Separation Science and Technology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713708471

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To cite this Article Leonard, Ralph A.(1988) 'Recent Advances in Centrifugal Contactor Design', Separation Science and Technology, 23: 12, 1473 — 1487
To link to this Article: DOI: 10.1080/01496398808075643
URL: http://dx.doi.org/10.1080/01496398808075643

SEPARATION SCIENCE AND TECHNOLOGY, 23(12&13), pp. 1473-1487, 1988

RECENT ADVANCES IN CENTRIFUGAL CONTACTOR DESIGN

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ABSTRACT

Advances are being made in the design of the Argonne centrifugal contactor for solvent extraction. These contactors are being built, tested, and used to implement the TRUEX process for the cleanup of nuclear waste liquids. These advances include 1) using off-the-shelf, face-mounted motors; 2) modifying the contactor so that relatively volatile solvents can be used; 3) adding a high-level liquid detector that can be used to alert the plant operator of process upsets; 4) providing secondary feed ports; 5) optimizing support frame design; 6) devising a linear design with external interstage lines so that stages can be allocated as needed for extraction, scrub, strip, and solvent cleanup operations; and 7) developing features that facilitate contactor operation in remote facilities.

INTRODUCTION

Solvent extraction equipment used to separate heavy metals (in particular, the actinides) from lighter metals and from each other has evolved considerably over the last 40 years. Packed columns were used initially but were soon replaced by pulsed columns, which, because of their greater efficiency, did not need to be as high, see Richards (1). Pulsed columns are still in use today. However, because there are cost benefits to further reducing the height of the solvent extraction facility, mixer-settler units have also been developed. At first, only gravity mixer-settlers (mixers with gravity settling zones) were used. Later, centrifugal mixer-settlers (mixers with centrifugal settling zones that are commonly called centrifugal contactors) were developed at Savannah River Laboratory (SRL); see Davis and Jennings (2), Kishbaugh (3), and Webster et al. (4). The centrifugal contactor has the advantage of compact size coupled with high throughput and high extraction efficiency. The SRL contactor has been in use at the Savannah River Plant since 1967.

In the late 1960s, a modified centrifugal contactor was developed at Argonne National Laboratory while work was being done on the original SRL contactor, see Bernstein et al. (5). The Argonne contactor is similar to the SRL contactor except that the paddle mixer under the centrifugal rotor is eliminated, and the liquids are mixed in the annular region between the rotor and its housing. This change simplifies the contactor design, lowers its cost, and makes it easier to do remote maintenance on the contactor. At the same time, the advantages of the SRL unit are retained in the Argonne centrifugal contactor.

Because of their simple design, Argonne centrifugal contactors are reliable, easy to use, and relatively inexpensive to build, operate, and maintain. The compact contactor stages give low liquid holdup, fast startup and shutdown, greater safety with respect to nuclear criticality by virtue of their small size, and high mass transfer efficiency. As a result, the Argonne centrifugal contactors are now being chosen when implementing new solvent extraction processes or upgrading existing facilities. In particular, contactors are being built, tested, and used with the TRUEX process to cleanup nuclear waste, see Horwitz et al. (6, 7), Leonard et al. (8), and Vandegrift et al. (9). As the contactor is used to test various TRUEX flowsheets and as flowsheets move from laboratory-scale testing to plant-scale operation, contactor design is being revised and new features are being added. These recent advances in centrifugal contactor design are discussed here.

CONTACTOR DESIGN AND OPERATION

A schematic of an operating contactor stage is shown in Fig. 1. Two immiscible liquids flow into the annular mixing zone, which is formed between the spinning rotor and the stationary housing. The liquid-liquid dispersion created by turbulent Couette flow in the annular mixing zone flows by gravity to the inlet in the bottom face of the rotor and thus into the centrifugal separating zone inside the rotor. Here the dispersion breaks rapidly under the high centrifugal force. The separated phases flow over their weirs and are thrown by centrifugal force from the rotor into their collector rings in the

