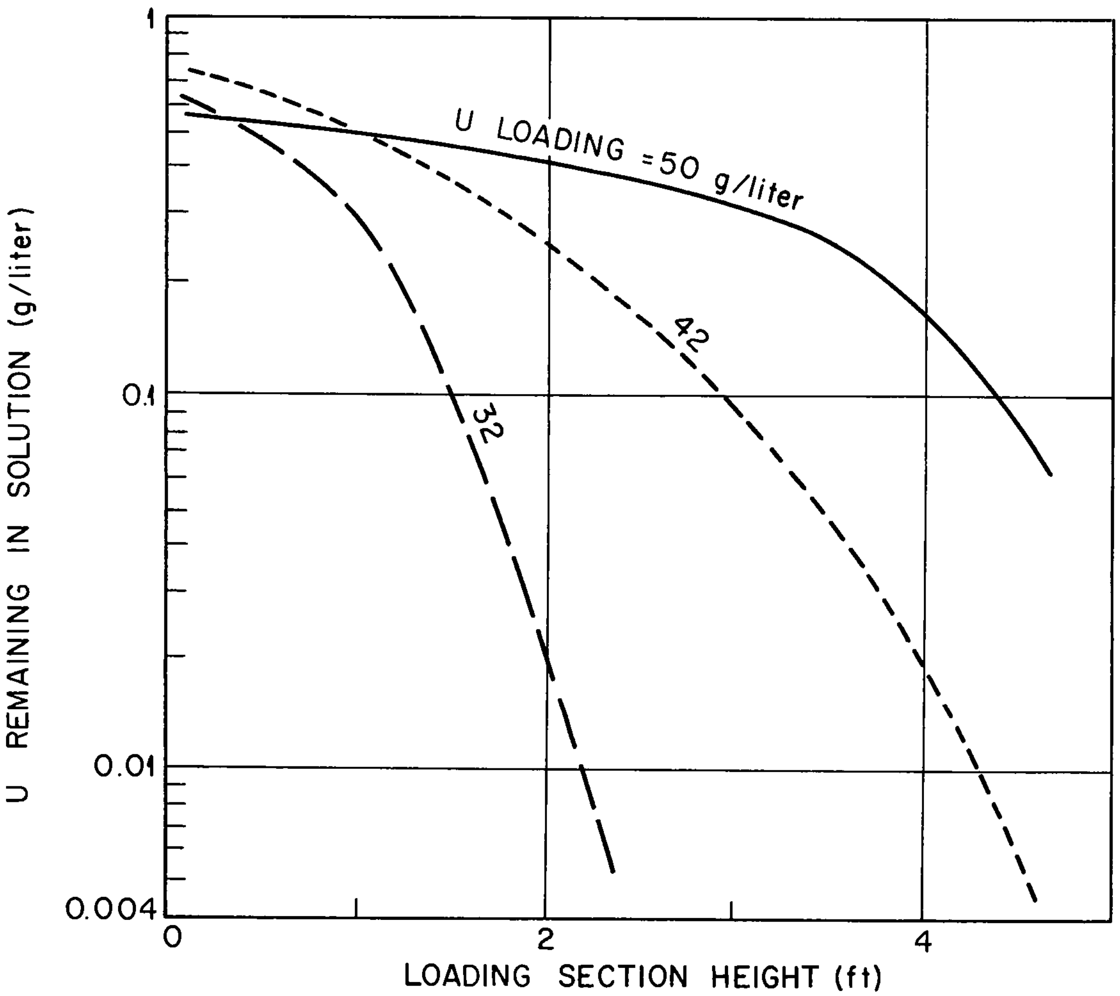

Fig. 5.1. Effect of Resin Loading on Column Height Required to Maintain Low Uranium Loss. Feed flow rate, 420-470 gal/hr/ft^2; resin, Permutit SK, 10-20 mesh; 2-in.-dia contactor.

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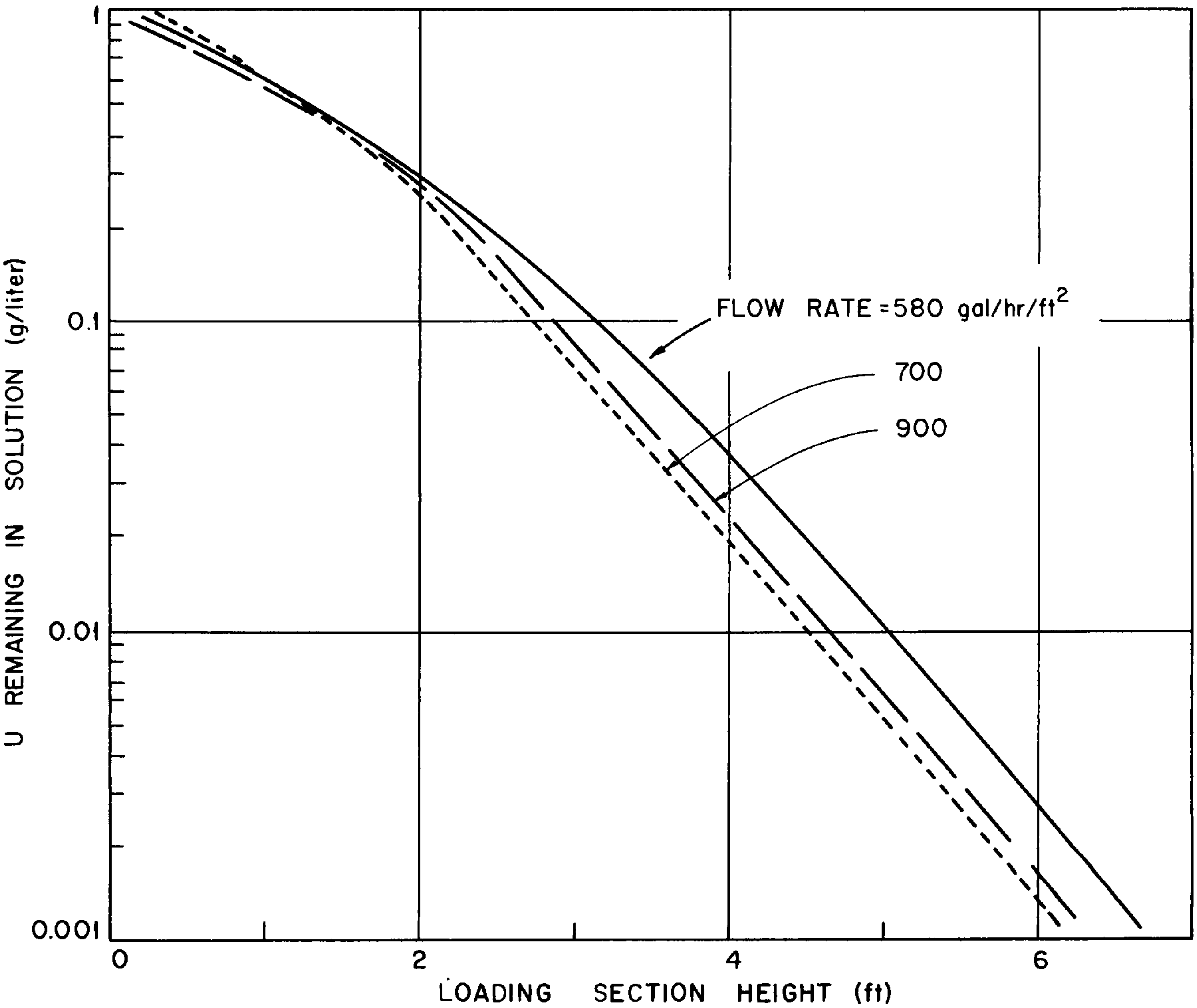

Fig. 5.2 Effect of Feed Flow Rate on Column Height Required to Maintain Low Uranium Loss with Resin Uranium Loading of 20 g/liter. Resin, Permutit SK, 10-20 mesh, 2-in.-dia contactor.

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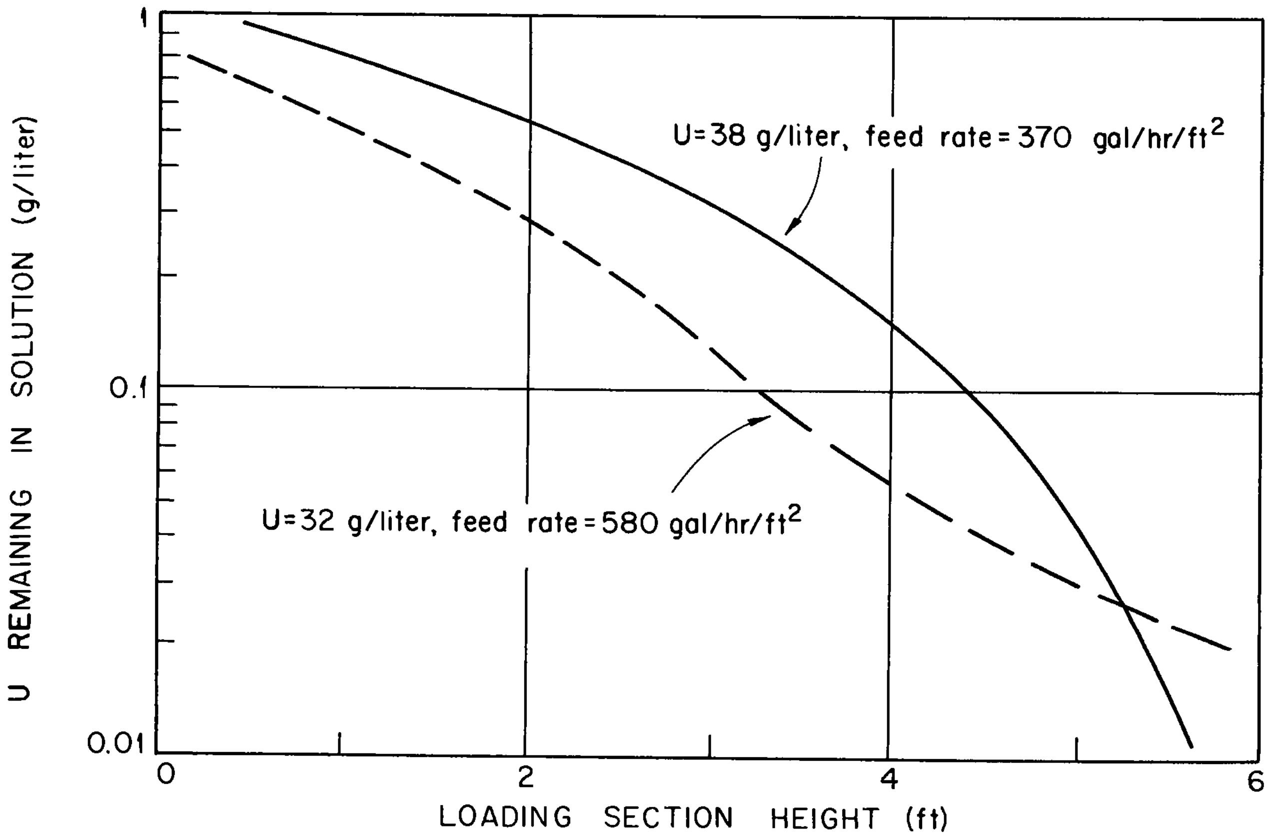

Fig. 5.3. Effect of Feed Flow Rate on Column Height Required to Maintain Low Uranium Loss with Resin Uranium Loading of about 35 g/liter. Resin, Permutit SK, 10-20 mesh; 2-in.-dia contactor.

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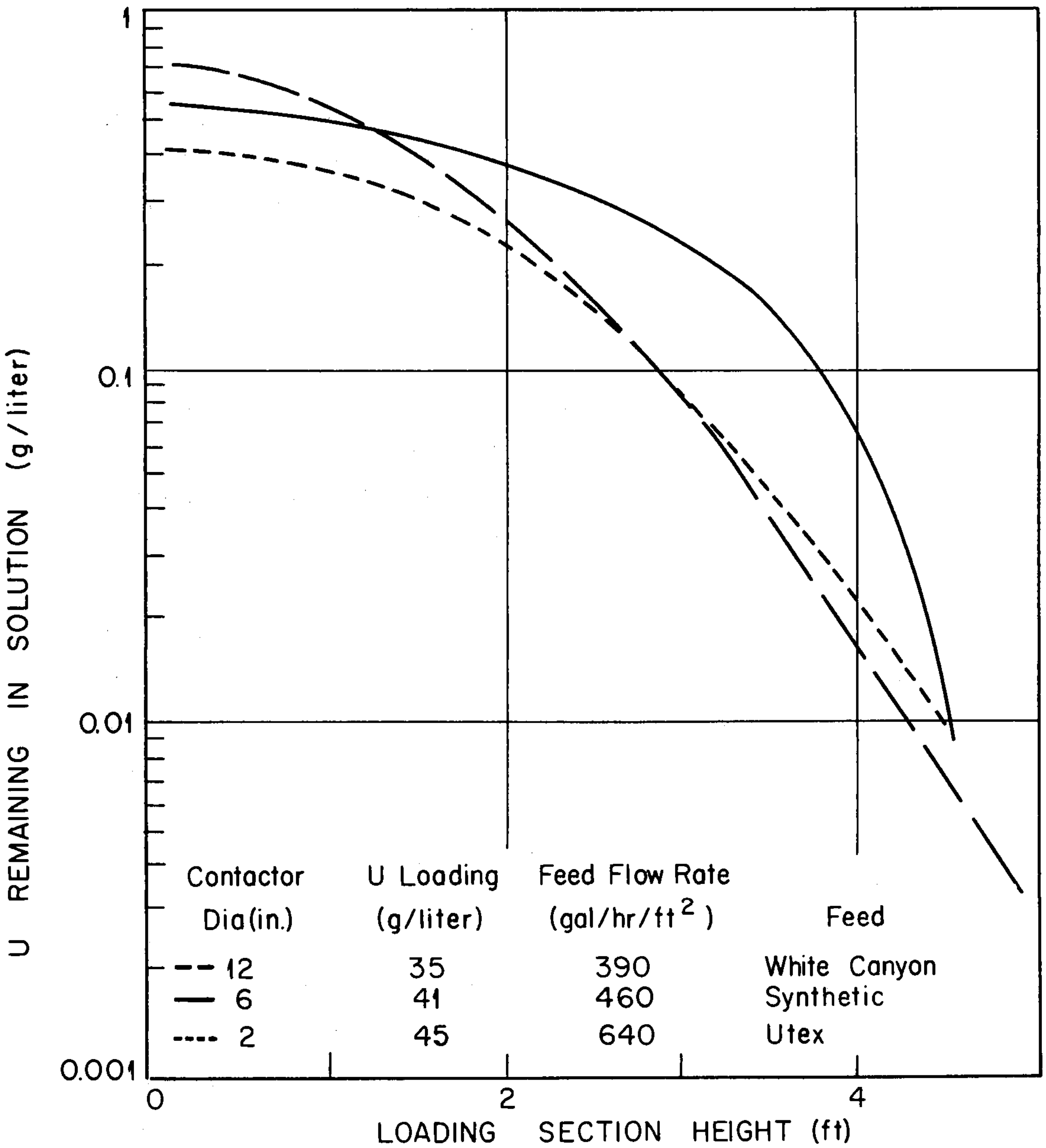

