THE DESIGN OF A CONTINUOUS ION-EXCHANGE PILOT PLANT FOR THE RECOVERY OF URANIUM FROM PARTIALLY CLARIFIED SOLUTIONS

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SYNOPSIS

A preliminary design is given for a pilot plant to recover uranium from partially clarified slime pulp by continuous ion exchange.   Process and plant-design methods are indicated briefly, and an outline is given of experimental work that should be undertaken before the start-up of the pilot plant.

CONTENTS

1. INTRODUCTION

For this study, it was necessary to produce a design for a pilot plant for recovering uranium from a partially clarified slimes pulp. The feed could range from a rate of 5.46 m^3/h and a concentration of 80 p.p.m. of uranium to a rate of 24.5 m^3/h, and a concentration of 18 p.p.m. of uranium. The pulp could contain about 13 per cent by weight of solids. A recovery of 90 per cent was to be obtained.

The amount of solids in the feed makes impossible the use of any contactor based on packed beds of ion-exchange resin, and various types of contactors based on the upward flow of solution through an unrestrained bed of resin have to be considered. In an Atomic Energy Board report[1] it is mentioned that a contactor developed by George et al.[2] in the United States Bureau of Mines has been selected. However, the reasoning behind this decision is not given in the report. A critical survey of the various published types of contactor suggests, that, for few contacting stages, the conventional multistage fluidized bed with valved downcomers (U.S. PAT. 2,632,720/1953) with an offset perforation tray (Brit.Pat.I,070,251/1967) would be the simplest. However, for the 5-to-1 range of flow-rates required, it is doubtful whether stable operation of the downcomers would be achieved. The lack of available studies of the hydraulic stability of the George contactor, and its obvious liability to dumping of the resin holdup on stoppage of the feed, make it unsuitable here, as discussed in Appendix II. Suitable improvements to the George type of contactor to overcome the possibility of dumping and to control the flow of resin between stages make it identical with the contactor already described by the investigator[3][4]. Therefore, the design suggested initially for this work is that already described[3]. This can be used in South Africa because there is no patent cover for this or most other designs in this country.

There remains some uncertainty about both the process and the design of the plant, and this could be cleared up more quickly in simple experiments than in the pilot plant itself. The outline of the experimental work necessary is given in the Appendices, and this could be put in hand straightaway. The data provided by manufacturers of ion-exchange resin are usually for use in conventional fixed-bed plants operated cyclicly, and this information is not adequate for the design of continuous ion-exchange processes.

RECOVERY OF URANIUM FROM PARTIALLY CLARIFIED SLIMES PULPS

The investigator is aware that at least four firms in the United Kingdom are carrying out development work on the engineering of continuous ion-exchange plants. Some of this work is very similar to the experimental work recommended in Appendix II. If there is any urgency about the construction of the pilot plant, it would be quicker to see first whether any of the work in the United Kingdom is applicable. However, if National Institute for Metallurgy (or the Chamber of Mines) wishes to retain the engineering know-how so that it can act as a consultant or contractor if full-scale plants are subsequently built, there would be sound reason not to share information with an engineering company. As manufacturers of ion-exchange resins have already been asked to produce RIP-type (resin-in-pulp) samples, the industry must know that there is now interest in RIP processes.

The pilot plant is not designed for minimum cost because of the requirement that it should handle a wide range of feed rates. There are more pumps than may be required on a full-scale plant, and the contactors have more stages than may really be necessary. These provisions allow operations to be varied to obtain different recoveries and product concentrations.

2. PROCESS DESIGN

This process design is based on the equilibrium data given in reference 5, and is generally similar to the process used by the United States Bureau of Mines[2]. The process is outlined in the block flow diagram (Figure 1) with appropriate quantities in the form of symbols for use in further calculations or computer programmes.

In dealing with resin, it must be recognized that solution is held in the pores of the resin and, unless wash water is used, this entrapped solution will contaminate other sections of the process. In some instances this contamination may not matter but for this design it is required to completely separate the impure feed from the pure eluate product. The minimum quantity of wash water with the suggested flowsheet is equal to the absolute volume of the resin that is displaced when the resin settles into the receiving vessel. Provision is made for increasing this minimum quantity by the use of an additional pump. The quantities of wash water are insignificant in comparison with the flow of feed; so this aspect of the process should present no problem.

The volume of transfer water associated with the resin has been shown[6] to be, to a close approximation, equal to (settled void fraction + $^1/_9$)x (settled volume of resin transferred). Should a different method of transferring the resin be used, such as ejectors, then this volume would be substantially increased.

The operating diagram (Figure 2) for the extraction process has been drawn up from equilibrium data[5]. For the two extremes of concentration of feed solution, the operating lines have been drawn for 90 per cent recovery of uranium in the feed, and for the resin to be loaded to 90 per cent of its capacity at the feed concentration and to be eluted down to a residual uranium concentration of 10 per cent of its capacity. It is clear from this diagram that the process with the more concentrated feed not only will produce a more concentrated eluate product but also will require less interfacial area for mass transfer because it is an easier separation. It also has the advantage that the slope of the operating line is less than it is for the dilute feed, and so the contactor could be smaller.

It has not been possible to draw the operating diagram for the elution process, because no equilibrium data are readily available. On the other hand, George[2] gives a flow ratio of about 3 when 1.5M sulphuric acid is used, which is claimed to elute 95 per cent of the uranium on the resin. This information appears to be adequate for the design of the elution process. He also quotes a residence time for the resin of 235 minutes, which is helpful in establishing the number of stages required in the elution contactor since this part of the process is probably solid-diffusion controlled. He mentions that a temperature of 55°C to 60°C was used, which may suggest that provision should be made on the pilot plant for heating jackets to be fitted to the elution contactor. In general, it should be noted that the elution process can contain a fairly large number of stages without significant additional cost either of plant or of resin. The large number of stages will enable the actual operating line to approach the equilibrium line, and thus to give a higher concentration of uranium in the eluate.

The solution in contact with the resin in the elution contactor will result from the mixing of the eluant feed with the wash water fed in and displaced from the bottom of the column. If it proves necessary to use more wash water than the minimum, and if this quantity is diluting the product undesirably, then a more concentrated eluant can be used, which is then diluted down to the required strength in the contactor by the wash

water.

3. PLANT DESIGN

This section of the report refers to the E.F.D. (Engineering Flow
Diagram) (Figure 3), which shows all significant items of plant in the form
of a flowsheet in elevation.   In some cases the specifications cannot be set
with any certainty until work suggested in the Appendices has been completed.
However, most of the main items can be designed in detail or ordered on the
basis of these specifications, because these will be unaltered whatever tray
design is finally settled on.   The plant layout can also be started for the
same reason.