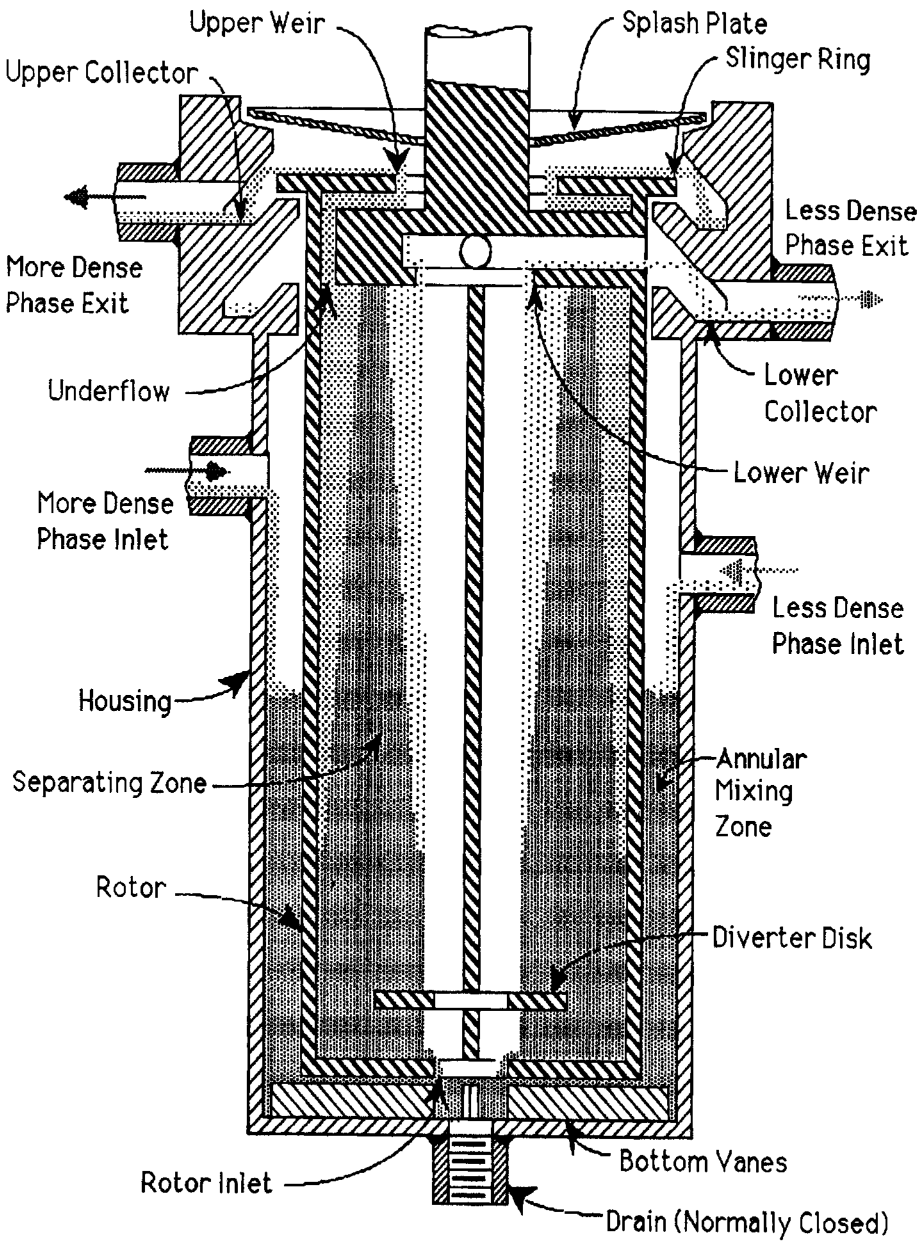

Fig. 1. Operating Contactor Stage.

housing. Each liquid leaves its collector ring through a tangential exit port. A slinger ring prevents the more-dense phase from leaking down into the collector ring for the less-dense phase.

To allow the dispersion to flow by gravity into the rotor, stationary radial vanes attached to the housing and located under the rotor are required to dissipate the rotational velocity of the dispersion. Vanes within the rotor keep the liquids spinning at the same speed as the rotor. A diverter disk, located above the rotor inlet, forces the entering dispersion into the middle region of the separating zone. When designing a contactor one must consider two factors. First, the rotor inlet must have a radius somewhat smaller than that of the lower weir for the dispersed liquids to be pumped through the rotor. Second, the radii for the lower and upper weirs must be chosen carefully so that the two vertical surfaces of the dispersion band are located within the separating zone of the rotor, that is, between the lower weir and the underflow to the upper weir. In a good design, contactor throughput is limited by the thickness of the dispersion band in the separating zone. Phase separation is generally considered satisfactory if each effluent from a contactor stage contains <1 vol % of the other phase.

