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AN IMPROVED ANNULAR CENTRIFUGAL CONTACTOR FOR SOLVENT EXTRACTION REPROCESSING OF NUCLEAR REACTOR FUEL

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"An Improved Annular Centrifugal Contactor for Solvent Extraction Reprocessing of Nuclear Reactor Fuel"

by

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SUMMARY

An improved annular centrifugal contactor has been developed for solvent extraction reprocessing of spent nuclear reactor fuel. The design is an extension of a contactor developed several years ago at Argonne National Laboratory. Its distinguishing features are high throughput, high stage efficiency and the ability to handle a broad range of aqueous-to-organic phase flow ratios and density ratios. Direct coupling of the mixing and separating rotor to a motorized spindle simplifies the design and makes the contactor particularly suitable for remote maintenance.

A unit that is critically safe by geometry is under test and a larger unit is being fabricated. Multi-stage miniature contactors operating on the annular mixing principle are being used for laboratory flow sheet studies.

The Chemical Engineering Division of Argonne National Laboratory is engaged in a program to modify the design of the type of centrifugal contactor now in use in the Savannah River Plant (SRP) for solvent extraction processing of production reactor fuel. Various elements of this program are being funded through Savannah River Laboratory (SRL) and Oak Ridge National Laboratory (ORNL). Our objective is to simplify the construction and improve the remote servicing capability while retaining the advantages of high throughput, short-residence time (and, thus, reduced solvent damage from exposure to radioactive feed solutions), rapid attainment of steady state operating conditions, and rapid flushout at the end of a processing campaign.

Figure 1 shows a single stage of the SRP contactor. Aqueous and organic streams enter the bottom of the mixing chamber from which they are discharged through a nozzle into the separating bowl or rotor. Under centrifugal force, the two phases are separated and are directed by a series of circular weirs into separate collectors. From these collectors the phases flow in opposite directions into adjacent contactors. An air-controlled aqueous weir is used to shift the aqueous-organic interface to an optimum position and thus permits the contactor to operate effectively over a broad range of flow ratios and density ratios.

The mixing paddle and bowl are mounted on a common shaft which is supported by a bearing assembly and is driven at 1750 rpm by a 5 hp motor. The bowl is 25 cm (10 in.) in diameter and about 43 cm (17 in) long with about 35 cm (14 in) settling zone. This unit has a capacity of ∿200-300 L/min (50-80 gpm) under Purex solvent extraction process conditions.

The SRP contactor is designed for remote replacement of the drive motor, the bearing assembly and the rotary air seal through which air pressure is applied to the weir. However, the mixing paddle is held captive in the mixing chamber. As a result, it is necessary to use concentric shafts so that the inner shaft remains behind with the bowl while the external shaft is removed with the motor and the bearing assembly. This requires special fabrication since such assemblies are not commercially available.

In 1970, when we first became involved in centrifugal contactor work, we built a smaller unit patterned after the SRP design as shown in Fig. 2. It has a bowl 10 cm (4 in) in diameter and a settling zone 30 cm (12 in) long. This unit was belt-driven at speeds up to 3500 rpm. In the course of our design effort, we conceived of a new mixing mode that completely eliminated the mixing chamber, mixing paddle and injection nozzle. This contactor is shown in Fig. 3 and is called the annular centrifugal contactor. In this unit, the aqueous and organic streams are fed into the sides of the casing and are mixed by skin friction as they flow downward in the annulus between the rotating bowl and the casing. Radial vanes at the base of the casing prevent fluid rotation beneath the rotor and direct the mixture into an orifice in the bottom of the rotor. From this point on, the operation is the same as in the Savannah River design. The SRP air-controlled weir system is used here and the separated phases are discharged into collecting rings from which they can flow into adjacent contactors. At a rotor speed of 2000 rpm this unit has a capacity of ~20-35 L/min (5-9 gpm). Capacity is ~50% higher at 3500 rpm. This performance is essentially the same as the contactor achieved when operating in the SR mixing mode and conforms to an extrapolation of the SR unit capacity when adjusted for rotor size and speed.

Converting to the annular mixing mode had a number of distinct advantages over the basic SRP design: (1) elimination of the mixing chamber, mixing paddle and a nozzle simplified fabrication; (2) the weight of the overhung bowl could be reduced and thus it would be easier to balance; and (3) the superstructure could be greatly simplified since the bowl is no longer held captive by the mixing paddle.