3.1. *EXTRACTION CONTACTOR (C1)*

This contactor has to process a feed containing up to about 6 per cent
of solids.   The operating range must cover 5.46 m^3/h to 24.5 m^3/h of feed
solution as average flow-rates.   The resin flow-rates are about
0.00937 m^3/h to 0.0172 m^3/h for the same range of feed rates, although
these are minimum values.

The diameter of the column sections will depend on the fluidizing
velocity that can be tolerated by the resin used in the actual pulp.   Once
this maximum velocity is established by experiments (Appendix I), the
diameter required follows simply from a knowledge of the maximum average
flow-rate (24.5 m^3/h), and the maximum instantaneous flow-rate. (24.5/0.9 =
27.3m^3/h)   The column cross-sectional area is obtained simply from dividing
the maximum instantaneous flow-rate by the maximum fluidizing velocity for
the system selected.   The height of each stage will depend on the results
of hydraulic tests to be carried out (Appendix II).   Similarly, the number
of stages will depend on the effective mass-transfer coefficients measured
with the actual pulp solutions.

Features of the column that are suggested in the E.F.D. include a
conical base of included angle 60°, an inclined baffle extending to the
centre line above the connection shown, an expanded top with launder
overflow protected by a 40-mesh wire screen to prevent loss of resin
particles that may be carried over, alternative resin connections to the
top three stages, and alternative feed connections to the bottom three
stages, and alternative feed connections to the bottom three stages. Each
stage should also have a ½-inch sampling point just above the tray and a

pair of large windows near the top of the section.   (See also Figure 4).

3.2. *ELUTION CONTACTOR (C2)*

Each part of this column has a different function, as indicated on the
E.F.D. The top section is provided to wash out any pulp that may be carried
over from the extraction column, because the higher velocity required would
use more water in the large-diameter column.   Some of the wash water fed in
near the top may be allowed to come out with the product, or, some product
may be recycled back with the washed-out pulp.

The elution section will take up most of the stages in the column and
may be varied by using different feed and take-off connections.

The eluant wash-out section is provided to prevent eluant being carried
across to the extraction column and being lost in the barren liquor.   The
wash-pump, P4, may not be used, because the minimum wash provided by the
displacement of the water from T2 may be sufficient.

The elution section must handle an average flow-rate of sulphuric
acid eluant in the range from 0.020 m^3/h to 0.060 m^3/h.   From the time-cycle
calculations, the ratio of maximum/average flow-rates is about 2.0, so that
the column cross-sectional area should be designed for 0.12 m^3/h when an
acceptable superficial velocity has been selected.   The resin flow-rates
will, be the same as they are for the extraction column.

The features of design mentioned for the extraction column are the
same here.   However, owing to its relatively small size, the tray design
will be different.   (See Figure 5).

3.3. *RESIN-COLLECTING TANKS (T1 AND T2)*

These tanks are directly below the contactors C1 and C2, and are
arranged so that resin can settle into the tanks through the valves CV3
and CV8.   The tanks should hold a supply of resin sufficient for three
hours of operation.

The shape suggested is that of a cylinder with a 60° conical base,
and a flanged lid.   If the internal diameter is about 18 inches, and the
cylinder depth is 6 inches, the internal volume will be about 0.070 m^3.   The
design pressure should be about 100 lb/in^2 hydraulic, in which case the top
lid will be thick enough to carry all the connections shown on the E.F.D.

3.4. *FLOW-REVERSAL TANK (T3)*

This tank must take the maximum air pressure in the line should valve CV18 fail to open. It must carry an adjustable two-position level-switch (LC3). During the reversal of the flow, the level of the solution at the lower set position rises to the upper set position and is then forced back to the lower position by air pressure. In order to make the flow-reversal volume accurate, the cross-sectional area should be between 0.5 to 0.75 times of that of contactor C1. The tank should be mounted as low as possible to assist the gravity flow of the resin and of the solution during flow reversal.

3.5. *FLOW-REVERSAL TANK (T4)*

The same criteria apply as for T3. However, this tank will be much smaller than T3.

3.6. *VALVES*

CV1, CV2

Air-operated diaphragm valves to be used in an on-off mode; CV1 air-to-close, CV2 air-to-open.

CV3, CV8

Air-operated straight through diaphragm valves (e.g. Saunders type K); air-to-open.

CV4, CV9

Air-operated diaphragm valves, air-to-open.

CV6, CV7

Air-operated diaphragm valves, air-to-close.

CV5, CV10

Air-operated diaphragm valves, air-to-open.

CV11, CV12, CV13, CV16

Three-way solenoid valves, standard materials to take water.

CV14, CV15

Three-way solenoid valves, stainless-steel construction to take 2M sulphuric acid.

CV17, CV18

Two-way solenoid valves, standard materials, to seat against pressure
of air supply.

CV19, CV20

Two-way solenoid valves, standard materials, to seat against pressure
of air supply.

3.7. *PUMPS*

P1

This should be a centrifugal pump capable of being throttled to below
20 per cent of its design capacity for long periods. The rated capacity
should be about 100 gal/min at a head of 80 to 100 feet.

P2, P3, P4, P7

These should be positive-displacement metering pumps, because these
provide the cheapest method of controlling flows in this range of flows.
Suitable units would be two DCL double-headed, M-type pumps with 38-1/h
heads. Standard materials of construction are required. Strainers
must be fitted on the inlets to these pumps.

P5, P6

Both these pumps should be metering pumps with a maximum capacity
of 70- 1/h. Essential features of P6 are a strainer on the inlet and a
pressure relief valve on the delivery to prevent solution from siphoning
out through the pump valves. The materials of construction must be
compatible with 1M to 2M sulphuric acid containing uranyl sulphate. A
strainer must also be fitted to the inlet of P5.

4. INSTRUMENTATION

The instrumentation specified will permit automatic operation of
the plant under the supervision of an operator. No provision is made
for automatic quality control or for automatic shut-down in case of faults.

FI1

This is a flow-rate indicator, 0 to 25 m^3/h.   Suitable instruments may be: Dall tube, venturi meter, magnetically coupled rotameter, electromagnetic flow-meter.   Orifice plates may tend to block up with deposited slime.

LC1, LC2

These are level controllers based on photoelectric cells.   Either a high level of resin in the base of contactor C1 or depletion of the resin in tank T1 will give a starting signal to an auxiliary timer, which causes tank T1 to be recharged.   The recharging action consists in shutting CV6, opening CV3 and CV4, and switching CV11 to recycle the output of pump P2. After 5 to 20 minutes, the auxiliary timer will reset the valves mentioned above to their normal positions until either of the initiating signals is received.

An alternative system could be based on two timers controlling the two periods, which could be adjusted on the basis of operating experience. Both photocells would then be superfluous.