Fig. 5.4. Scale-up Comparison of 2-, 6-, and 12-in.-dia. Contactors.

loaded anion-exchange resin and is preferred over the cheaper chloride systems because it can be used in stainless steel equipment. However, ammonium nitrate is several times as expensive as sodium chloride, and its use is complicated by various methods of recycle. Fresh ammonium nitrate used once was consumed at a rate of about 4 lb per pound of uranium when the resin (Permutit SK) was loaded with uranium to 40 g/liter, and the concentration of uranium on the resin was reduced 1000-fold in 3 ft. Recycled ammonium nitrate, containing sulfate up to 60 g/liter, was not nearly so effective, giving only a 100-fold reduction in 7 ft of column when 5 lb of ammonium nitrate was consumed per pound of uranium (Fig. 5.5).

The eluting efficiency of recycled ammonium nitrate was also complicated by the method of precipitating uranium as diuranate. When magnesium oxide was used instead of ammonia, the sulfate was present as the magnesium salt and this had a further detrimental effect on elution (Fig. 5.6) when the ammonium nitrate containing it was recyled. Quite independent from the inefficient elution with nitrate containing sulfate, was the loss of nitrate by occupation of the resin-exchange sites. When fresh ammonium nitrate was used, containing no sulfate, half was consumed just to occupy the resin and was lost in the barren waste from the loading. When ammonium sulfate was introduced upstream from the nitrate eluting agent, this lost nitrate was displaced with sulfate and effectively eluted uranium. Consumption of 2.5 rather than 4 lb of ammonium nitrate was demonstrated, but a corresponding amount of ammonium sulfate was used (Fig. 5.7). The natural follow-up of this scheme was not obvious at first and was not demonstrated continuously, but may be shown from a fixed bed experiment (Fig. 5.8). When uranyl sulfate--loaded anion-exchange resin is treated in a fixed bed with ammonium nitrate, a rich cut of sulfate is eluted ahead of the uranium and the nitrate[3] (Fig. 5.9). This free sulfate may be made to serve two useful functions. First, by its absence from the recycled nitrate, it causes less elution interference. Second, it may displace valuable nitrate when fed upstream from the nitrate eluting agent. All the sulfate will not be available free from uranium, and therefore all the nitrate will not be recovered from the resin, but

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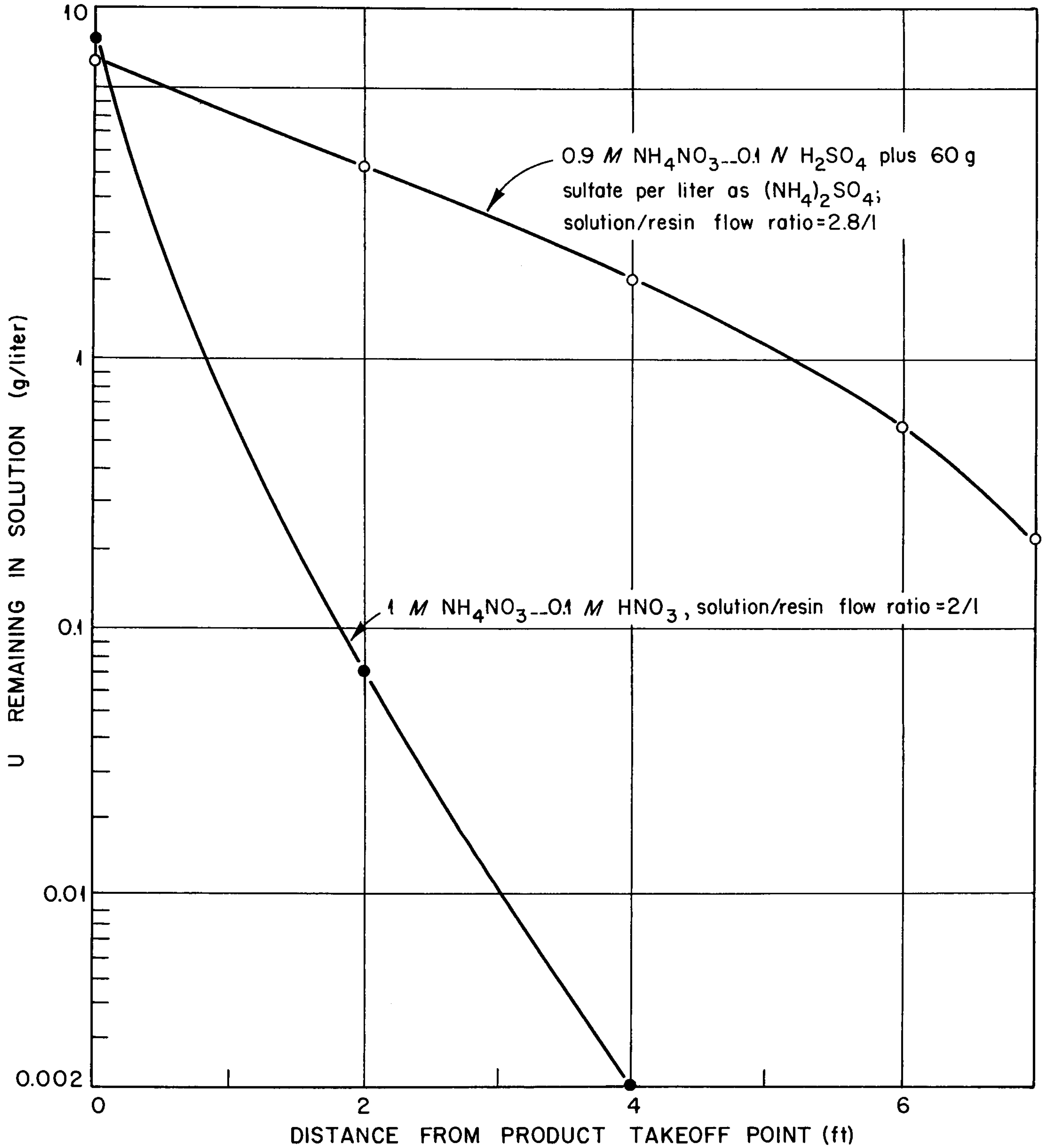

Fig. 5.5. Effect of Presence of Sulfate Ion on Column Height Required in Uranium Elution with Ammonium Nitrate. Resin, Permutit SK-20, 10-20 mesh; 2-in.-dia column.

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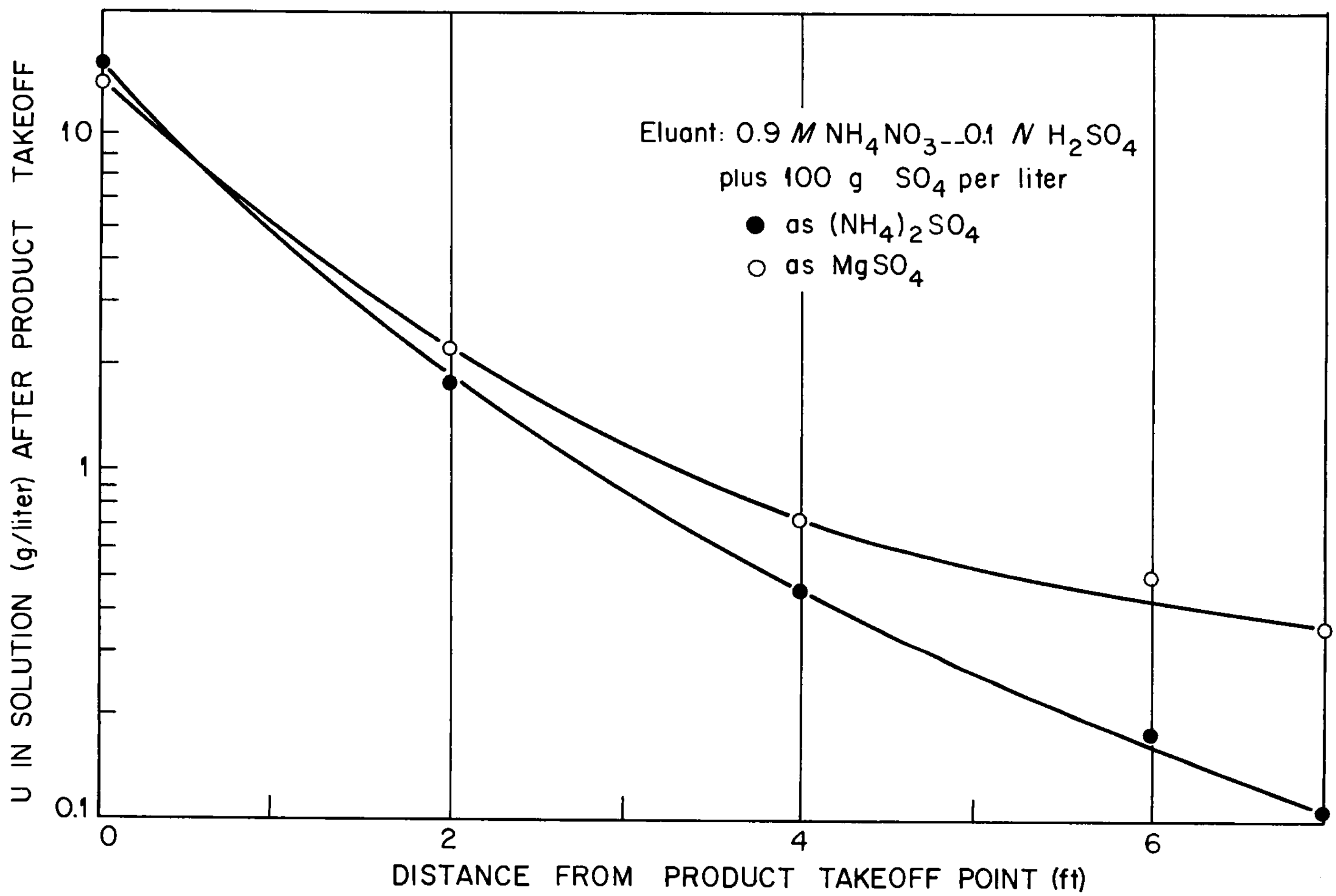

Fig. 5.6. Comparion of Effect of Magnesium and Ammonium Sulfates in Recycled Ammonium Nitrate on Elution of Uranium from Permutit SK-20. 2-in.-dia contactor; solution/resin flow ratio = 2.5/1.