During the past year we have designed and built an annular contactor in which the rotor is directly coupled to a 1 hp, 1800 rpm commercial precision motorized spindle as shown in Fig. 4. The motorized spindle is mounted on a plate which is bolted to a large angle bracket. The angle bracket is in turn bolted to the top of a heavy horizontal plate and the contactor casing is bolted to the bottom of the plate. The rotor is suspended from the motorized spindle and is held in place by a hollow drawbar that passes through the hollow shaft of the spindle. A rotory air seal is mounted on top of the draw bar to supply air pressure to the air-controlled weir.

The contactor was fabricated in the ANL shops with rather modest requirements on tolerances. No dimensions are held to closer than 0.001 in. The finished rotor did not require any corrections for dynamic balance and testing with a vibration detector showed the motorized spindle and rotor assembly had the same performance as high precision grinding machinery.

Although this specific unit has not yet been adapted for remote handling, the basic concept is straightforward. Electrical and air lines would be uncoupled, the support bracket would be unbolted and the entire assembly (bracket, motorized spindle and rotor) would be lifted out. An identical replacement assembly could then be installed and reconnected.

This contactor has a rotor 9 cm (3.5 in) in diameter with a settling zone 22 cm (8.5 in) long. Figure 5 shows the rotor suspended beneath the mounting plate. The upper slot is one of four discharge ports for the aqueous phase; the lower slot (actually three parallel holes) is one of four discharge ports for the organic phase. Figure 6 is a top view of the casing showing the four radial vanes at the bottom.

The contactor is currently undergoing hydraulic tests to measure separating capacity at various aqueous-to-organic flow ratios. As shown in Fig. 4, inlet streams enter the sides of the casing and the separated streams are discharged from the collector rings. In the test facility each phase is pumped from a supply tank into an elevated tank from which it flows down through a rotameter, through the contactor and back to the supply tank.

The results of tests made with 30% tributylphosphate (TBP) in n-dodecane (nDD) as the organic phase and 0.5 M nitric acid as the aqueous phase are shown in Fig. 8. Maximum separating capacity or throughput ranges from 5 L/min (1.3 gpm) to 13 L/min (3.4 gpm) at various aqueous-to-organic (A/O) flow ratios. (Maximum separating capacity is measured as the throughput that is reached when contamination of each effluent stream by the other reaches 1%.) At 5 L/min flow rate, residence time is ∿3 sec in the mixing zone and ∿15 sec in the separating zone of the rotor. Weir pressure measurements show that in the A/O range from 0.1 to 2.0, (the typical Purex Process range) a common weir pressure can be found that would operate all stages at about 80% of their maximum throughput.

We plan to test performance at higher rotor speeds and to measure extraction efficiency using natural uranium in nitric acid as the aqueous phase and 30% TBP/nDD as the organic phase. Similar tests made some years ago in the first annular contactor showed extraction and stripping efficiencies above 95%.

The contactor will then be adapted for remote handling tests and will also be subjected to extended running tests to evaluate the performance of the motorized spindle.

This contactor is considerably smaller than the SRP contactor described earlier. We are now engaged in the preliminary stages of designing an annular contactor that has a bowl of the same size as the SRP contactor. We have procurred a 5 hp, 1800 rpm motor to drive the bowl. We expect to build this large unit and install it in the test facility before the end of the fiscal year.

We have also built two eight-stage miniature annular centrifugal contactors for studying solvent extraction kinetics and for developing flow sheets. Figure 7 shows one of these contactors. The rotors are 2 cm (.75 in) ID and the settling zones are 3.3 cm (1.3 in) long. The rotors are driven by a common drive belt at about 6000 rpm with throughputs of up to 120 mL/min depending upon the A/O flow ratio. These miniature units do not have the air-controlled weir used in the larger contactors. We are presently investigating the possibility of building the rotors with replaceable aqueous weirs so that a broader range of flow ratios and density ratios can be handled.

Conclusions

The Argonne Annular centrifugal contactor is a natural evolution of the basic design that was first developed at the Savannah River Laboratory. In our design we retain such desirable performance characteristics of the SRL design as high stage efficiency, high throughput, short-residence time and reduced radiation damage to the solvent. We also retain the desirable mechanical features such as the overhung rotor (which eliminates the need for a bottom bearing) and the air-controlled weir (which permits the same unit to be used for a broad range of flow ratios and density ratios). We see our primary improvement as resulting from simplification of the design. These changes permit the use of commercially available components, reduce the complexity and cost of fabrication and improve the adaptability to remote servicing. We, therefore, believe that the annular centrifugal contactor can be readily applied to a broad variety of potential solvent extraction systems in the laboratory as well as in the production plant.