RECENT ADVANCES

In general, the recent advances in contactor design have been the result of changes required for the good operation of specific process flowsheets, for remote-handling situations, and for continuous contactor use in a process plant. Also at work has been an underlying philosophy that the design should be as simple as possible. A simpler design should result in lower capital and operating costs, easier contactor use, and contactors that are more reliable and easier to maintain.

Besides advances in contactor design, contactor operation with the organic phase as the more-dense phase has now been tested. In theory, such operation should not pose any particular problems. Argonne centrifugal contactors were run with the organic phase as the more-dense phase and found to work quite well, see Leonard et al. (8). In these tests, the more-dense organic phase contained both an extractant, either tributyl phosphate (TBP) or octyl(phenyl)-N,N-diisobutylcarbamoylmethyl-phosphine oxide (CMPO) or both, and a diluent, either carbon tetrachoride (CCl_4) or tetrachloroethylene (TCE).

Off-the-Shelf Motors

While the initial work on the Argonne contactor by Bernstein et al. (5) used an air-controlled weir that actually required two weirs for the more-dense phase, Leonard et al. (10) demonstrated that only a single weir is needed. The drawback to this change is that contactor operation is optimum for only one organic-to-aqueous (O/A) flow ratio for a given pair of immiscible liquids with the density of each phase specified. The contactor can no longer be optimized for the specific liquid densities and phase ratios by adjusting the air pressure over an air-controlled weir. Thus, the contactor is no longer as flexible and cannot be applied if the phase densities, and, more important, the ratio of phase densities are outside the design range. However, for a given process, a design can usually be found that will allow good contactor operation at 70 to 80% of maximum throughput over a typical range of phase densities and for all O/A flow ratios.

The immediate advantages of using only a single weir for the more-dense phase are the elimination of a motor with a hollow shaft and the rotary air seal. With the rotary air seal gone, there is one less mechanical part to fail. With the hollow motor shaft gone, one can use an off-the-shelf motor which is smaller and simpler and which costs much less than the motorized spindles that have been used in the past. In addition, many motors are of the face-mounted type. By proper design of the motor mount block, these motors can be made self-locating and special locating pins can be eliminated. Initially, a coupling with set screws was used to connect the motor to the rotor, as indicated in Fig. 2. Later this design was improved by including a captive clamping nut on the coupling, which is put onto the motor shaft with a very close fit and held in place using a roll pin as indicated in Fig. 3.

With contactors having 4-cm diameter rotors, a small motor with a 5/16-in. (7.9 mm) shaft diameter was found to work well. With contactors having 10-cm diameter rotors, a motor with a 7/8-in. (22.2 mm) shaft diameter was required to reduce vibrations to an acceptable level. (Vibrations are acceptably low when the movement of the motor shaft relative to the motor housing is within the range specified by the motor manufacturer. This specification is set to keep the motor bearings from being overstressed, and so, ensures long life for the bearings.) This large shaft size for the 10-cm contactor presents a design problem in that off-the-shelf motors with this shaft size start at 1 hp (746 W), much more power than is required for the 10-cm contactor. Work is continuing in this area to see if it is possible to purchase, at a reasonable price, off-the-shelf motors which have a much smaller size and require much less power but still have a large 5/8- to 7/8-in. shaft. For example, a vibrational model was used to study a rotating unit consisting of the motor-rotor and the contactor-rotor of the 10-cm contactor. The results showed that a 1/6-hp, off-the-shelf motor modified to have a larger 5/8-in. shaft with the same bearing stiffness would result in a contactor with vibrations reduced to an acceptable level. The shaft diameter can be reduced from 7/8- to 5/8-in. because the mass of the 1/6-hp motor is much less than that of the 1-hp motor.

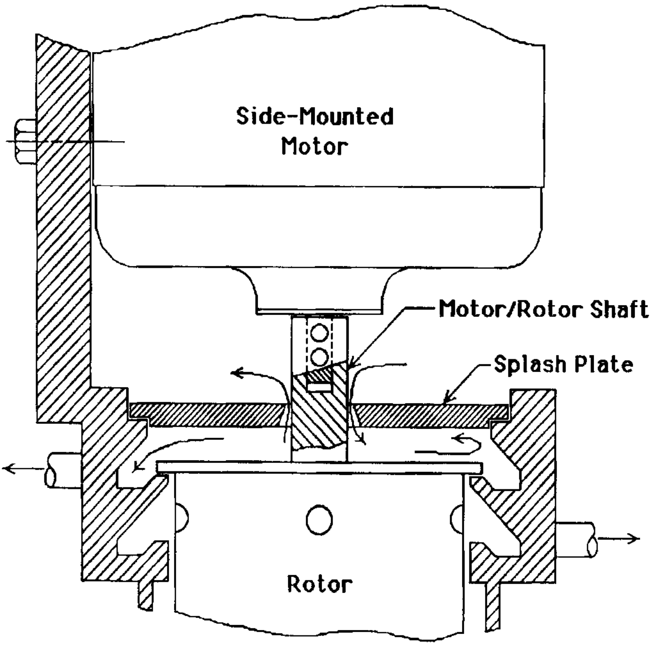

Fig. 2. Open Contactor Stage.