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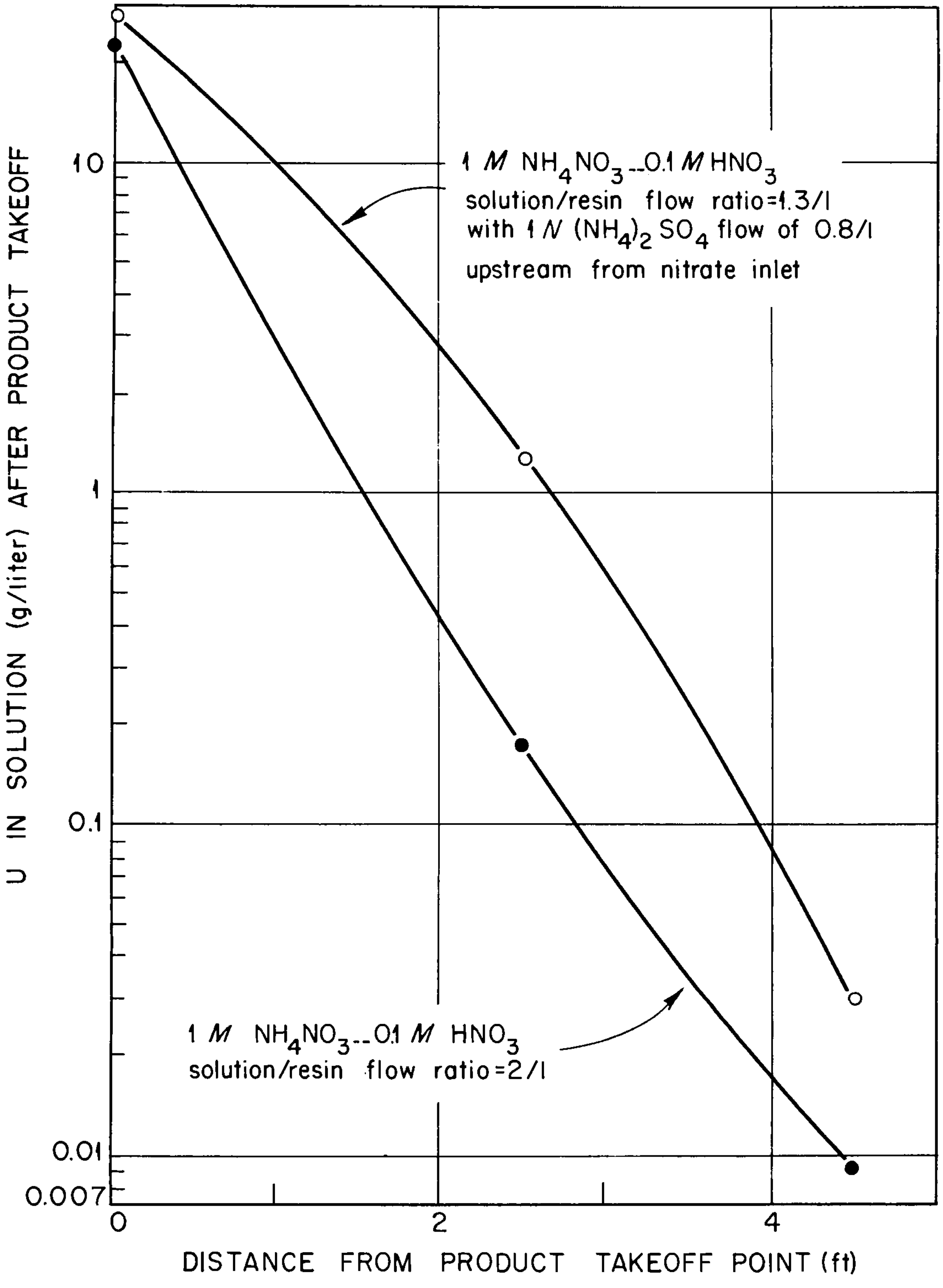

Fig. 5.7. Comparison of Uranium Elution with and without Nitrate Displacement with Ammonium Sulfate.

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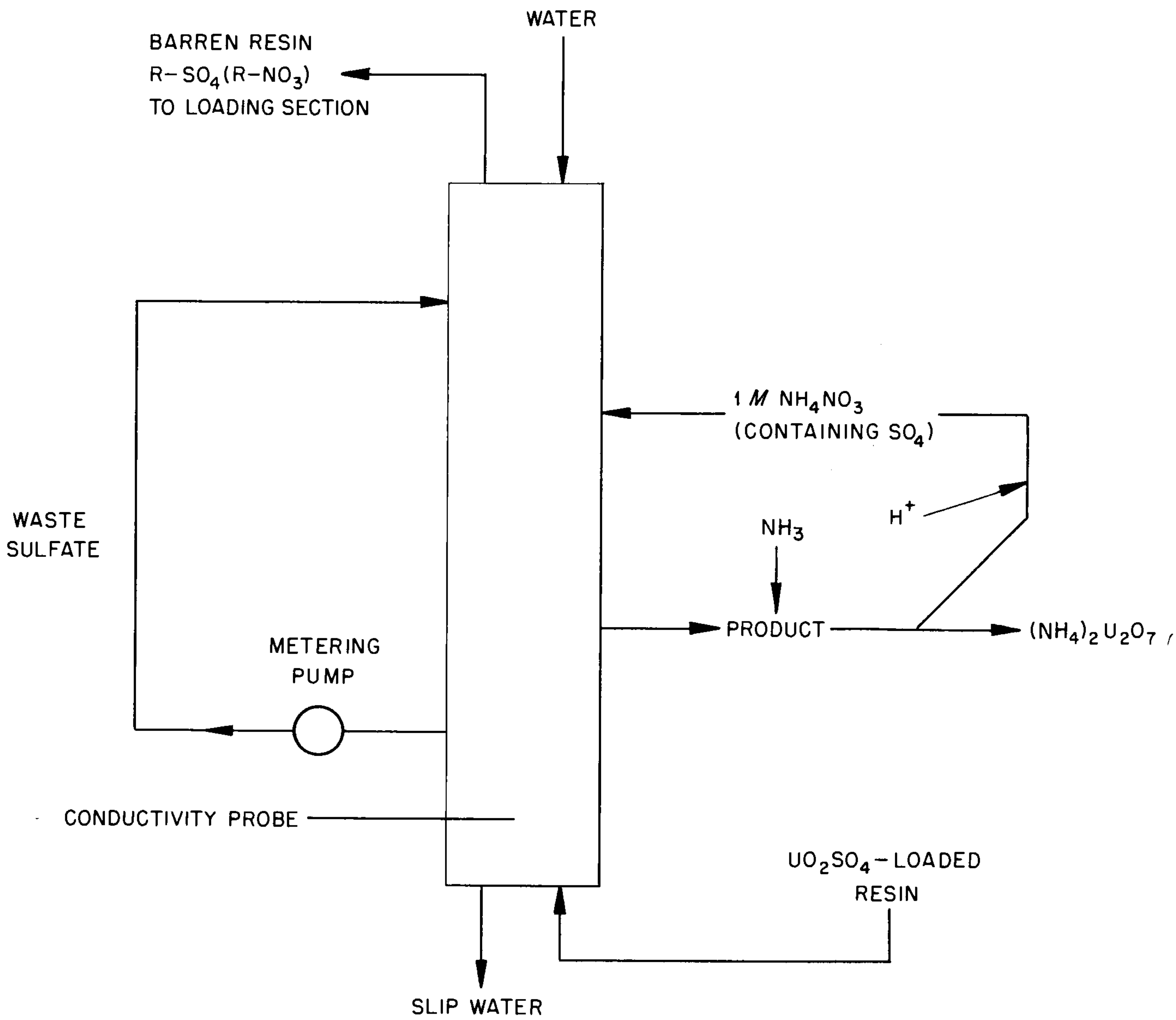

Fig. 5.8. Method of Recycling Nitrate Eluant in Sulfate-loading Equipment (Elution Section of Higgins Continuous Contactor).

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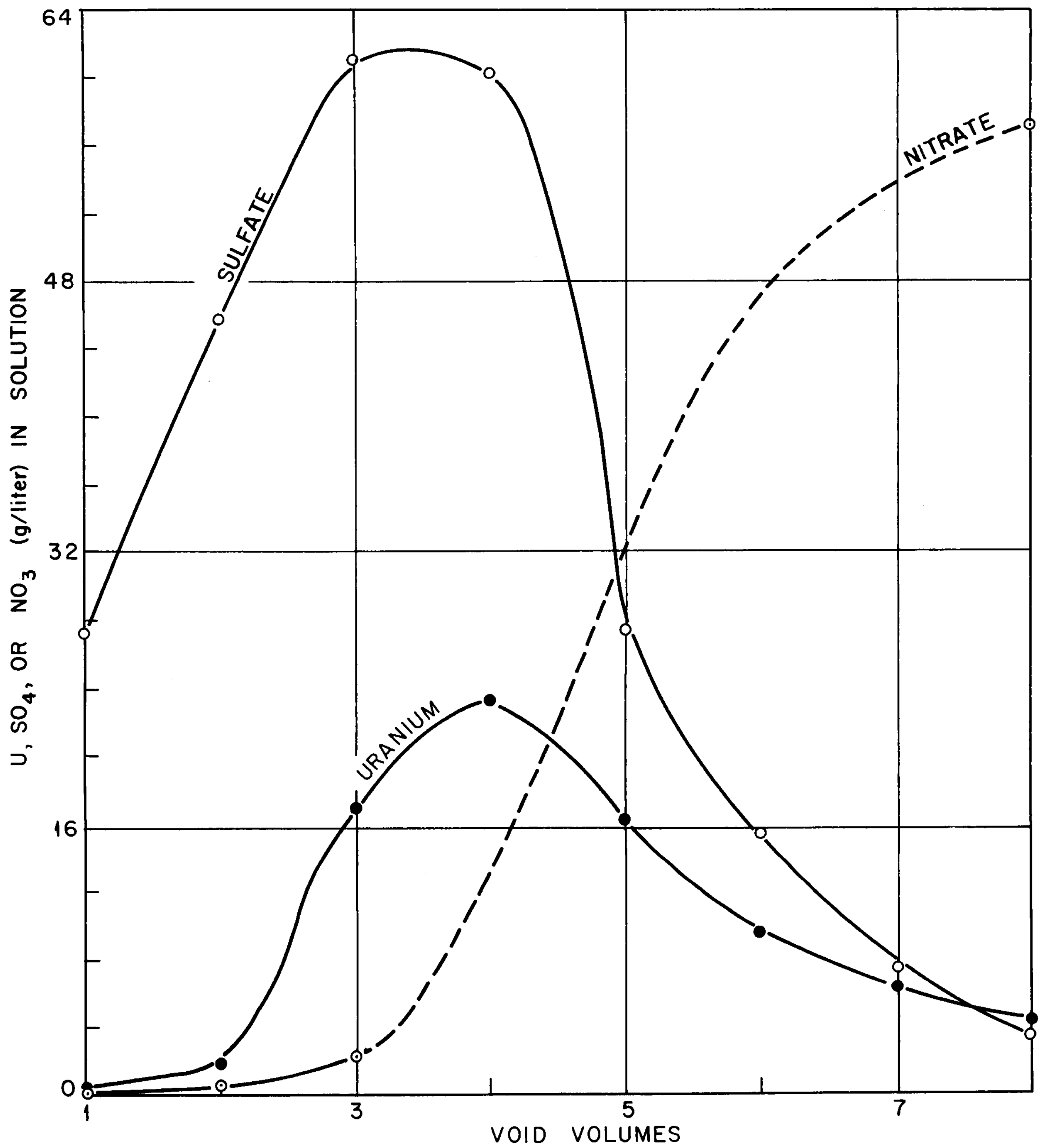

Fig. 5.9. Fixed-bed Elution of Uranyl Sulfate--loaded Permutit SK-20 resin with 0.9 *M* NH_4NO_3--0.1 *M* HNO_3.

the nitrate loss should be materially reduced.

5.5 1 M NaCl Elution

Sodium chloride was not quite so efficient, mole for mole, as ammonium nitrate, but 1 M NaCl--0.1 N H_2SO_4 gave good elution (Fig. 5.10). Sodium chloride was considered sufficiently cheap that no recycle need be considered, although it could be recycled in a manner similar to that described for the nitrate.

5.6 5 M NaCl--H_2O Elution

The concentrated sodium chloride elution of uranyl sulfate--loaded resin is really two elutions, i.e., elution first of the sulfate with chloride and then elution of the uranium with water.

Sulfate has been eluted with strong chloride in two ways, which are largely a choice between instrumentation and mechanical handling. In strong chloride the chloride ion preferentially displaces sulfate and a stoichiometric consumption is closely approached. In 3 ft of column the consumption was 2.5-3 lb of NaCl per pound of uranium, which is the least expensive eluting system demonstrated. Conductivity control of interfaces is necessary because the salt rate is difficult to meter at rates less than the resin rate (Fig. 5.11).

If relatively rapid 5 M NaCl flow is used, the sulfate elution is accomplished in a few inches and no delicate flow control is necessary. The NaCl is used over and over by adding a stoichiometric amount of $CaCl_2$ to precipitate sulfate.

The elution of uranium from strong chloride--uranyl resin is remarkably efficient and simple. A 1000-fold reduction in the resin uranium concentration is accomplished in 3 ft of column with a water flow equal to the resin flow (Fig. 5.12).

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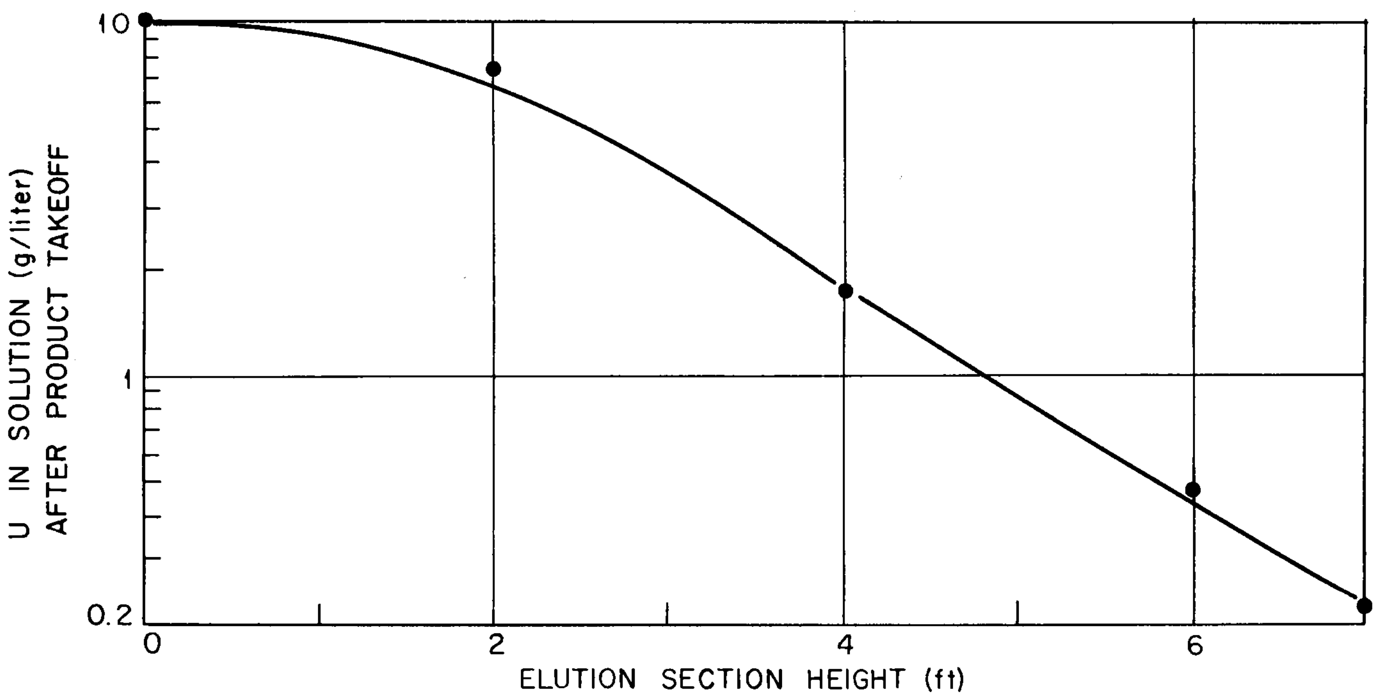

Fig. 5.10. Elution of Uranium from Permutit SK-20 with 1 *M* NaCl–0.1 *N* H_2SO_4. 2-in.-dia contactor; solution/resin flow ratio = 2.8/1.