LC4, LC5

This control system will be an exact duplicate of LC1, and LC2 or its equivalent.

LC3, LC6

The simplest two-position level switch that gives an electrical signal to the control panel is required.   A cheap and reliable device is based on a reed switch and a magnetic float.   The position of the switches can be adjusted to vary the volume of the flow reversal.

TIMERS

Each contactor must be controlled by a timer that is independently adjustable, automatically resetting, and started by an electric signal.   A suitable model is sold by Crouzet Limited (France and United Kingdom).   It would be a saving if all timers were identical so that spare units could be held.

During the period of forward flow in contactor C1 (which is timed by the timer), solenoid valves (not shown) keep CV2 open, and CV1, and CV5 closed.   Solenoid valves CV17 and CV18 are also closed.   When the timer

comes to the end of the period of forward flow, it shuts CV2 and opens CV1, CV5, and CV17. The timer then resets itself and awaits a start signal. This action stops the flow upwards through the contactor, and the flow is reversed by gravity, the solution level in tank T3 rising to the top level-switch of LC3. When this switch is activated, the control board closes CV17 and opens CV18, thus driving the solution level down in T3 again. When the solution reaches the lower level-switch of LC3, the timer is started, thus closing CV1, CV5, and CV18, and opening CV2.

The procedure for contactor C2 is similar, with the exception that CV13, CV14, CV15, and CV16 are operated in parallel tc by-pass the pumps during reverse flow.

5. GENERAL

For start-up and commissioning purposes it is essential that each solenoid valve controlled by automatic methods should have independent manual control. The control panels for the two contactors should be laid out separately although they may be in the same rack.

Minor items such as pressure gauges, neon indicators on control outputs, and the use of self-indicating relays on plug-in bases are not specified here.

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APPENDIX I

PROCESS DEVELOPMENT WORK

Resin life

This variable has a pronounced effect on the overall costs of continuous ion-exchange operation, and, therefore, tests on the various resins under consideration should start as soon as possible.

The test rig already in operation at the Chamber of Mines Research Laboratories provides a somewhat accelerated attrition of the resin compared with its duty in the actual plant. The extent of this acceleration is uncertain at the present. It is suggested that the rig should be operated daily for several months with a given sample of resin until significant attrition is recorded. If a suitable location is found where the rig can operate unattended overnight without the danger of flooding the laboratory, this would obviously provide the required information more quickly.

A size analysis could be done every day in the first week of the test, and then every subsequent week. All material below an arbitrary standard of, say, 30 mesh could be regarded as lost since it would be carried out of the process with the pulp barren effluent. The cost of an attrition loss of 5 to 10 per cent per month would be marginal, although a higher loss would probably occur in the initial period while the more fragile beads are fractured. Any continuing loss of more than 10 per cent per month would make the process uneconomic.

Superficial velocities

The bed expansion should be measured with the various resins being considered at different upwards velocities with the *actual pulp slurry* and the same pH and other chemical properties as the slime leach overflow. Possible problems that could occur are the flocculation of pulp particles on the resin and the flocculation of pulp to form a viscous suspension that may entrain the resin.

The object is to obtain as high a linear velocity as possible in order to accommodate the 5-to-1 turndown required. It may be necessary to elutriate a small fraction (5 to 10 per cent) of the resin supplied.

When a suitable maximum linear velocity has been determined, the diameter of the extraction column can be calculated.

Equilibria

Further necessary information on the process is the equilibrium line for each of the resins with the actual leached slime pulp. A previous Chamber of

Mines Report[5] gives sufficient description of the method.

There are no suitable published data on the equilibria in the elution process despite the fact that George[2] gives the operating conditions and flow-rates. If any attempt is to be made to design the elution process systematically, equilibrium curves similar to those for the extraction will have to be obtained for the various resins in different strengths of sulphuric acid. It is suggested provisionally that the acid concentrations used should be 1M, 2M, and 3M.

Mass-transfer coefficient

The recovery to be obtained in the extraction column will depend jointly on the mass-transfer coefficient and the interfacial area. The mass-transfer coefficient (KL) based on the liquid film can be predicted with some accuracy for some simple chemical systems, but here the basic physico-chemical data are lacking. Therefore, for practical purposes, it would be quicker and more reliable to measure the values of KL actually obtained in the extraction system than to measure conductivities.

In the concentrations under discussion, the uranium is so dilute that, when solutions flow through a fluidized bed, the output concentration remains constant for a period of at least 30 minutes, even with a relatively small quantity of resin. The difference in concentration can be used to calculate the instantaneous mass flux through the interfacial area of the resin in the fluidized bed, and, if the equilibrium relation is known for that resin, the value of KL in the experiment can be calculated.

A further useful point to verify would be whether the values of KL measured with pure uranium solutions were substantially changed when leached slime pulps were used.

APPENDIX II

PLANT DEVELOPMENT WORK

The major part of the development is expected to be in the design of a suitable tray for the extraction section. The elution section is comparatively so small that a single-entry tray will be adequate. Thus no difficulty is anticipated with the hydraulic operation ᴏⱼ the elution section, although there is obvious scope for optimization of the number of trays used, and of the concentration and ratio of flow-rates of eluant. When the full-scale plant is set up, the tray design used for the extraction section of the present pilot plant can be adapted to the larger requirements for a full-scale elution process. It is noticeable in the publications by George et al.[2] that little awareness of the problems discussed here is apparent. Certainly no systematic approach is used.

Pressure drop

It is required to know the pressure drop across the tray in forward flow that is necessary to fluidize across the whole width of the tray. This problem is analogous to that in the design of gas-fluidized beds. The correct liquid-flow distribution can be obtained at the highest flow-rate by making the pressure drop over the tray equal to the pressure drop over the bed itself; but, at the low flow-rate, this may allow instability to occur.

It is suggested that the first tests should be carried out on a single tray fitted with a controlled liquid feed. The minimum flow-rate at which resin dumped by hand on one side of the tray is fluidized when liquid feed is started should be noted. The pressure drop over the tray itself should be measured as well. The operation over a range of 1 to 5 times the minimum flow-rate should be verified.

Liquid residence-time distribution

An important criterion of tray design is that there should be no significant bypassing of the liquid stream due to jets or uneven flow distribution. Gross maldistribution will be detected by the pressure-drop experiments above, and, when even fluidization is apparently obtained, it will be helpful to check the flow pattern by a simple chemical experiment.

Under the conditions visualized, it will be easier to infer the residence-time distribution from measurements of apparent mass-transfer coefficient (KL) by the use of a well-known chemical system like the neutralization of sulphuric or nitric acids by a strong-base resin in the OH form.