Reduced Evaporative Losses

Control of the evaporative loss rate of the solvent diluent is not a big problem when the diluent has low vapor pressure, as is the case for normal paraffin hydrocarbon (NPH). However, when a volatile diluent such as CCl_4 is used, the open contactor design shown in Fig. 2 has significant evaporative losses of solvent diluent, see Leonard et al. (8). In this design, if air from the contactor stage, which will contain acid fumes, moves past the splash plate, the fumes are dissipated in the general laboratory area and do not represent a particular corrosion problem for the motor, which is made of plain steel and aluminum. To control the movement of air past the splash plate, and so, control the evaporative loss rate of a volatile diluent, a closed contactor was designed, as shown in Fig. 3. To protect the motor from acid fumes, an air purge is introduced just below the motor face. This open space is kept small so that a low flow rate can be used for the air purge with a resulting small evaporative loss of the diluent. In addition, one should use a less volatile diluent whenever possible and keep the exit ports submerged or

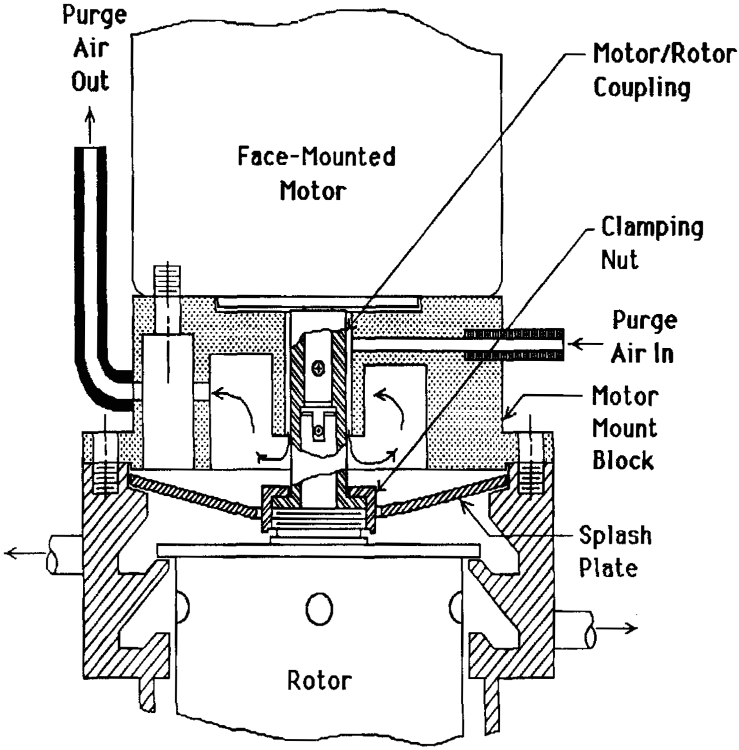

Fig. 3. Closed Contactor Stage.

closed using a liquid trap so that rotor pumping of air does not create excessive air flow through the contactor. Moreover, evaporative losses can occur after the contactor is shut down because of heat from the motor. This occurs when the motor rotor stops turning and the heat transfer to the motor walls is reduced. When the less volatile but equally effective TCE was substituted for CCl_4 and these other changes were made, the evaporative loss rate for the diluent dropped from 7% to $\lesssim$ 0.12% for a single pass through a 14-stage 4-cm contactor.