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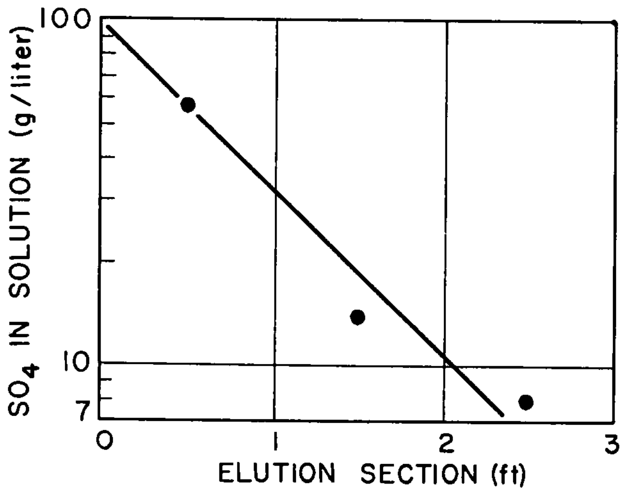

Fig. 5.11. Elution of Sulfate from Uranyl Sulfate-loaded Permutit SK Resin (20-40 mesh) with 5 *M* NaCl. Solution/resin flow ratio=0.6/1

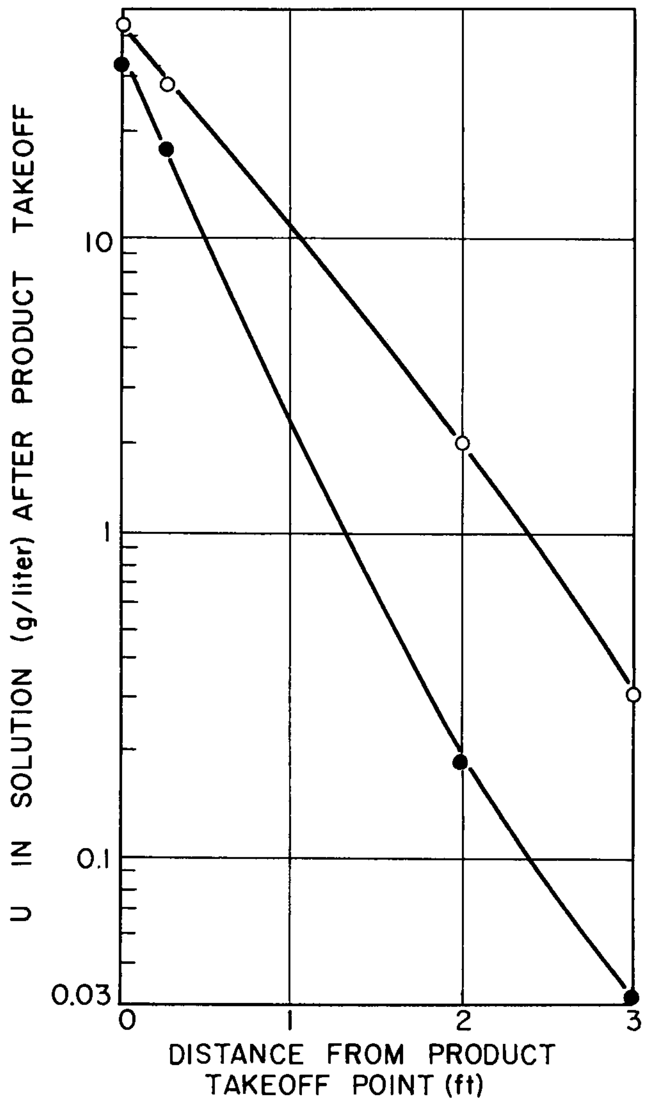

Fig. 5.12. Elution of UO_2Cl_2 from Amberlite XE-123 with Water after Conversion from UO_2SO_4 with 5 *M* NaCl Containing 10 g of Sulfate per liter. ○ Water/resin flow ratio=0.5/1 (1.25 void volumes of water); ● water/resin flow ratio=1/1 (2.5 void volumes of water; 2-in.-dia contactor.

6.0 REFERENCES

1. I. R. Higgins, "Mechanical Features of the Higgins Continuous Ion Exchange Column", ORNL-1907 (Sept. 29, 1955).

2. I. R. Higgins, J. T. Roberts, "Development of the Excer Process, I," ORNL-1696 (March 19, 1956). J. A. Marinsky, "Development of the Excer Proces, II," ORNL-1979 (March 27, 1956).

3. A. Pruess, Rohm and Haas Company, Private communications.

7.0 APPENDIX

This report covers the initial studies in the Higgins continuous ion-exchange contactor for handling suspended solids. There were many hours of running time with flow and chemical conditions not necessarily always ideally adjusted, but with very good mechanical preformance. The significant variables are discussed in the body of this report. Much additional information may be derived from examination of the run data. It should be kept in mind that many of the data were taken at unsteady state. For example, many of the loading and stripping data should be examined independently.

7.1 Column Arrangements

Figures 7.1 through 7.5 show the various experimental setups used.

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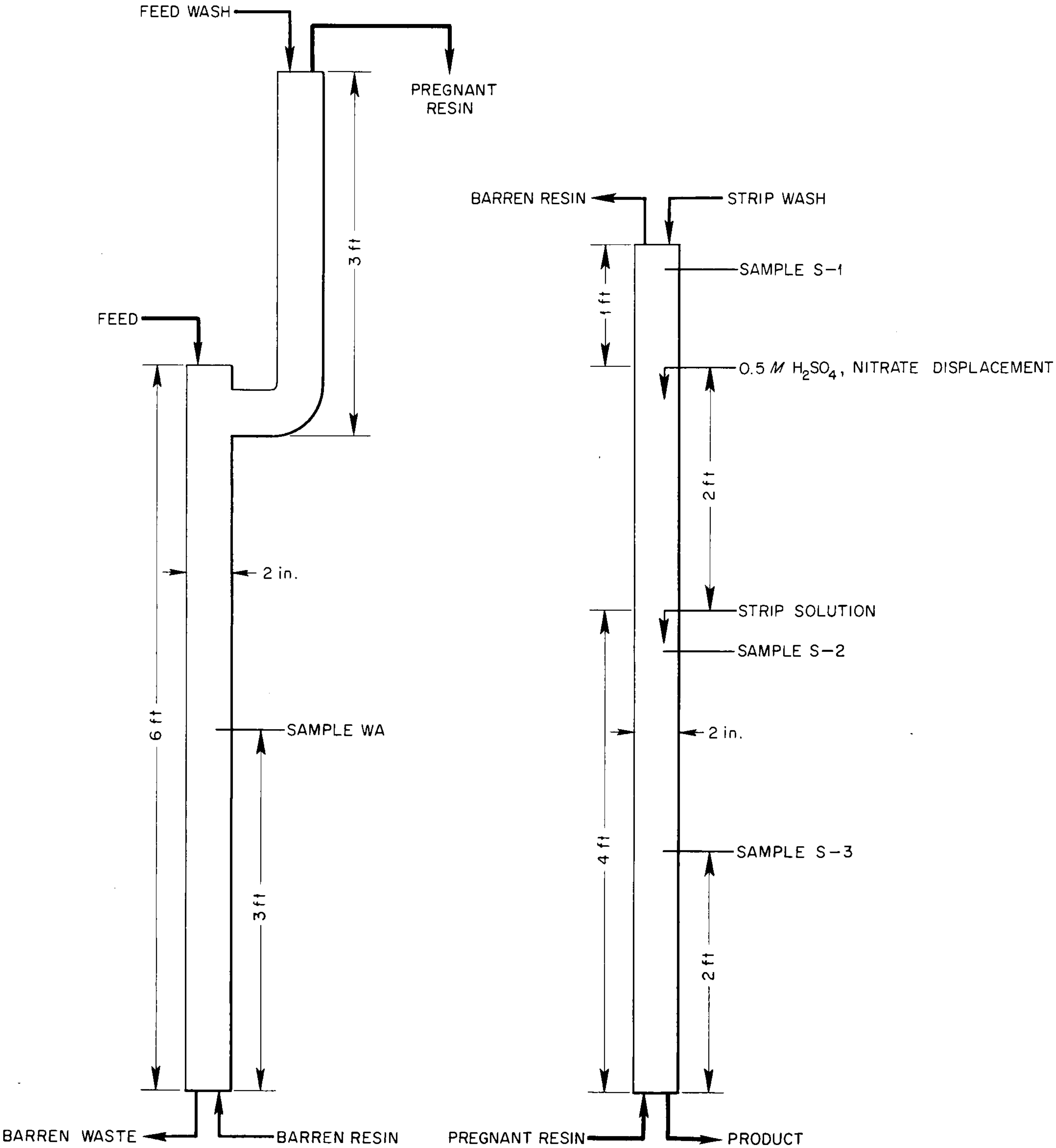

Fig. 7.1. Contactor Arrangement No. 1.

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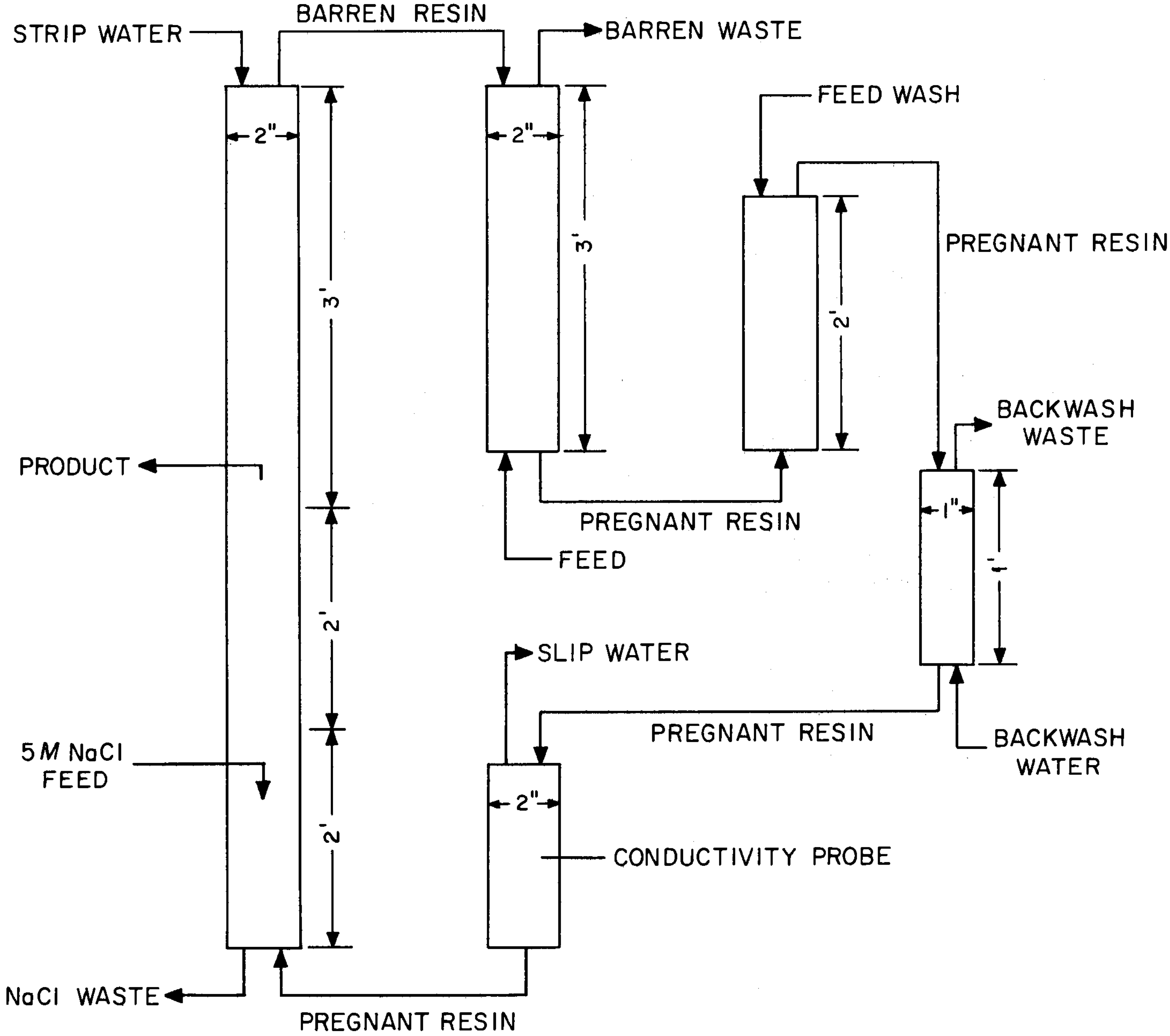

Fig. 7.2. Contactor Arrangement No. 2.