An accurate prediction[7] of KL in a perfectly fluidized bed is given by

$$Sh = (0.81/\varepsilon)(Re^{0.5}(Sc)^{0.3}.$$

Where Re is the Reynolds' number, Sh the Sherwood number, and Sc the Schmidt number, all the linear dimensions are referred to particle diameters, and the superficial velocity is used in Re. The diffusion coefficient for a neutralization reaction is given[8] as

$$D= 2D_H \cdot D_{NO_3} / (D_H + D_{NO_3})$$

Therefore, if a fairly close size range of resin particles is used, the theoretical value of KL can be predicted from the correlation above for the experimental conditions of flow, temperature, and voidage, but use of conductance values for the relevant ions for calculating their diffusion coefficients. Fairly dilute acids can be used if both initial and final normalities can be measured; if N/100 acid is used, a steady output value will be held for a long time. It must be remembered that, in neutralization reactions, the interface concentration of diffusing species is effectively zero; so the driving force in mass transfer is simply the bulk concentration of diffusing species.

If the measured apparent values of KL are close to the theoretical, the tray design is performing satisfactorily at that velocity. If they are very much lower, it can be inferred that the liquid is bypassing the resin.

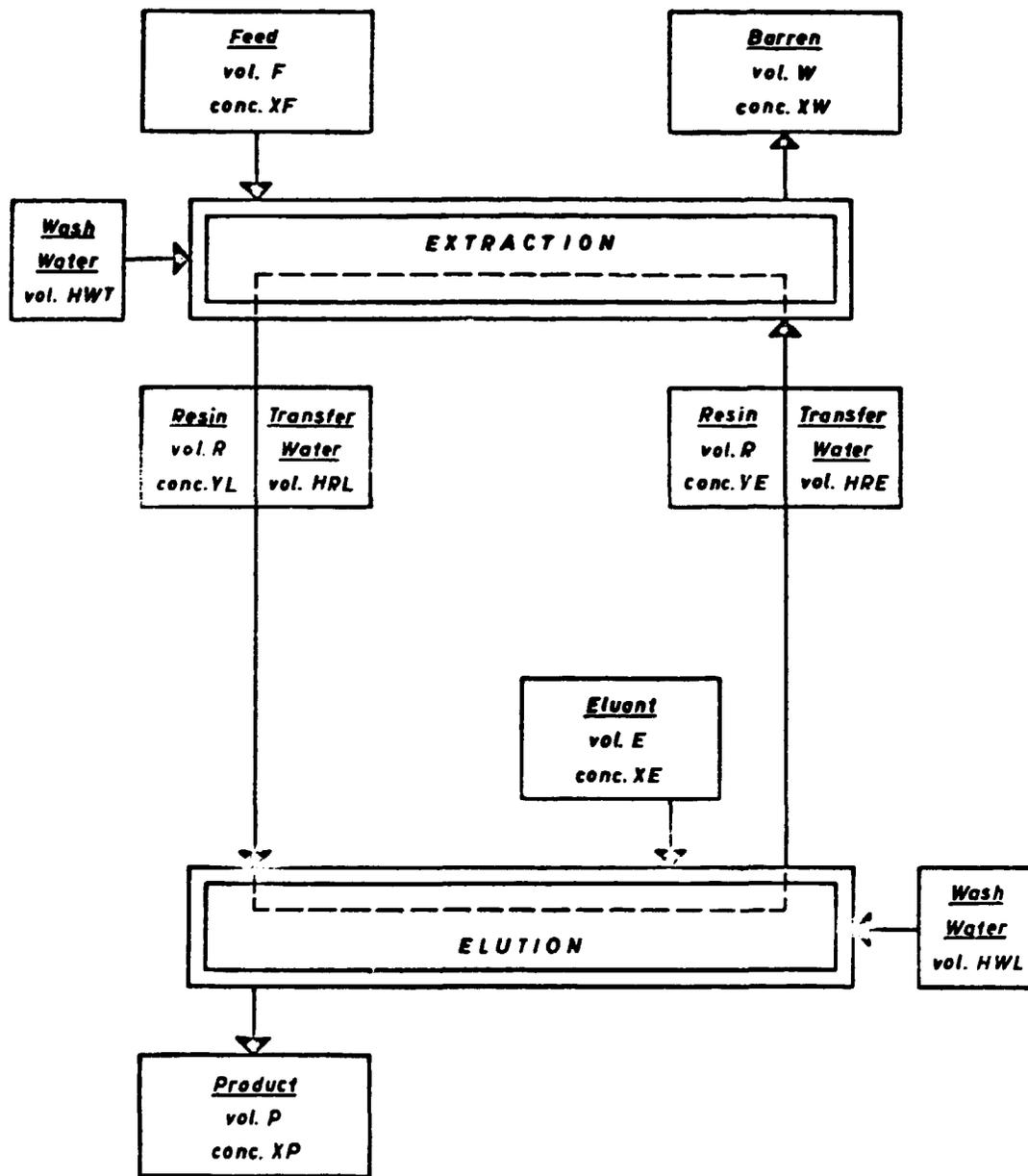*Stability of multiple trays*

A problem in the design of any multiple-stage solids contactor is to ensure that the hold-up of solids on each stage remains constant. In a contactor handling fluids only, this is readily achieved by a weir or some variant on that principle. Some designs of multistage fluidized beds also operate on the principle of downcomers and weirs. However, such a system is inherently unstable unless each downcomer has a valve or seal pot, as described in a number of publications.

A useful requirement for a tray is that it should retain its hold-up of solids when liquid flow ceases, so that the concentration profile in the solid phase is maintained during temporary shutdowns. In the extraction section of the process being considered, the steady-state solids-concentration profile would take about a week to establish, and

this requirement would be more important than it would be in a process with a higher flow-rate of resin. It is clear that the principle of the contactor described by George[2] would not allow resin to be retained on stages during a stoppage of liquid feed. However, all the other fluidized-bed designs allow resin to be retained. This is perhaps the strongest reason why this report does not recommend the adoption of the George contactor.

The essential requirement for stability of multiple stages is that the flow of the solids out of the stage must vary with the hold-up of the solids on it. Thus, a higher rate of feed of solids to the stage must result in a higher rate of flow from it, otherwise accumulation or depletion of solids may occur during operation. Systematic testing of a typical prototype stage for stability has been reported[4], and it is suggested that similar work should be carried out on prototype stages that have been found satisfactory by the previous tests. The work reported by George[2] gives more data than any other publication on multistage continuous ion exchange does, but it can be inferred from mass-balance discrepancies on each stage of Figure 5[2] that either fluctuating hold-up of resin or unsteady-state operation occurs in a multiple-stage contactor of that design.