Detection of High Liquid Level

Except for a contactor leak, most problems with contactor operation will cause the liquid level in one or more contactor stages to rise. To detect this, we now design each stage with a sight tube made of a translucent (fairly transparent) fluoro-

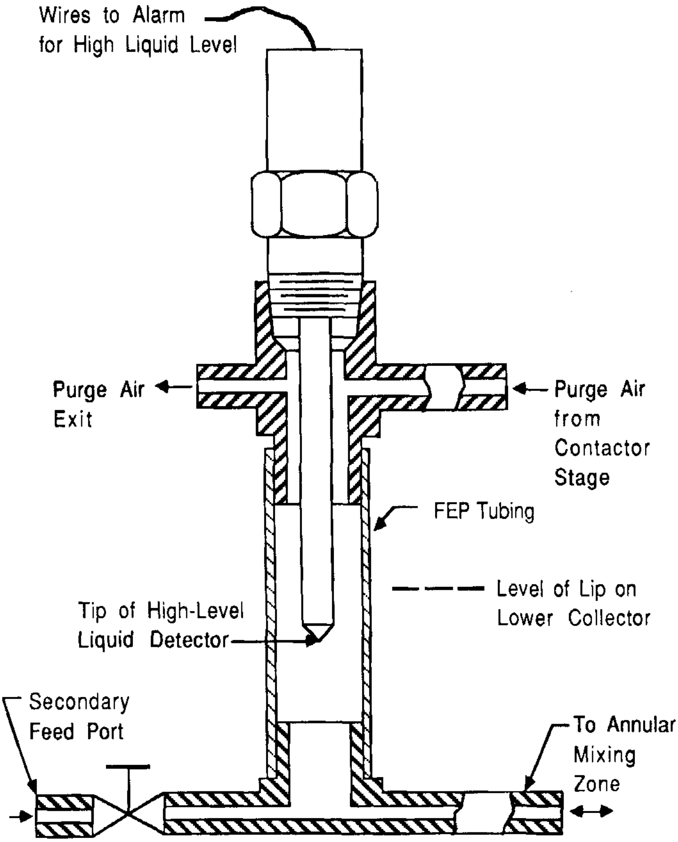

Fig. 4. Detector for High Liquid Level.

carbon resin called FEP (fluorinated ethylene propylene). This tube allows visual observation of a high liquid level and is good for short test runs. For long-term plant operation, a detector that senses a high liquid level and activates the appropriate alarm should be put in each sight tube, as shown in Fig. 4. The detector should be set low enough that it alerts the operator to a high liquid level before the dispersion in the mixing zone reaches the lip of the lower collector ring. When the dispersion reaches this lip, it exits with the less-dense phase and causes unsatisfactory operation. The detector shown in Fig. 4 is a relatively inexpensive optical (infrared) probe that is an off-the-shelf item. It will detect either the organic or aqueous phase. Note that the liquid level tube has been combined with the exit line for the air purge. Because of this design, the air in the top of the tube is not trapped, and so, the liquid in the mixing zone can rise up the tube unhindered.

Other probe types that have been considered are a thermistor, an ultrasonic detector, a capacitance probe, and a conductivity device. A thermistor detector would sense the increased thermal conductivity of the liquid relative to air. One should test to see that it would stand up to the process liquids and, if appropriate, to radiation. An attractive feature of both the ultrasonic detector and the capacitance device is that they could be located outside the FEP tube. The ultrasonic detectors are more difficult to install than the optical probes and must be calibrated for the geometry of the FEP tube with the process liquids inside. The capacitance devices are good for detecting aqueous phases since water has a dielectric constant that is 80 times that of air; they are not as effective with organic phases since their dielectric constants are, typically, only twice that of air.

Secondary Feed Ports

A secondary feed port for each stage can be added as shown in Fig. 4. Such a small feed port would be useful in a variety of situations that could arise in plant operation. Three examples are 1) returning solution that was taken for chemical analysis; 2) adding concentrated acid to a stage where, for some reason, the acid concentration was too low; and 3) disposing of liquid that was drained from a contactor stage during a process upset.

Improved Support Frame

Support frames have often used an angle iron design like that shown in Fig. 5. While this design has worked, access to the bottom drains was limited because they are low. If the support legs were made longer, drain access would still be limited because, to get the required stiffness for the longer legs, they must be made more bulky. In addition, the legs make it more difficult to work on the interstage lines. Use of the angle iron, rather than a flat iron frame, yielded the the necessary stiffness in the support frame. However, the vertical parts of the angle made it harder to remove a face-mounted motor. All three problems were solved by the use of a lower support frame based on a box beam design, as shown in Fig. 6. This design is particularly attractive because it gives the maximum stiffness for a given frame weight.