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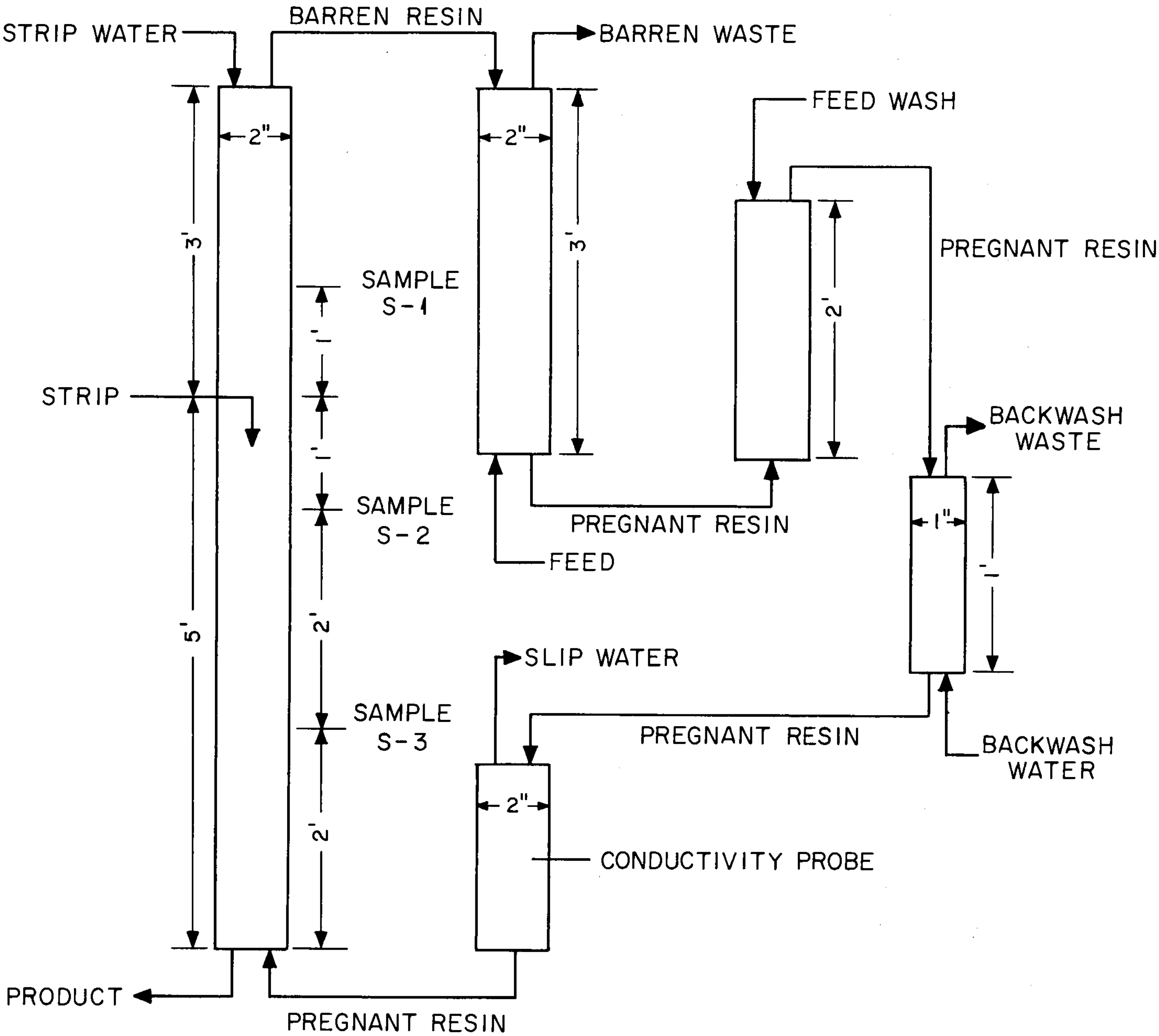

Fig. 7.3. Contactor Arrangement No. 3.

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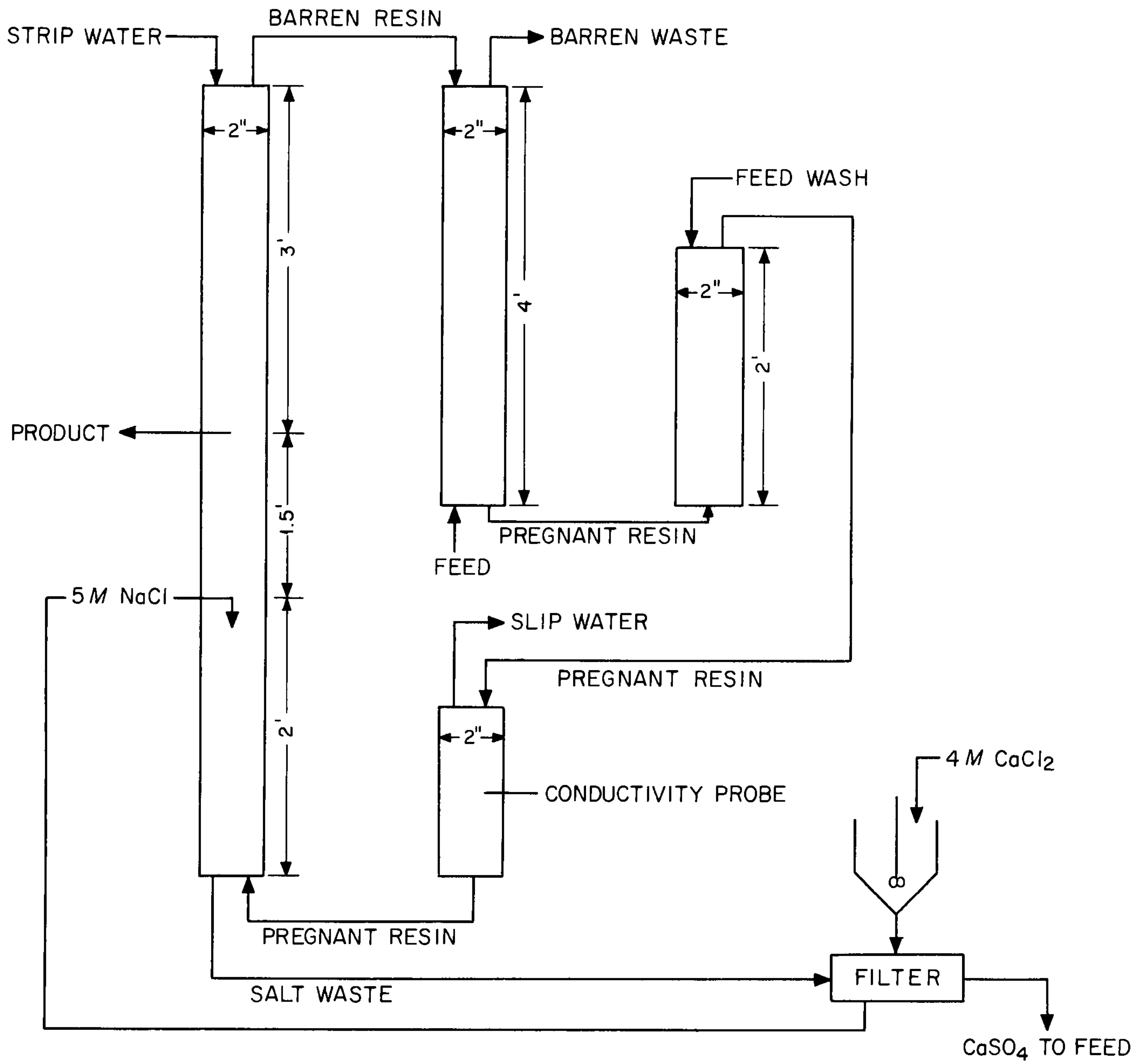

Fig. 7.4. Contactor Arrangement No. 4.

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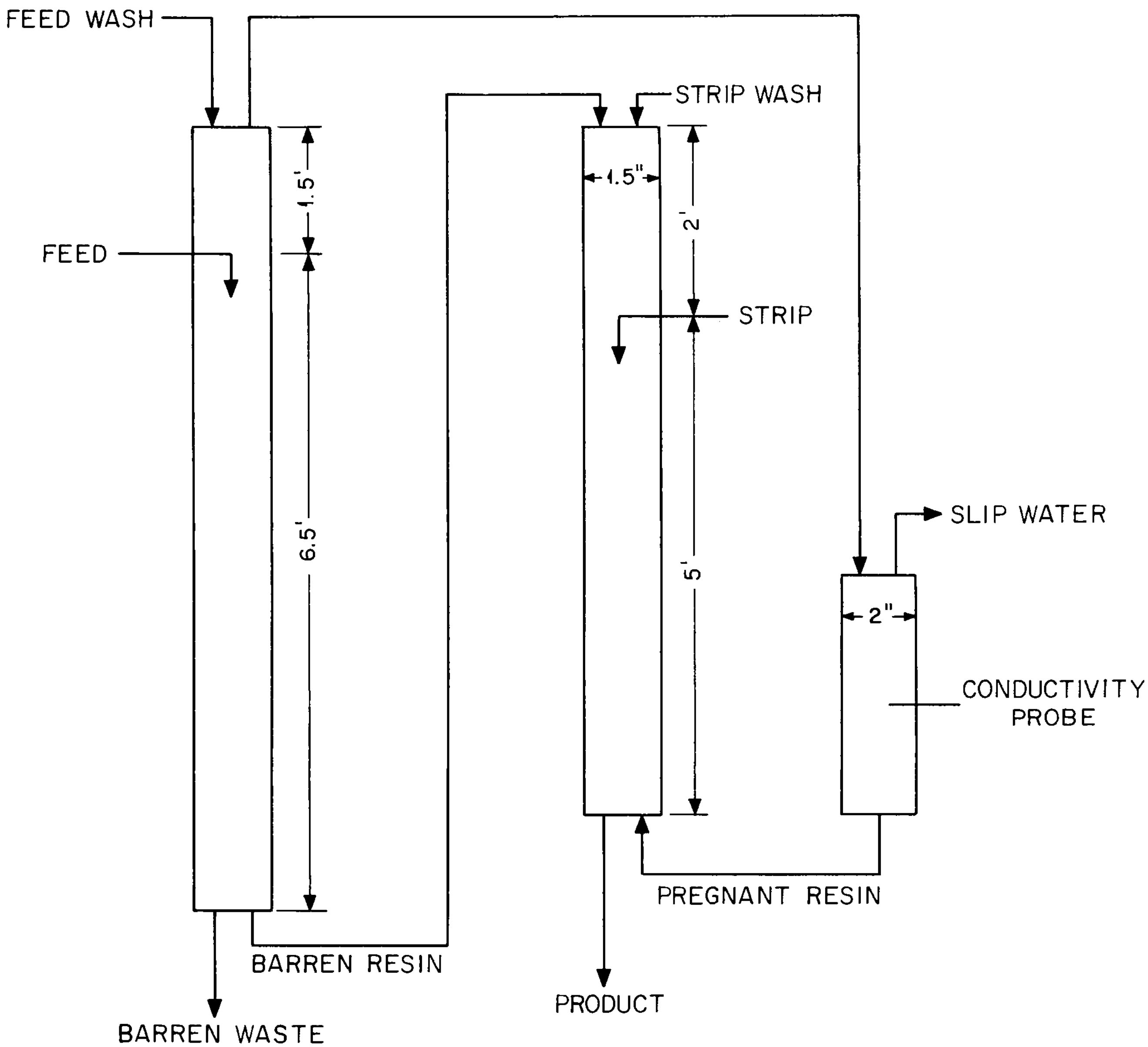

Fig. 7.5. Contactor Arrangement No. 5.