Feed
vol. F
conc. XF

Barren
vol. W
conc. XW

Wash Water
vol. HWT

E X T R A C T I O N

Resin
vol. R
conc. YL

Transfer Water
vol. HRL

Resin
vol. R
conc. YE

Transfer Water
vol. HRE

Eluant
vol. E
conc. XE

E L U T I O N

Wash Water
vol. HWL

Product
vol. P
conc. XP

Volume Balance

$HWL\ min = HWTmin = (1-\epsilon)R$

$HRE = HRL = (\epsilon + 0.111)R$

$W = F + HWT + HRE$

$P = E + HWL + HRL$

Mass Balance on Uranium

$F(XF) - W(XW) = R(YL - YE) = P(XP)$

Notes:

1. Resin measured as bulk settled volumes of voidage ϵ

2. $0.3 < \epsilon < 0.4$

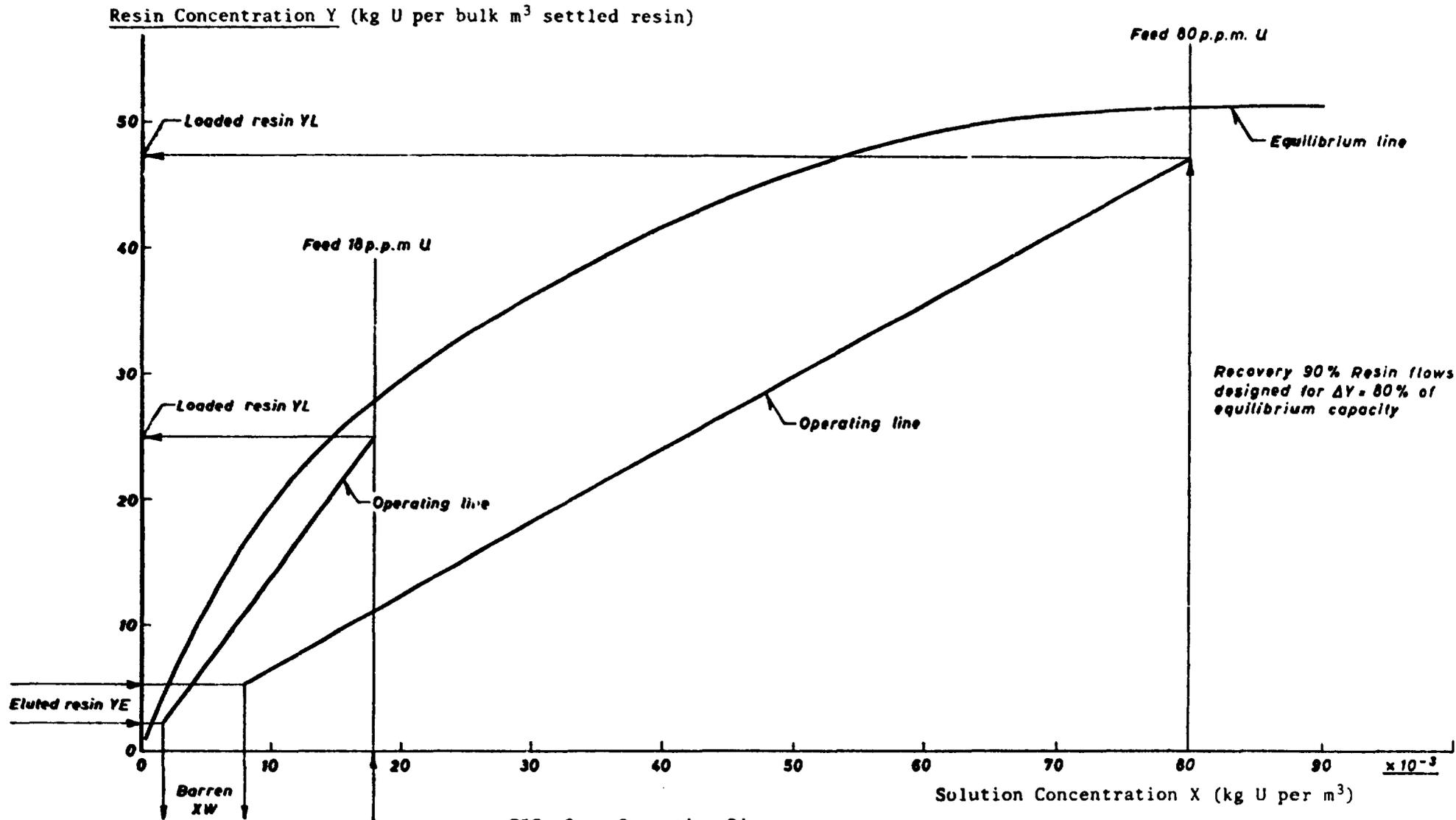FIG. 1.   Block Flow Diagram of Uranium Recovery by Continuous Ion Exchange
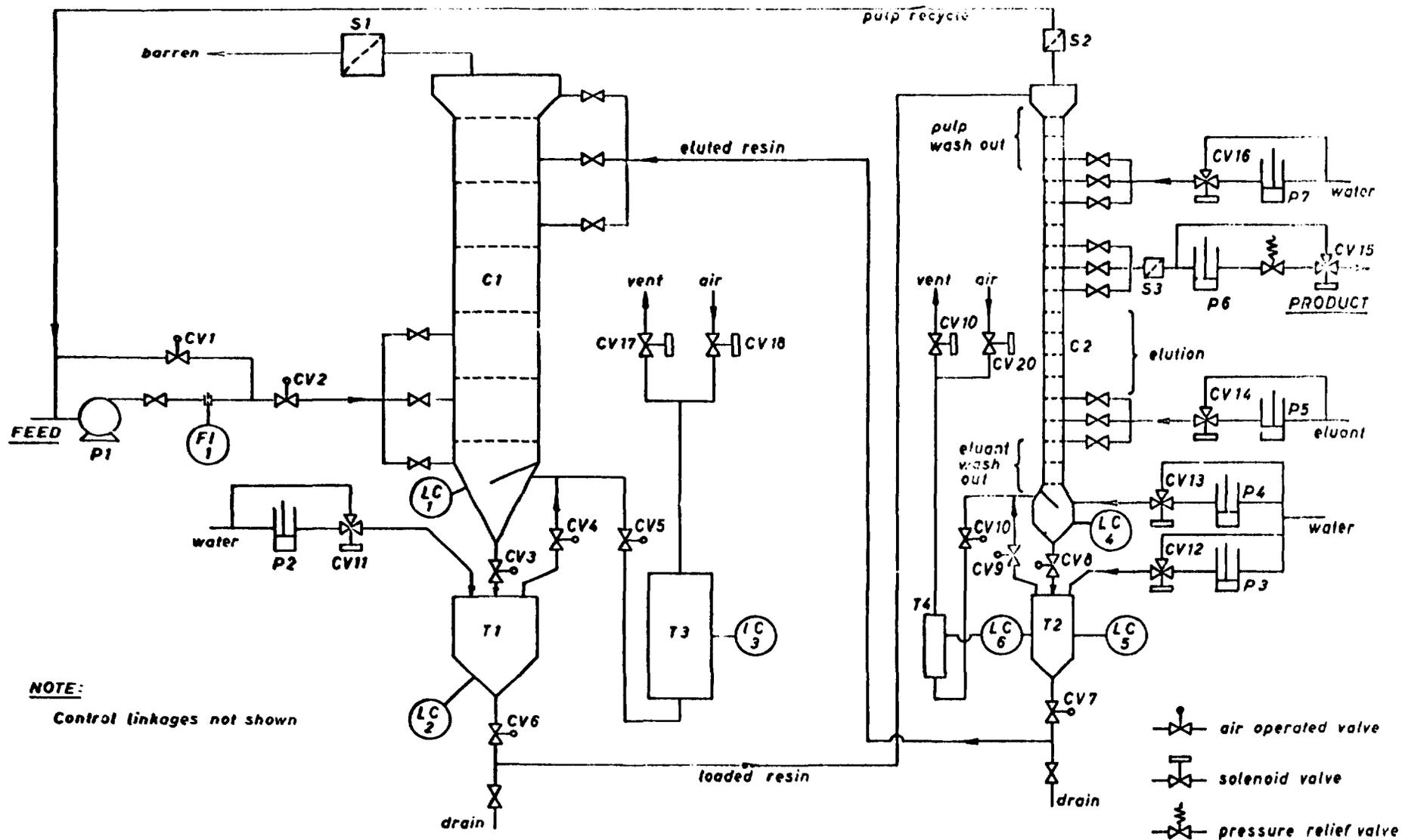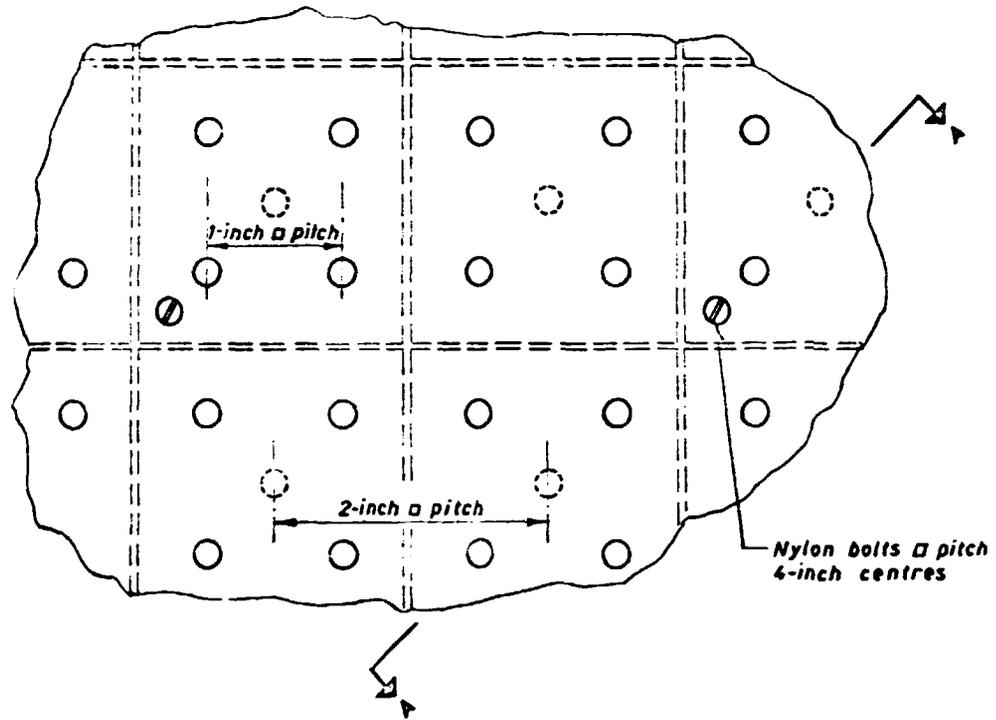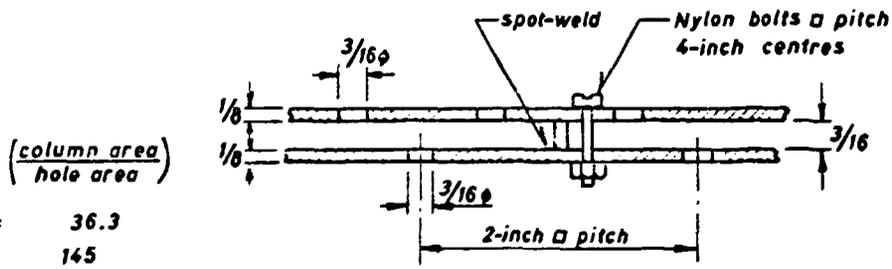
FIG. 2. Operating Diagram