Linear Contactor Design

A linear contactor design, (that is, a contactor having the stages connected in a row, with the interstage lines to each

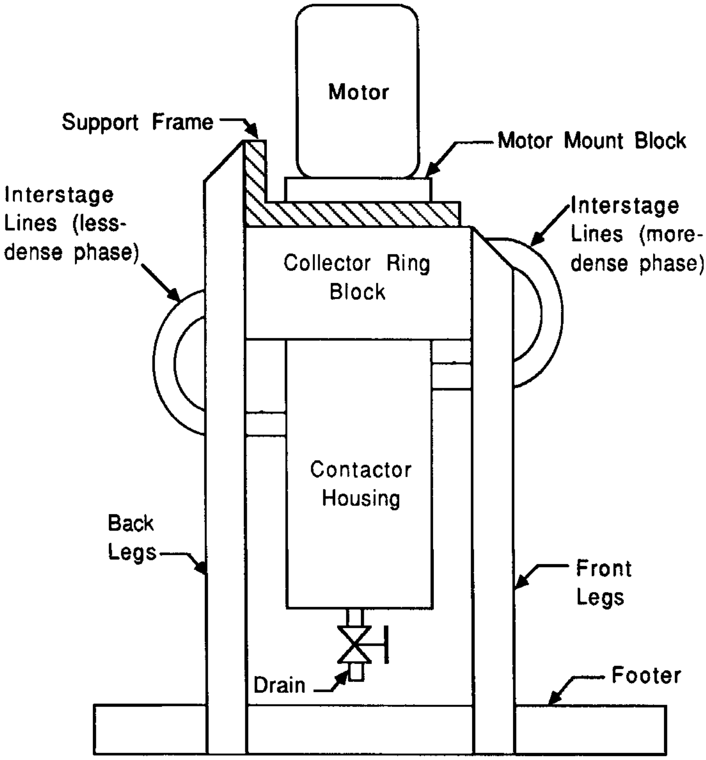

Fig. 5. Use of Angle Iron for Support Frame.

stage being accessible) gives a solvent extraction unit that is flexible. The number of stages in a section and the number of sections can be varied as needed for a particular flowsheet. This flexibility is not required if the same flowsheet is run all the time. However, in some cases, such as the clean up of actinides from nuclear waste solutions, the waste composition can vary. In these cases, the linear contactor design can be quite useful in implementing the required flowsheet for a particular waste. In general, the linear contactor design gives the people in process operations the opportunity for instituting improvements through 1) reassignment of the process stages, including the addition or deletion of a single stage to an extraction section; 2) adding more process stages as needed; and 3) improving the process chemistry. In Fig. 7, the linear contactor design with accessible interstage lines is shown for a 4-stage, 10-cm contactor.

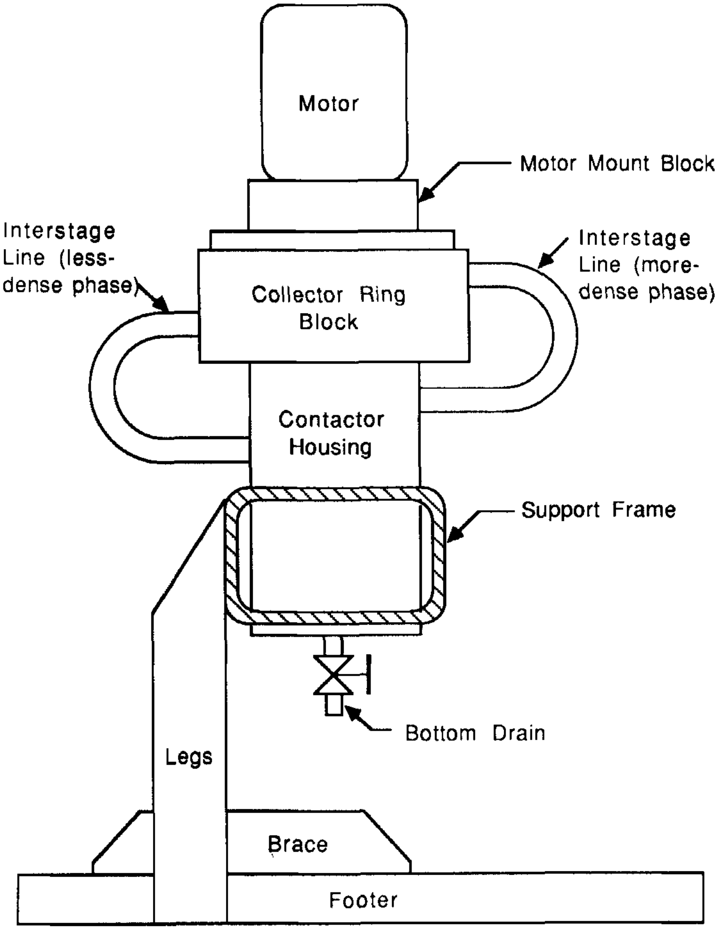

Fig. 6. Use of Box Beam for Support Frame.