Fig. 7.1. Contactor Arrangement No. 1

Feed: Lukachukai pulp

Strip: 2 M NH_4NO_3—0.1 M HNO_3

Run Time (Hr)	Flow Rates (ml/min)						Uranium (g/liter)					
	Resin	Feed	Feed Wash	Strip	Strip Wash	0.5 M H_2SO_4	Barren Waste	Product Solution	W-A	S-1	S-2	S-3
Run 1, Nov. 24, 1954; 0.55 g U per liter in feed												
1	25	340	49	37	25	13	0.031	---	0.0015		0.071	0.205
2	25	370	56	50	50	23	0.020	---	0.0016			
3	25	310	55	30	23	13	0.0021	---	0.001			
4	25	400	55	47	33	20	0.0039	---	0.0016			
5	25	270	55	37	30	13	0.0025	---	0.0022	0.0028	0.054	0.130
6	25	430	60	37	40	20	0.0023	1.55	0.0021			
7	25	230	67	37	30	13	0.0023	1.80	0.0018			
8	25	200	--	33	30	13	0.0017	1.80	0.0016	0.022	0.050	0.640
9	35	250	55	33	30	13	0.0016	1.80	0.0016			
10	35	230	60	33	30	16	0.0015	1.37	---			
11	35	230	60	33	30	16						
Run 2, Dec. 6 and 7, 1954; 0.64 g U per liter in feed												
3	25	400	66	33	30	20	0.005	---	0.0024	0.020	0.053	1.20
4	25	400	60	33	30	20	0.0068	---	0.0012		0.102	1.99
5	25	400	66	46	33	23	0.0043	3.1	0.0019		---	---
6	25	400	66	40	30	20	0.0029	4.94	---		0.310	4.38
7	25	330	66	40	30	23	0.00076	1.83	0.0005			
8	25	400	72	43	33	20	0.0013	2.82	0.00068		0.025	1.81
9	25	400	66	40	30	23	0.0019	1.99	0.0015		0.017	

Run Time (hr)	Flow Rates (ml/min)						Uranium (g/liter)					
	Resin	Feed	Feed Wash	Strip	Strip Wash	0.5 M H_2SO_4	Barren Waste	Product Solution	W-A	S-1	S-2	S-3
Run 3, Dec. 8 and 9, 1954; 6.3% solids and 0.33 g U per liter in feed												
1	25	660	66	33	30	20	0.0018	1.40	0.00085	0.022	0.22	0.96
2	25	570	66	40	40	26	0.0017	1.84	0.0008	0.066	0.11	0.86
3	25	600	66	42	23	20	0.0018	1.34	0.0008	0.08	0.05	0.54
4	25	600	66	33	23	20	0.003	1.78	0.0014			
5	25	600	66	33	26	20	0.004	2.25	0.0015	0.016	0.09	0.49
6	25	600	66	33	30	20	0.001	3.68	0.0007			
7	25	600	60	33	33	18	0.0012	2.5	0.00094	0.0054	0.029	0.125
8	25	700	60	33	33	20	0.0012	4.9	0.0012	0.0075	0.0235	1.24
9	25	660	66	33	26	18	0.0013	5.2	0.0014	0.0077	0.330	7.68
Run 4, Dec. 10, 1954; 6.3-13% solids (0.16-0.45% >100 mesh, 1.2-4.5% >190 mesh, 1.8-4.8% >325 mesh), 0.45-0.65 g U per liter in feed.												
1	25	800	50	37	20	17		1.29				
2	25	600	60	40	40	23	0.005	3.10	0.0019	0.019	0.07	0.94
3	25	680	65	40	28	27		5.60				
4	25	680	59	33	25	43	0.0012	2.22	0.0032	0.0012	0.01	0.33
5	25	---	57	40	32	23		---				
6	25	540	57	33	28	27	0.0018	1.11	0.0008	0.001	0.01	1.22
7	25	685	63	37	30	18		3.70				
8	25	620	63	28	25	28	0.0009	4.90	0.0012	0.03	0.04	2.10
9	25	600	60	41	30	23		3.80				
10	25	640	63	40	28	23	0.0006	---	0.0012	0.004	0.04	4.05
11	25	585	59	33	30	20		2.50				
12	25	520	61	36	32	25	0.0011	7.20	0.036	0.26	1.24	17.20
13	25	320	63	40	30	21		4.90				
14	25	430	66	57	32	26	0.0042	---	0.092	0.27	0.67	15.80
15	25	620	72	54	28	25		1.33				
16	25	400	84	56	30	28	0.073	5.80	0.0057	0.44	1.14	7.43
17	25	---	50	47	30	16		4.55				
18	25	340	80	57	25	25	0.0054	2.10	0.0024	0.31	0.80	13.80

Run 4 (cont'd)

Run Time (hr)	Flow Rates (ml/min)						Uranium (g/liter)					
	Resin	Feed	Feed Wash	Strip	Strip Wash	0.5 M H_2SO_4	Barren Waste	Product Solution	W-A	S-1	S-2	S-3
19	25	340	70	47	28	25	---	---	---	---	---	---
20	25	300	63	50	30	25	0.026	---	0.0012	0.06	0.17	4.32
21	25	400	83	47	34	25	---	1.15	---	---	---	---
22	25	230	91	43	17	25	0.0018	2.08	0.0015	0.005	0.03	0.29
23	25	170	50	35	25	25		---				
24	25	480	59	37	25	26	0.0025	---	0.0022	0.05	0.28	3.40
25	25	500	59	63	34	23	---	---	---	---	---	---
26	25	---	60	37	25	25	0.0017	---	0.0019	0.09	0.37	7.9
27	25	520	57	40	22	25	---	3.2	---	---	---	---
28	25	---	--	54	27	25	---	5.2	---	---	0.92	7.80
29	25	500	53	--	--	--	---	---	---	---	---	---

Strip: 5 M NaCl, followed by water
5 M NaCl reused after sulfate removal with $CaCl_2$;
$CaSO_4$ recycled to feed

Fig. 7.2. Contactor Arrangement No. 2

Run Time (hr)	Flow Rates (ml/min)									Uranium (g/liter)				
	Resin	Feed	Feed Wash	Strip Water	Feed NaCl	Waste NaCl	Product	Slip Water	Back Wash	Barren Waste	Product	NaCl Waste	Back Wash	Slip Water
Run 5, Jan. 6-12, 1955; 8% solids (1.2% >200 mesh), 0.36 g U per liter in feed;														
1	13	660	47	30	40	40	40	3	70	---	---	---	---	---
2	13	440	45	68	36	58	20	6	70	---	---	---	---	---
3	13	600	54	30	37	43	28	21	90	0.006	2.0	0.13	---	0.036
4	13	330	37	47	37	30	30	23	90	0.0027	---	---	0.023	---
5	13	600	40	47	33	43	20	20	90	0.0018	---	0.17	---	0.024
6	13	530	53	40	36	40	20	20	68	0.002	---	0.56	---	0.025
7	13	530	40	33	33	33	17	17	68	0.0016	4.49	1.93	---	0.0094
8	13	600	53	44	37	40	20	17	68	0.0014	4.85	2.80	---	0.0064
9	13	670	48	40	37	37	18	17	68	0.0014	4.07	2.93	---	0.0062

Run 5 (cont'd)

Run Time (hr)	Flow Rates (ml/min) Resin	Feed	Feed Wash	Strip Water	Feed NaCl	Waste NaCl	Prod-uct	Slip Water	Back Wash	Uranium (g/liter) Barren Waste	Prod-uct	NaCl Waste	Back Wash	Slip Water
10	13	670	42	40	37	35	18	18	68	0.0011	4.45	3.13	---	0.0037
11	13	670	40	33	33	33	18	20	68	0.00094	8.85	4.19	---	0.0051
12	13	720	40	37	37	33	18	18	68	0.00093	10.80	2.36	---	0.0048
13	13	---	--	--	--	--	29	16	68	0.0039	7.80	1.90	---	0.0041
14	13	510	48	48	40	29	29	16	68	0.001	11.2	3.65	---	0.0047
15	13	700	--	--	--	--	23	18	68	0.0016	5.7	3.40	0.078	0.0074
17	13	---	--	53	33	40	--	17	68	0.0017	9.2	4.11	---	0.051
18	13	670	40	38	37	--	24	17	68	0.0024	11.6	5.80	---	0.028
19	13	670	40	--	37	35	--	16	68	0.0031	10.6	3.90	---	0.024
20	13	650	40	40	37	37	24	18	100	0.0030	24.4	1.82	---	0.014
21	13	620	43	45	38	32	23	20	100	0.0037	19.2	4.17	---	----
22	13	680	43	33	33	32	18	18	100	0.0026	26.6	4.25	0.0115	----
23	13	620	43	35	35	23	18	13	100	0.0018	14.5	5.42	---	0.0089
24	13	600	43	32	35	36	18	15	100	0.0022	25.6	4.17	---	----
25	13	660	49	44	42	27	20	20	100	0.004	15.8	3.87	---	0.013

Strip: 1 M NH_4NO_3--0.1 M HNO_3

Fig. 7.3. Contactor Arrangement No. 3

Run Time (hr)	Flow Rates (ml/min) Resin	Feed	Feed Waste	Strip	Strip Wash	Slip Water	Back wash	Prod-uct	Uranium Content (g/liter) Barren Waste	Prod-uct	Slip Water	Back Wash	S-1	S-2	S-3
Run 6, Jan. 21, 1955; 7% solids (1.2% >325 mesh), 0.68-0.84 g U per liter in feed															
1	13	600	37	30	30	---	23	---	0.00093	---	0.0023	0.0034	---	---	--
2	13	660	53	33	30	23	23	42	0.00074	1.58	---	---	---	---	--
3	13	700	37	33	32	23	23	35	0.00074	3.74	---	0.0041	---	0.0056	0.175
4	13	700	40	25	--	23	23	33	0.001	7.32	0.0044	---	---	---	--
5	13	660	37	30	30	23	23	28	0.001	8.13	---	---	---	---	--
6	13	---	--	23	23	31	23	19	0.00093	---	---	---	---	---	--
7	13	600	37	25	25	33	23	17	0.00077	10.30	0.0005	0.0019	---	---	--
8	13	600	33	25	27	37	20	18	0.00066	5.80	0.0006	0.006	---	---	--

Run 6 (cont'd)

Run Time (hr)	Flow Rates (ml/min)								Uranium Content (g/liter)						
	Resin	Feed	Feed Waste	Strip	Strip Wash	Slip Water	Back Wash	Prod-uct	Barren Waste	Prod-uct	Slip Water	Back Wash	S-1	S-2	S-3
9	13	600	42	25	27	33	20	18	0.00063	1.86	0.0006	---	---	---	---
10	13	630	39	27	27	65	20	44	0.00060	3.60	0.0008	---	---	---	---
11	13	660	40	27	27	33	20	25	0.00056	4.00	0.0007	---	0.01	0.048	10.37
12	13	600	39	37	33	32	20	27	0.00064	6.50	0.0006	---	---	---	---
13	13	630	39	27	27	33	20	27	0.00048	9.55	0.0006	0.003	0.009	0.008	2.80
14	19	---	33	28	28	30	24	27	0.0032	4.90	0.0004	0.004	0.034	0.007	1.58
15	19	640	42	30	29	29	24	27	0.0016	1.44	---	---	---	0.056	3.74
16	16	---	37	30	29	25	24	35	0.0021	4.45	---	---	---	0.072	3.08
17	13	---	39	33	29	25	24	40	0.0014	8.95	---	---	---	0.066	1.92
18	13	370	40	32	30	25	24	28	0.0016	11.62	---	---	---	0.17	2.20
19	13	640	40	32	29	23	24	40	0.0019	13.50	0.0005	0.007	---	0.10	1.28
20	13	370	25	19	17	23	24	21	0.0032	---	0.0006	0.009	---	0.06	0.88
21	13	415	28	26	20	25	24	24	0.0034	4.70	---	---	---	0.06	8.35
22	8.5	330	28	28	22	22	24	22	0.0031	2.44	---	---	---	0.45	12.65
23	8.5	---	25	28	19	13	24	38	0.0031	11.6	---	---	---	0.59	1.40
24	8.5	385	25	23	20	13	24	27	0.0025	40.5	---	---	---	0.09	0.82
25	8.5	400	25	22	20	13	24	30	0.0026	29.6	---	0.011	---	0.08	0.30
26	8.5	400	25	22	20	17	24	24	0.0027	19.6	0.0004	---	---	0.08	0.19
27	8.5	430	25	17	20	13	24	32	0.0016	8.70	---	0.012	---	0.05	0.04
28	8.5	425	25	22	20	13	24	29	---	8.70	---	---	---	0.03	0.03
29	8.5	---	25	22	20	13	24	30	0.0019	6.16	---	---	---	0.006	0.03
30	8.5	330	25	25	20	13	24	30	---	8.20	---	---	---	---	---
31	8.5	340	25	22	20	13	24	28	0.0019	7.50	0.005	---	---	---	---
32	13	340	25	22	20	22	24	27	---	7.5	---	---	---	0.005	---
33	13	340	25	24	20	23	24	22	0.0018	4.0	---	---	---	0.02	1.60
34	13	370	25	--	25	18	24	28	---	11.9	---	---	---	0.10	2.4
35	13	---	25	25	23	15	24	35	0.0011	18.4	---	---	---	0.14	0.9
36	13	---	25	--	--	--	24	--	---	15.4	---	---	---	---	---

Feed: Utex leach pulp

Strip: 1 M NH_4NO_3--0.1 M HNO_3

Run Time (hr)	Flow Rates (ml/min)								Uranium Content (g/liter)				
	Resin	Feed	Feed Wash	Strip	Strip Wash	Slip Water	Back Wash	Product	Barren Waste	Product	Back Wash	Slip Water	S-3
Run 7, Feb. 10, 1955; 12% solids (0.7% >325 mesh), 0.63 g U per liter in feed													
1	13	480	56	28	30	50	230	---	0.0063	---	0.005	0.0019	---
2	13	600	43	47	37	8	100	75	0.023	2.44	---	---	---
3	13	600	41	33	33	22	100	44	0.014	1.60	---	---	---
4	13	570	50	38	33	26	100	41	0.0064	2.44	---	---	---
5	13	540	44	37	33	20	100	45	0.010	2.44	---	---	---
6	13	---	44	30	27	27	170	33	0.0062	4.51	---	---	---
7	13	470	45	30	27	25	170	33	0.0096	4.85	---	---	---
8	13	490	49	33	33	23	170	40	0.006	7.40	---	---	---
9	13	720	47	40	27	23	170	38	0.0105	17.10	---	---	---
10	13	580	43	37	27	23	170	46	0.0034	11.95	---	---	---
11	13	580	--	37	27	23	170	46	0.0034	7.90	0.009	0.0018	0.395

Feed: Mallinckrodt slag leach adjusted to 3.6-5.6 g U and 26.5 g carbonate per liter; 5% slurry, 2.5% MgF_2, 2.5% MnO_2, <1% >325 mesh