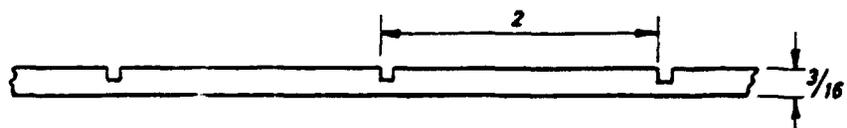FIG. 3.   Engineering Flow Diagram of Uranium Recovery by Continuous Ion Exchange.

PLAN VIEW OF TRAY ASSEMBLY

1-inch □ pitch

2-inch □ pitch

Nylon bolts □ pitch 4-inch centres

spot-weld — Nylon bolts □ pitch 4-inch centres

$3/16\phi$

$1/8$

$1/8$

$3/16$

$3/16\phi$

$3/16\phi$

2-inch □ pitch

$\left(\dfrac{column\ area}{hole\ area}\right)$

upper tray: 36.3

lower tray: 145

PROJECTED SCRAP SECTION AT A-A

2

$3/16$

ELEVATION VIEW OF SPACER BAFFLE

FIG. 4.   Extraction Contactor Tray for Uranium Recovery by Continuous Ion Exchange.
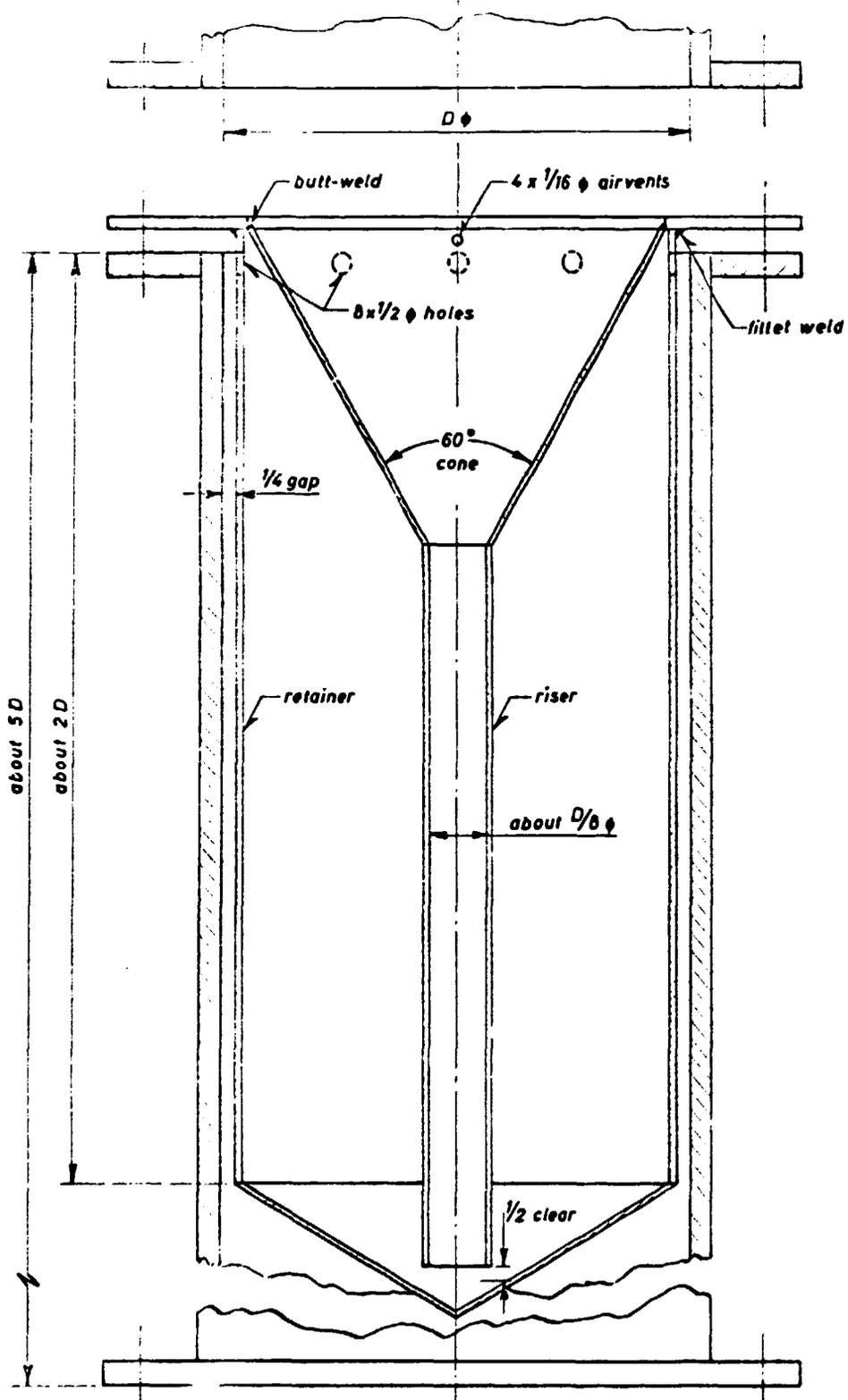
NOTES:

Matls: s.s. sheet and nylon.

Assembly: 1. Baffles to fit into each other to formgrid, which is spot-welded
         in position onto lower tray.

         2. Upper tray held in position only by nylon bolts.

         3. Lower tray to extend between column flanges.

Dimensions in inches.

Labels within the figure:

butt-weld · 4 x 1/16 φ airvents · fillet weld · 8x1/2 φ holes · D φ · 60° cone · 1/4 gap · retainer · riser · about 5 D · about 2 D · about D/8 φ · 1/2 clear
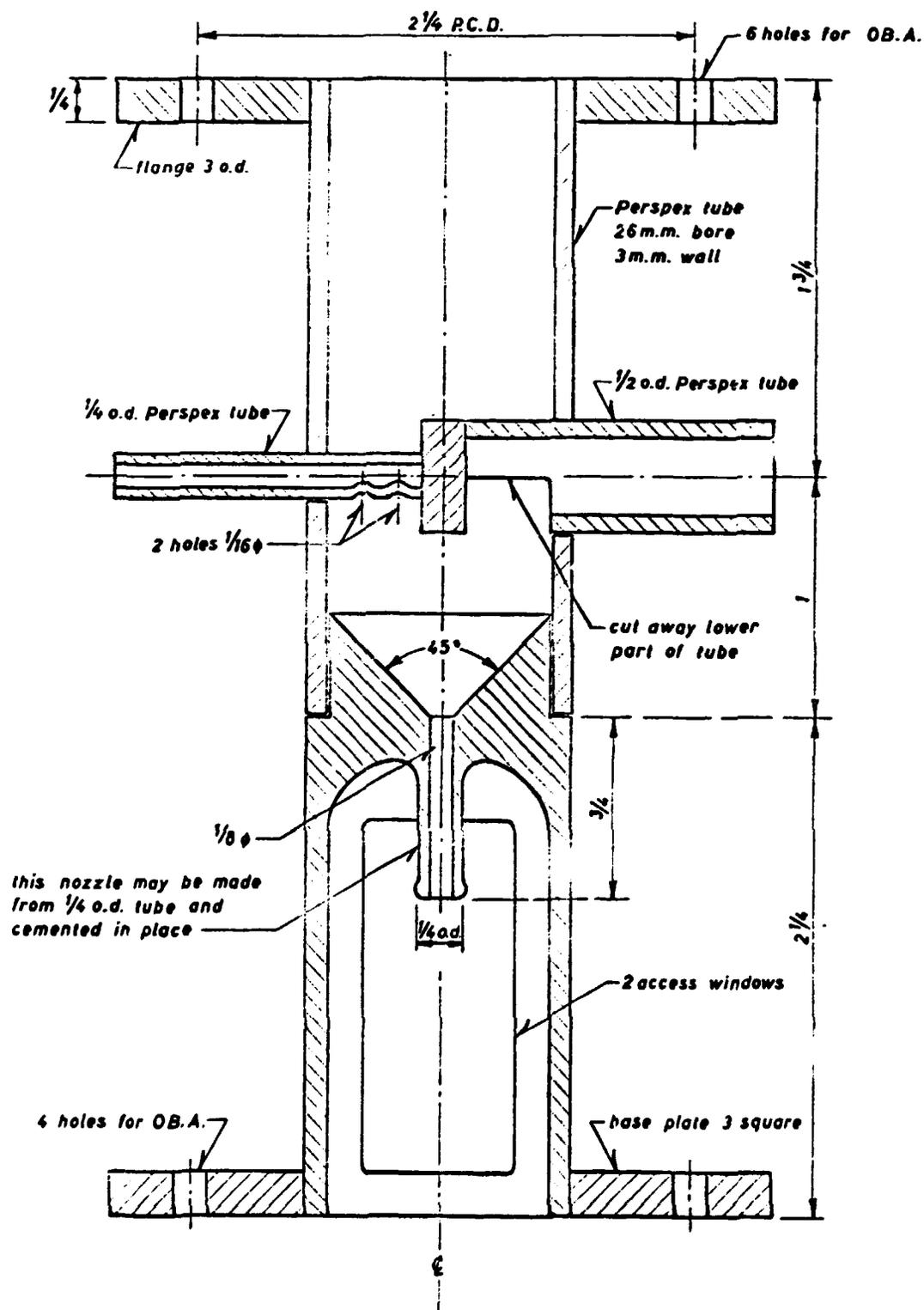
MATLS: Perspex, PVC, or light s.s. Pipe sections may be rubber-lined m.s.
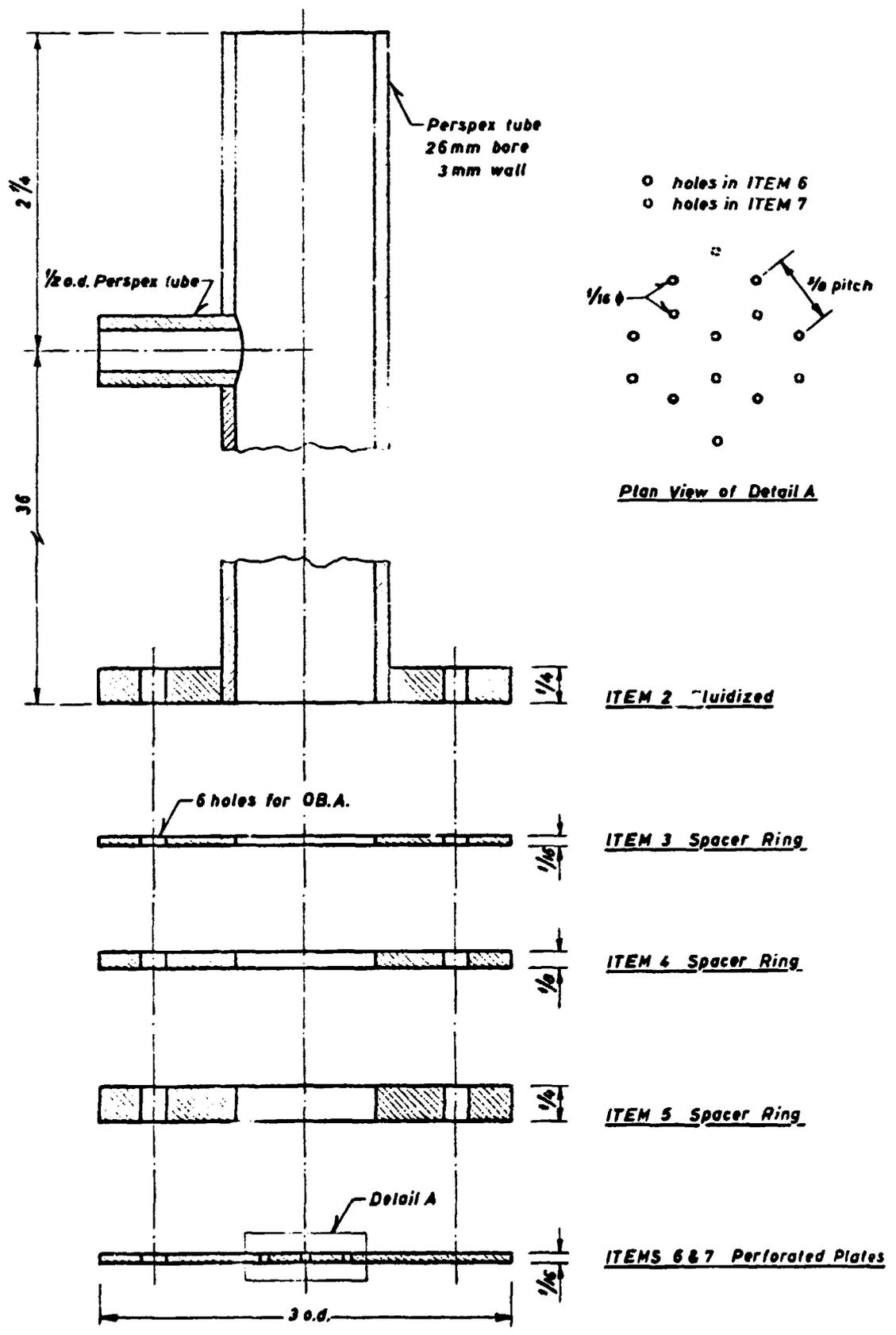Dimensions in inches.

NOTES: 1. Nozzles not shown.
    2. A series of columns may be connected simply by joining the base of the cone
       to the top of the next column with a pipe of volume equal to the retainer.

FIG. 5.   Elution Contactor Tray

2¼ P.C.D.

6 holes for O.B.A.

¼

flange 3 o.d.

Perspex tube
26 m.m. bore
3 m.m. wall

1³⁄₄

¼ o.d. Perspex tube

½ o.d. Perspex tube

2 holes ¹⁄₁₆ϕ

cut away lower
part of tube

45°

1

¹⁄₈ ϕ

3⁄4

this nozzle may be made
from ¼ o.d. tube and
cemented in place

¼ o.d.

2¼

2 access windows

4 holes for O.B.A.

base plate 3 square

℄

MATLS: Perspex
JOINTS: cemented
FINISH: machined
SCALE: approx. 1½ full size
Dimensions in inches except where otherwise stated.

FIG.6.   Fluidized-Bed Support

Perspex tube
26mm bore
3mm wall

½ o.d. Perspex tube

○ holes in ITEM 6
○ holes in ITEM 7

1/16 ⌀   3/8 pitch

Plan View of Detail A

ITEM 2 Fluidized

6 holes for OB.A.

ITEM 3 Spacer Ring

ITEM 4 Spacer Ring

ITEM 5 Spacer Ring

Detail A

ITEMS 6 & 7 Perforated Plates

3 o.d.

SCALE: Approx. full size
MATLS: Perspex
Dimensions in inches exept where otherwise stated

FIG. 7.   Fluidized-Bed Components