Remote Operation

The simple design of Argonne centrifugal contactor makes it generally suitable for remote operation using manipulators or, for the heavier parts, a crane. Operator observation would be by television monitor or through a heavily shielded glass window. For remote operation, the liquid level detectors and the open space below the contactor for easy access to the bottom drains become especially important. The addition of a guide piece to aid in the installation of interstage lines and long handles on the drain valves would also be helpful.

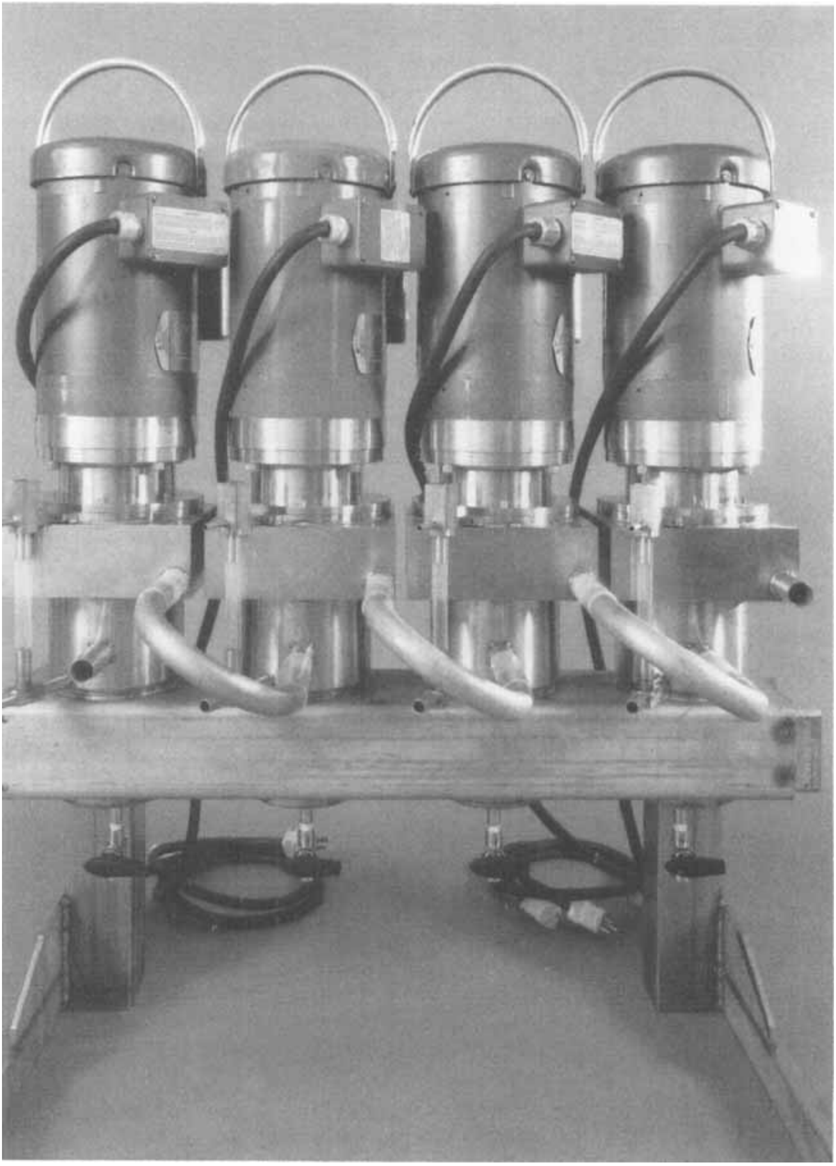

Fig. 7. Linear Contactor Design.