Strip: 1 M $NaHCO_3$

Resin: Permutit SK, regular, 20-40 mesh

Run 8, Feb. 16-23, 1955													
1	51	450	50	33	37	---	250	---	---	---	---	---	---
2	51	450	50	57	43	---	250	---	0.240	---	---	0.00023	---
3	51	400	50	58	45	47	250	55	0.028	28.8	0.00008	---	2.35
4	51	370	50	58	45	50	250	53	0.019	34.0	---	---	0.940
5	51	330	50	60	50	50	250	63	0.0067	28.6	---	---	3.91
6	51	400	50	67	50	53	250	62	0.00305	27.4	---	---	3.00
7	51	400	50	67	50	53	250	63	0.00135	27.4	---	---	2.75
8	51	430	50	67	50	50	250	58	0.0047	14.1	---	---	---
9	51	430	50	67	50	50	250	63	0.0035	27.2	---	---	---

Run 8 (cont'd)

Run Time (hr)	Flow Rates (ml/min) Resin	Feed	Feed Wash	Strip	Strip Wash	Slip Water	Back Wash	Product	Uranium Content (g/liter) Barren Waste	Product	Back Wash	Slip Water	S-3
10	51	430	50	67	50	50	250	63	0.0030	24.8	0.00015	0.00023	---
11	51	460	50	67	50	--	250	--	---	---	---	---	0.36
12	51	430	50	60	50	50	250	63	0.0035	---	---	---	1.72
13	51	430	50	63	50	50	250	63	---	22.0	---	---	2.54
14	77	400	67	77	67	--	300	50	---	24.8	---	---	1.64
15	77	390	83	95	77	79	300	93	---	26.4	---	---	5.75
16	77	370	83	95	100	83	300	150	0.02	16.4	---	---	1.62
17	77	400	83	120	100	80	300	150	---	10.8	---	0.00098	2.14
18	77	400	83	120	100	83	300	140	---	11.74	0.00011	---	1.72
19	77	400	83	120	100	83	300	140	0.0043	13.36	---	---	2.12
20	77	400	83	120	100	80	300	75	0.0077	11.2	---	---	---
21	77	400	83	120	100	80	300	140	0.018	13.7	---	---	---
22	77	---	83	120	100	80	300	138	0.0128	14.6	---	---	---
23	77	320	83	118	100	80	300	140	0.010	13.6	---	---	---
24	77	420	83	126	100	80	300	140	0.004	7.9	---	---	---
25	77	420	83	118	100	80	330	140	0.006	11.2	---	---	---
26	77	390	83	---	100	80	330	140	0.005	13.5	---	0.00015	---
27	77	360	83	118	100	80	330	132	0.0025	10.6	---	---	---
28	77	450	83	136	100	80	330	132	0.0032	11.9	---	---	---
29	77	---	83	118	100	80	330	132	0.0075	15.4	---	---	---
30	77	---	83	118	100	80	330	132	0.550	14.6	---	---	---
31	77	530	83	118	100	80	330	132	0.550	16.6	---	---	---
32	77	670	83	118	100	80	330	140	1.10	17.8	---	---	---
33	77	600	83	118	100	80	330	132	---	18.4	0.003	0.00034	---

Feed: Synthetic; 0.1 M $MgSO_4$, 0.05 M H_2SO_4, 10% bentonite, 0.94 g U per liter

Strip: 1 M NH_4NO_3--0.1 N HNO_3

Resin: Permutit SK-20

Run 9, March 1, 1955

Run Time (Hr)	Flow Rates (ml/min)								Uranium Content (g/liter)			
	Resin	Feed	Feed Wash	Strip	Strip Wash	Slip Water	Back Wash	Product	Barren Waste	Product	S-2	S-3
1	11	420	83	46	43	23	300	70	0.0036	---	---	---
2	11	430	50	33	31	17	300	47	0.0015	---	---	---
3	11	400	67	29	31	23	210	40	0.0024	---	---	---
4	11	450	50	26	18	20	150	26	0.005	---	---	---
5	11	450	63	25	25	22	---	26	0.0142	---	---	---
6	11	450	58	25	23	28	166	18	0.11	---	---	---
7	11	450	33	25	23	28	166	18	---	---	---	---
Feed diluted 1/2, 5% bentonite, 0.442 g U per liter												
8	11	800	66	33	23	32	250	28	3.125	4.40	---	---
9	11	880	61	27	23	25	170	23	0.140	8.10	---	---
10	11	740	70	23	23	26	170	23	0.140	12.08	---	0.07
11	11	820	66	27	23	26	170	--	---	14.20	---	0.460
Feed: Lukachukai pulp, 6% solids, 0.325 g U per liter												
12	13	800	66	25	17	32	170	17	0.0025	---	---	---
13	13	860	66	27	20	26	170	28	0.0026	---	---	---
14	13	830	66	22	43	26	170	26	0.0025	---	---	---

Feed: Synthetic, 0.1 M $MgSO_4$, 0.05 M H_2SO_4, 0.92 g U per liter

Run 10

1	11	700	66	23	--	18	118	41	0.0013	21.0	---	---
2	11	600	66	33	30	17	118	45	---	---	---	---
3	11	650	66	36	20	18	118	43	0.002	9.76	---	0.46
4	11	630	66	25	20	18	118	32	---	---	---	---
5	11	---	66	26	23	18	118	28	0.0021	9.56	---	0.18

Run 10 (cont'd)

Run Time (hr)	Flow Rates (ml/min)								Uranium Content (g/liter)			
	Resin	Feed	Feed Wash	Strip	Strip Wash	Strip Water	Back Wash	Product	Barren Waste	Product	S-2	S-3
6	11	600	66	26	23	18	118	30	---	---	---	---
7	11	600	66	26	20	18	118	28	0.0022	14.50	---	0.16
8	11	615	66	26	23	18	118	30	---	---	---	---
9	11	615	66	26	23	18	118	30	0.0023	16.52	---	0.14
10	11	615	66	26	23	18	118	28	---	---	---	---
11	8.5	600	66	20	16	15	118	27	0.004	14.2	---	0.03
12	8.5	570	58	16	16	15	118	27	---	17.9	---	---
13	8.5	580	58	18	16	13	118	24	0.023	17.6	---	---
14	8.5	600	66	20	16	15	118	23	---	15.7	---	---
15	8.5	600	58	20	16	13	118	23	0.103	19.6	---	0.05
16	8.5	600	66	20	16	15	118	25	0.052	13.1	---	---
17	8.5	600	63	20	16	13	118	22	0.084	---	---	---
18	8.5	640	66	17	16	14	118	20	0.094	16.4	0.003	0.072
19	8.5	600	65	16	15	14	118	18	0.102	---	---	---
20	8.5	600	66	16	15	14	118	18	0.200	19.24	0.009	0.16
21	8.5	600	66	16	15	14	118	18	0.200	---	---	---
22	8.5	600	66	16	15	13	118	18	0.195	21.3	---	---
23	8.5	600	66	16	15	13	118	18	0.180	---	---	---
24	8.5	600	66	16	15	13	118	18	0.160	22.0	0.009	0.82
25	21	915	86	23	20	23	133	27	0.138	28.3	0.023	2.28
26	21	915	80	30	22	20	133	33	0.125	25.2	---	---
27	17	915	83	30	25	18	133	41	0.148	35.6	---	---
28	17	915	74	33	26	18	133	41	0.125	25.2	0.076	3.50
29	17	1000	77	33	28	20	133	40	0.112	22.8	---	---
30	17	900	83	30	25	18	133	33	0.086	23.6	0.10	0.82

Feed: 0.47 g U per liter

Run Time (hr)	Resin	Feed	Feed Wash	Strip	Strip Wash	Strip Water	Back Wash	Product	Barren Waste	Product	S-2	S-3
31	8.5	1120	63	16	15	12	133	23	0.0152	19.8	---	0.188
32	8.5	1200	63	16	15	10	133	22	0.029	24.9	---	0.188
33	8.5	1200	60	16	15	12	133	22	0.023	15.6	---	0.054
34	8.5	1200	60	16	15	12	133	22	0.030	23.6	---	0.030
35	8.5	1200	60	16	15	12	133	22	0.036	21.6	---	0.034

Run Time (hr)	Flow Rates (ml/min)								Uranium Content (g/liter)			
	Resin	Feed	Feed Wash	Strip	Strip Wash	Slip Water	Back Wash	Prod-uct	Barren Waste	Prod-uct	S-2	S-3
Feed: Utex pulp, 12% solids, 0.71 g U per liter; Strip: 1 M NH_4NO_3 (used once) containing 36.6 g SO_4 per liter												
36	10	620	47	18	15	13	133	21	0.085	15.8	---	0.28
37	10	670	53	17	18	17	133	18	0.075	15.2	---	0.50
38	10	400	60	20	15	18	133	18	0.028	10.0	---	2.66
39	10	640	53	20	15	17	133	18	0.059	11.0	---	---
40	10	640	---	28	15	17	133	27	0.084	13.7	---	---
41	10	640	53	33	17	20	133	35	0.030	21.8	---	---
42	10	570	67	27	17	15	133	37	0.047	23.6	0.63	4.17
43	10	500	67	38	17	15	133	38	0.021	19.64	0.64	4.17
44	10	420	67	35	17	13	133	38	0.027	16.40	0.27	2.75
Feed: Utex pulp, 8% solids, 0.50 g U per liter												
45	10	840	---	27	17	13	133	33	0.019	---	---	---
46	10	980	70	27	17	15	133	27	0.036	---	---	---
47	10	800	67	31	17	16	133	28	0.056	13.2	0.344	2.94
48	10	1000	---	25	17	18	133	25	0.087	10.10	---	---
49	10	920	110	30	17	22	133	23	0.096	9.96	---	---
50	10	---	---	27	17	18	133	23	0.078	11.04	1.10	5.00

Feed: Synethetic, 0.2 M $MgSO_4$, 0.05 M H_2SO_4, 0.73 g U per liter

Strip: 1 M NH_4NO_3--0.1 N HNO_3; 0.5 M $(NH_4)_2$ SO_4 stream introduced 1.5 ft above strip inlet

Contactor arrangement No. 3

Run 11, April 4-5, 1955

Run Time (Hr)	Flow Rates (ml/min)								Uranium Content (g/liter)			
	Resin	Feed	Feed Wash	Strip	Strip Wash	0.5 M H_2SO_4	Slip Water	Prod-uct	Barren Waste	Prod-uct	S-2	S-3
1	11	730	67	23	15	10	---	---	0.019	---	---	---
2	11	630	53	25	14	12	12	30	0.0095	---	---	---
3	11	600	53	22	14	10	15	32	0.007	---	---	---

Run 11 (cont'd)

Run Time (hr)	Flow Rates (ml/min) Resin	Feed	Feed Wash	Strip	Strip Wash	0.5 M H_2SO_4	Slip Water	Prod-uct	Uranium Content (g/liter) Barren Waste	Prod-uct	S-2	S-3
4	11	630	64	15	14	12	13	33	0.0051	6.36	---	0.35
5	11	---	---	---	14	10	13	25	0.0043	13.2	---	---
6	11	600	53	18	14	10	13	27	0.0195	12.3	---	0.26
7	12	600	67	17	14	12	13	25	0.003	12.7	---	---
8	12	570	50	10	12	10	12	30	0.0036	16.3	---	---
9	12	630	56	13	10	12	13	25	0.0036	18.0	---	1.09
10	12	---	64	15	12	10	13	22	0.0036	16.4	0.032	1.20
11	12	600	50	15	14	10	13	25	0.0078	21.9	---	1.76

Strip: 1 M NaCl; 0.1 M HCl stream introduced 1.5 ft above inlet

Run 12, April 6-7, 1955

1	12	630	67	20	15	---	12	27	0.002	19.8	---	---
2	12	610	67	22	14	---	15	24	0.0015	19.8	---	---
3	12	600	67	23	14	---	13	30	0.0034	16.4	0.084	2.26
4	12	600	56	22	14	---	13	24	0.0044	17.0	0.074	6.3
5	12	600	64	22	14	---	13	22	0.0027	14.0	0.096	10.0
6	12	600	56	23	14	---	13	24	0.0028	12.8	0.127	8.48
7	14	600	67	26	15	---	14	30	0.0128	12.8	0.098	7.43
8	14	580	57	26	15	---	14	28	0.0152	14.8	0.230	---
9	14	670	58	36	18	---	28	32	0.021	14.4	1.42	13.9
10	14	580	58	35	18	---	15	35	0.030	16.8	1.56	---
11	14	600	64	35	18	---	15	35	0.014	16.4	0.71	8.4

Feed: Synethetic, 0.2 M $MgSO_4$, 0.05 M H_2SO_4, 0.64 g U per liter

Resin: Permutit SK-20

Strip: 5 M NaCl

Fig. 7.4. Contactor Arrangement No. 4

Run Time (hr)	Flow Rates (ml/min)								Uranium Concentration (g/liter)		
	Resin	Feed	Feed Wash	Strip Water	Strip NaCl	Waste NaCl	Slip Water	Product	Barren Waste	Product	Waste NaCl
					Run 13, May 4, 1955						
1	12	670	58	25	30	33	12	10	0.0013	---	---
2	12	600	50	21	25	23	12	9	---	---	---
3	12	600	58	13	25	20	12	10	0.0008	42.32	---
4	12	600	50	20	25	28	9	8	---	---	5.32
5	12	600	58	20	25	29	10	7	0.0049	---	---
6	12	---	50	20	25	30	9	9	---	---	5.16
7	12	600	58	20	25	23	9	9	0.0029	23.3	8.1
8	12	600	58	20	25	26	9	9	0.0029	44.9	---
9	12	580	58	17	24	26	9	4	---	46.2	---
10	12	620	58	20	25	29	9	5	0.0011	46.6	---
11	12	600	58	18	25	23	9	6	---	45.6	---
12	12	640	58	17	24	23	9	9	0.0049	55.6	---
13	12	640	58	20	25	26	9	9	---	53.6	9.2
				Feed: Changed to Utex pulp, 8% slurry, 0.5 g U per liter, recycled salt contained 23.7 g sulfate per liter							
14	12	660	100	18	25	27	12	9	0.0039	44.8	---
15	12	700	100	18	23	23	12	9	0.0052	51.7	---
16	12	700	100	22	25	22	12	9	0.0038	45.0	---
17	12	640	100	20	25	21	13	9	0.0041	44.4	---
18	12	---	100	22	23	23	13	10	0.006	44.4	---
19	12	600	100	20	25	25	12	10	0.0089	48.0	9.2