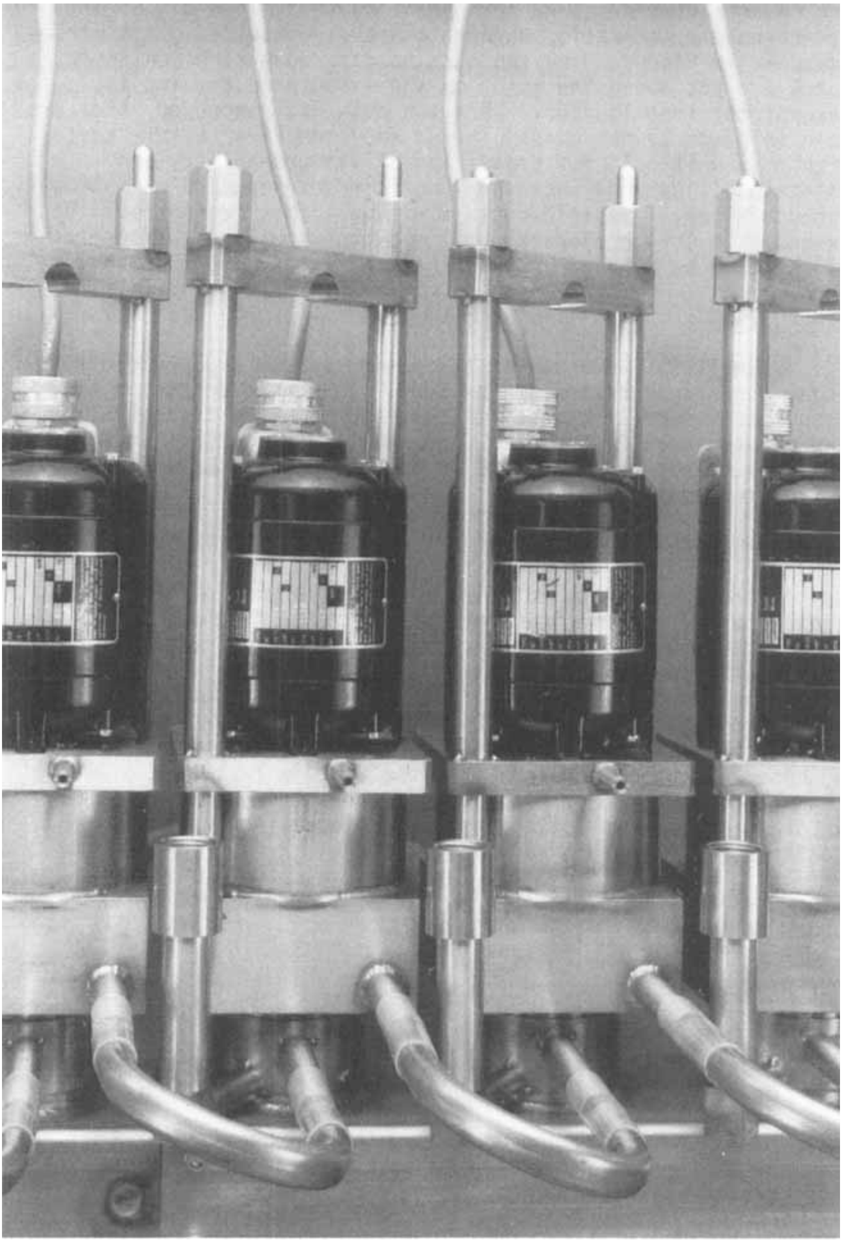

Fig. 8. Remote-Handled Contactors.

A contactor designed for operation in a glove box or in remote-handled operation through a heavily shielded glass window is shown in Fig. 8. The two nuts holding down each contactor stage are put above the motor on the guide pins to simplify motor/rotor installation. When the nuts are unscrewed, they are held in place by the guide pin for easy removal. Future tests with this unit call for evaluation of its operability and maintainability in a glove box and in remote-handled operation through a heavily shielded glass window. This design could be extended to canyon processing if the couplings for the interstage lines could be removed and reconnected in canyon operations.

CONCLUSIONS

Significant advances in the design of the Argonne centrifugal contactor continue to be made. The basic contactor has been improved to 1) reduce its cost and simplify its operation and maintenance, 2) handle a wide variety of process flowsheets, 3) allow remote handling, and 4) operate continuously in a full-scale process plant.

ACKNOWLEDGMENTS

Vibrations in the rotating motor/rotor unit of the 10-cm contactor were modeled by Professor Larry C. Mitchell and K. J. Young, both of the Department of Mechanical Engineering, Virginia Polytechnic Institute and State University, Blacksburg, Virginia. Much of the mechanical and hydraulic testing of the 10-cm contactor was done by David B. Chamberlain, Argonne National Laboratory, and John E. Stangel, a co-op student at Argonne National Laboratory from the Georgia Institute of Technology. Robert C. Frank, a designer at Argonne National Laboratory, took an active part in implementing the various features of the mechanical design.

This work was supported by the U. S. Department of Energy under Contract W-31-109-Eng-38.

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