Feed: Los Ochos pulp, 11% solids; 0.86 g U per liter

Resin: Amberlite XE-123

Recycled NaCl contained 10.4 g sulfate per liter

Run Time (hr)	Flow Rates (ml/min)								Uranium Concentration (g/liter)		
	Resin	Feed	Feed Wash	Strip Water	Strip NaCl	Waste NaCl	Slip Water	Prod-uct	Barren Waste	Prod-uct	Waste NaCl
					Run 14, May 11-19, 1955						
1	13	660	66	22	23	23	12	10	0.0056	8.85	---
2	13	660	66	25	25	17	25	9	0.019	14.4	---
3	13	660	66	23	23	18	25	8	0.025	5.8	---
4	13	710	44	40	22	38	22	5	0.0275	48.6	---
5	13	---	60	33	25	44	22	8	0.030	68.2	---
6	13	680	60	33	23	30	22	8	0.132	64.0	---
7	13	---	66	27	27	44	20	8	0.230	44.6	---
8	13	630	90	20	25	20	17	7	0.320	20.8	---
9	13	---	---	---	---	17	---	---	0.124	22.8	---
					Feed: Los Ochos, 8% slurry, 0.98 g U/l						
10	13	640	78	22	26	26	22	8	0.250	40.4	---
11	13	670	80	37	25	32	23	5	0.192	56.6	---
12	13	650	65	23	28	23	20	9	0.236	58.0	---
13	13	650	83	32	25	32	20	9	0.230	77.8	---
14	13	---	83	30	32	30	20	8	0.300	61.2	---
15	13	640	83	23	30	23	20	8	0.250	62.4	---
16	13	280	83	27	25	17	20	9	0.082	60.4	---
17	13	560	66	22	27	27	20	10	0.032	63.2	---
18	13	510	67	36	27	32	17	9	0.0112	75.9	---
19	13	530	73	31	27	33	17	10	0.012	31.2	---
20	13	500	73	24	27	25	12	10	0.013	38.4	---
21	13	330	67	18	23	20	9	9	0.018	54.2	---
22	13	370	67	27	23	23	9	10	0.017	65.5	---
23	13	420	67	27	23	23	9	10	0.015	55.9	---

Run 14 (cont'd)

Run Time (hr)	Flow Rates (ml/min)								Uranium Concentration (g/liter		
	Resin	Feed	Feed Wash	Strip Water	Strip NaCl	Waste NaCl	Slip Water	Prod-uct	Barren Waste	Prod-uct	Waste NaCl
					Feed: 0.70 g U per liter						
24	13	470	81	33	57	74	---	16	0.00046	---	---
25	13	570	100	35	33	46	---	14	0.0007	---	---
26	13	360	130	50	33	42	25	15	0.00084	---	---
27	13	580	92	62	33	58	25	13	0.00092	---	---
28	13	440	83	50	33	52	22	12	0.00145	---	---
29	13	440	83	40	33	42	22	11	0.039	---	---
30	13	450	83	33	33	32	15	14	0.0012	---	---
31	10	480	78	35	28	26	14	14	0.0013	---	---
32	10	450	83	36	22	17	20	18	0.0010	16.8	---
33	10	415	83	33	30	32	17	13	0.0010	32.8	---
34	10	450	78	35	12	12	14	13	0.003	27.7	---
				Mechanical breakdown (broken screen) Feed: 0.73 g U per liter							
35	13	630	83	35	33	42	17	13	0.030	---	---
36	13	700	83	35	33	33	20	12	0.027	---	---
37	13	670	83	36	33	37	20	12	0.035	---	---
38	13	520	83	36	33	40	20	12	0.033	---	---
39	13	570	83	36	33	38	20	12	0.043	10.9	---
40	13	550	83	36	33	36	22	12	0.028	---	---
41	13	550	83	36	33	38	20	11	0.016	12.9	---
42	13	570	83	36	33	36	20	12	0.012	---	---
43	13	600	83	36	33	36	20	12	0.011	30.1	---
					Feed: 0.5 g U/l						
44	10	250	83	33	33	42	17	12	0.0096	---	---
45	10	415	83	33	33	42	20	12	0.012	---	---
46	10	330	70	30	30	22	9	12	0.0066	---	---
47	10	415	83	24	33	28	20	13	0.0071	28.9	---
48	10	415	80	33	33	38	20	12	0.0066	39.9	---

Feed: Los Ochos pulp, 0.63-0.76 g U per liter

Strip: 0.9 M NH_4NO_2, 0.1 N H_2SO_4

Resin: Permutit SK-20

Fig. 7.5. Contactor Arrangement No. 5

Run 15, Aug. 4, 1955

Run Time (hr)	Flow Rates (ml/min)							Uranium Concentration (g/liter)	
	Resin	Feed	Feed Wash	Strip	Strip Wash	Slip Water	Product	Barren Waste	Product
1	13	700	90	44	70	---	---	---	---
2	13	400	50	50	50	42	67	---	---
3	13	620	80	100	46	13	116	0.0115	---
4	13	600	60	66	53	---	---	---	---
5	13	---	---	---	---	---	---	0.012	---
6	13	450	53	62	57	17	108	0.0032	---
7	13	680	66	62	58	29	67	0.0052	
8	13	540	48	38	30	20	58	0.002	10.6
9	13	680	53	38	30	23	48	0.003	9.88

Strip: 1.03 M NO_3^- , 0.21 M H^+, 0.4 M $SO_4^=$

10	13	580	60	30	30	35	35	0.00065	12.8
11	13	330	58	33	25	22	37	0.00084	12.0
12	13	590	53	33	28	22	42	0.00058	11.2
13	13	600	58	33	26	20	45	---	10.6
14	13	600	55	33	25	20	43	0.00070	11.17
15	13	640	50	33	24	20	40	0.0013	---
16	13	520	55	30	24	20	38	0.0055	---
17	13	530	58	53	27	20	58	0.0069	---
18	13	530	53	50	26	20	50	0.0095	9.46
19	13	830	---	50	26	20	70	0.0075	9.88

Strip: 0.6 M NO_3^-, 0.3 M H^+, 0.6 M $SO_4^=$

20	10	670	58	50	20	13	70	0.0062	---
21	10	630	58	55	25	14	59	0.0083	---
22	10	630	55	30	17	15	33	0.0088	---
23	10	630	55	22	17	15	30	0.015	---
24	10	---	---	37	---	---	---	---	---
25	10	---	---	37	---	17	38	---	---

Feed: Synthetic, 0.2 M $MgSO_4$, 0.05 M H_2SO_4, 0.94 g U per liter

Strip: 1 M NaCl, 0.05 M H_2SO_4

Contactor arrangement No. 5

Run 16, Aug. 23, 1955

Run Time (hr)	Flow Rates (ml/min)							Uranium Concentration (g/liter)	
	Resin	Feed	Feed Wash	Strip	Strip Wash	Slip Water	Product	Barren Waste	Product
1	10	385	50	50	17	13	66	0.012	---
2	10	400	50	42	17	12	50	0.008	---
3	10	400	50	25	17	12	33	0.0011	---
4	10	400	50	25	17	12	27	0.0021	7.5
5	8	415	50	20	17	15	25	0.00265	10.0
6	8	380	50	20	21	8	21	0.00205	11.2
7	8	415	50	20	12	12	25	0.00103	10.3
8	8	400	50	20	17	12	20	0.00078	6.1
9	8	400	50	20	17	12	21	0.00115	4.8
10	8	400	50	20	17	12	20	0.0018	10.0
			Feed: 0.97 - 1.11 g U per liter						
11	8	400	50	17	17	10	25	0.00135	9.4
12	8	400	50	17	17	12	27	0.00025	8.7
13	8	400	50	17	17	12	27	0.0018	8.7
14	8	380	50	17	17	12	25	0.0019	6.7
15	8	400	50	22	17	12	25	0.0032	5.9
16	8	380	50	22	17	12	27	0.0038	6.5
17	8	400	50	33	17	12	42	0.0052	5.8
18	8	380	50	33	17	12	33	0.011	8.5
19	8	350	50	33	17	12	48	0.012	9.2
20	8	415	50	33	17	12	43	0.013	8.6
21	8	400	50	33	17	12	44	0.026	8.3
22	15	530	50	33	33	50	33	0.011	15.1
23	15	435	50	41	33	18	47	0.018	18.8
24	15	530	50	41	33	17	52	0.021	16.0
25	15	530	50	41	33	17	60	0.010	12.5
26	15	600	50	41	33	18	62	0.009	9.1

Run 16 (cont'd)

Run Time (hr)	Flow Rates (ml/min) Resin	Feed	Feed Wash	Strip	Strip Wash	Slip Water	Product	Uranium Concentration (g/liter) Barren Waste	Product
				Feed: 0.87 g U per liter					
27	25	750	58	50	47	30	67	0.050	8.9
28	25	830	58	50	37	33	67	0.035	10.8
29	25	885	61	92	46	37	102	0.039	10.2
30	25	830	70	80	30	30	85	0.32	7.6

Feed: Synthetic, 0.2 M $MgSO_4$, 0.05 M H_2SO_4, 0.96 g U per liter

Strip: 1 M NH_4NO_3, 0.1 M HNO_3

Resin: Permutit SK-20

Run 17, Sept. 8, 1955

Run Time (hr)	Resin	Feed	Feed Wash	Strip	Strip Wash	Slip Water	Product	Barren Waste	Product
1	40	750	58	100	87	33	---	0.043	6.10
2	40	830	58	130	87	33	215	0.031	9.6
3	40	830	58	130	87	33	200	0.007	5.0
4	40	830	58	116	87	41	170	0.014	7.6
5	40	830	58	116	87	33	200	0.014	5.6
				Feed: 1.0 g U per liter					
6	50	1080	58	100	87	10	170	0.002	6.3
7	50	1000	58	100	87	10	170	0.006	7.1
8	50	1000	60	102	104	14	225	0.015	8.0
9	50	950	57	98	94	10	170	0.017	7.3
10	50	920	58	100	87	10	170	0.034	6.8
11	50	1000	58	100	87	10	170	0.006	5.5
12	60	1180	50	100	92	8	132	0.0148	5.5
13	60	1220	58	100	87	8	132	0.0012	---
14	60	1300	58	87	80	9	150	0.053	---
15	60	1400	58	110	70	9	150	0.021	---
16	60	1280	58	100	90	7	150	0.029	7.0

Feed: 0.94 g U per liter

Strip: 0.9 M NH_4NO_3, 0.1 N H_2SO_4

Run 18, Oct. 3 - 11, 1955

Run Time (hr)	Flow Rates (ml/min)							Uranium Concentration (g/liter)	
	Resin	Feed	Feed Wash	Strip	Strip Wash	Slip Water	Product	Barren Waste	Product
1	10	---	33	20	17	---	---	0.006	6.8
2	10	630	33	23	25	18	30	0.014	11.4
3	10	620	33	23	25	20	30	0.013	11.2
4	10	620	33	23	25	17	30	0.022	15.6
5	10	620	33	23	25	17	30	0.019	16.7
Strip: 0.9 M NH_4NO_3, 0.1 N H_2SO_4, 0.31 M $(NH_4)_2SO_4$									
6	10	580	30	17	20	18	20	0.0029	19.1
7	10	580	33	25	20	14	37	0.0030	16.6
8	10	500	35	33	20	17	43	0.010	7.7
9	10	580	33	25	23	14	45	0.012	4.4
10	10	600	33	27	24	17	37	0.009	10.3
Strip: 0.9 M NH_4NO_3, 0.1 N H_2SO_4, 0.63 M $(NH_4)_2SO_4$									
11	10	550	33	27	20	14	43	---	---
12	10	580	33	32	23	14	43	0.0084	---
13	10	660	33	35	35	15	50	---	---
14	10	600	33	32	22	15	43	---	15.0
15	10	---	33	---	25	15	42	---	---
16	10	600	33	33	23	17	43	0.007	12.2
Strip: 0.9 M NH_4NO_3, 0.1 N H_2SO_4, 1.05 M $(NH_4)_2SO_4$									
17	10	600	33	33	25	17	50	0.0037	12.0
18	10	620	37	38	25	14	50	0.0074	12.4

Run 18 (cont'd)

Run Time (hr)	Flow Rates (ml/min)							Uranium Concentration (g/liter)	
	Resin	Feed	Feed Wash	Strip	Strip Wash	Slip Water	Product	Barren Waste	Product
Strip: 0.9 <u>M</u> NH_4NO_3, 0.1 <u>N</u> H_2SO_4, 1.05 <u>M</u> $MgSO_4$									
19	10	500	33	33	23	17	37	0.0116	14.9
20	10	500	37	40	23	14	52	0.0112	16.0
21	10	500	35	38	26	15	50	0.0081	7.2
22	10	500	35	33	23	14	47	0.0066	13.2