References

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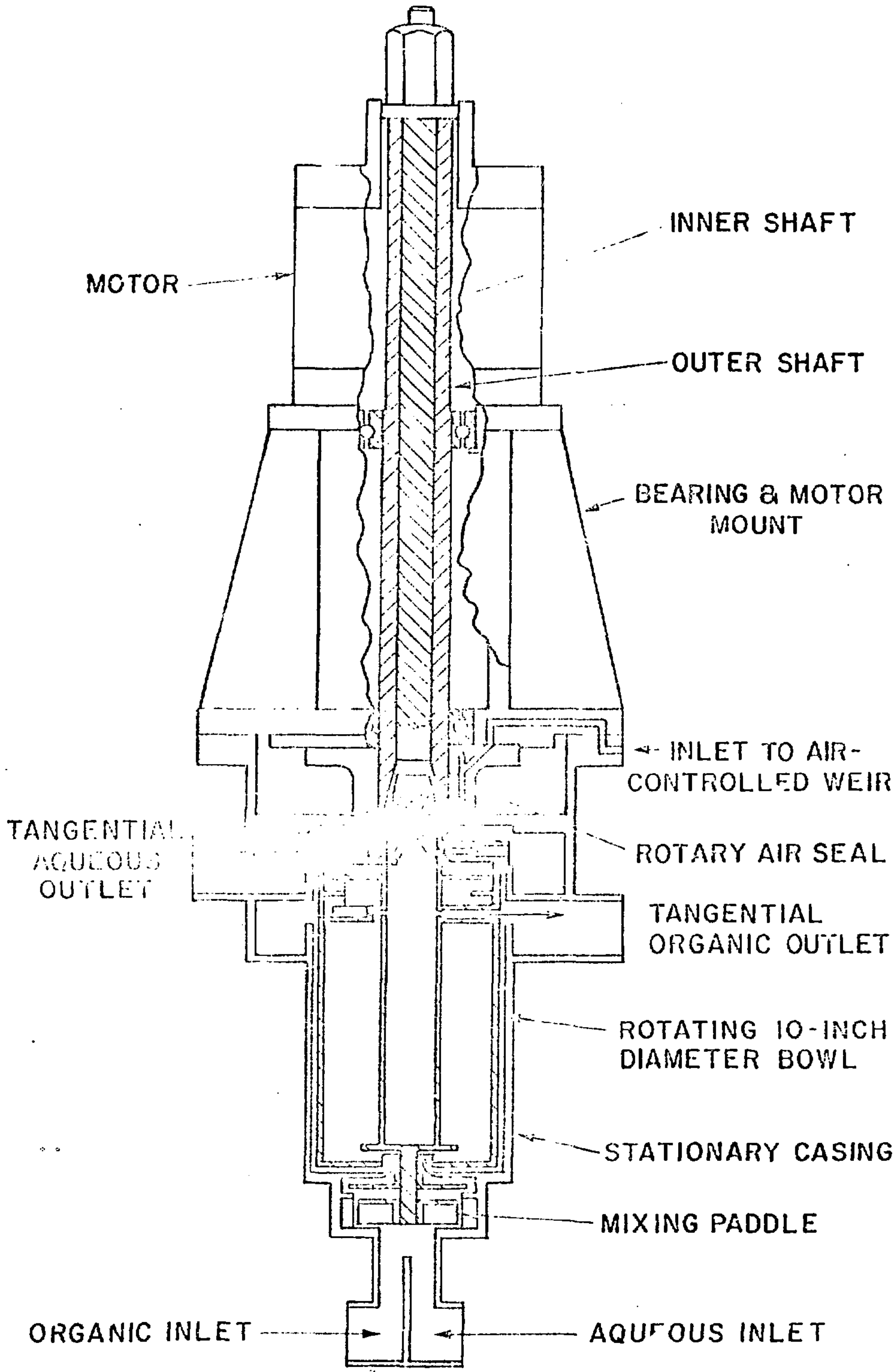

FIG. 1. CENTRIFUGAL CONTACTOR - SAVANNAH RIVER PLANT

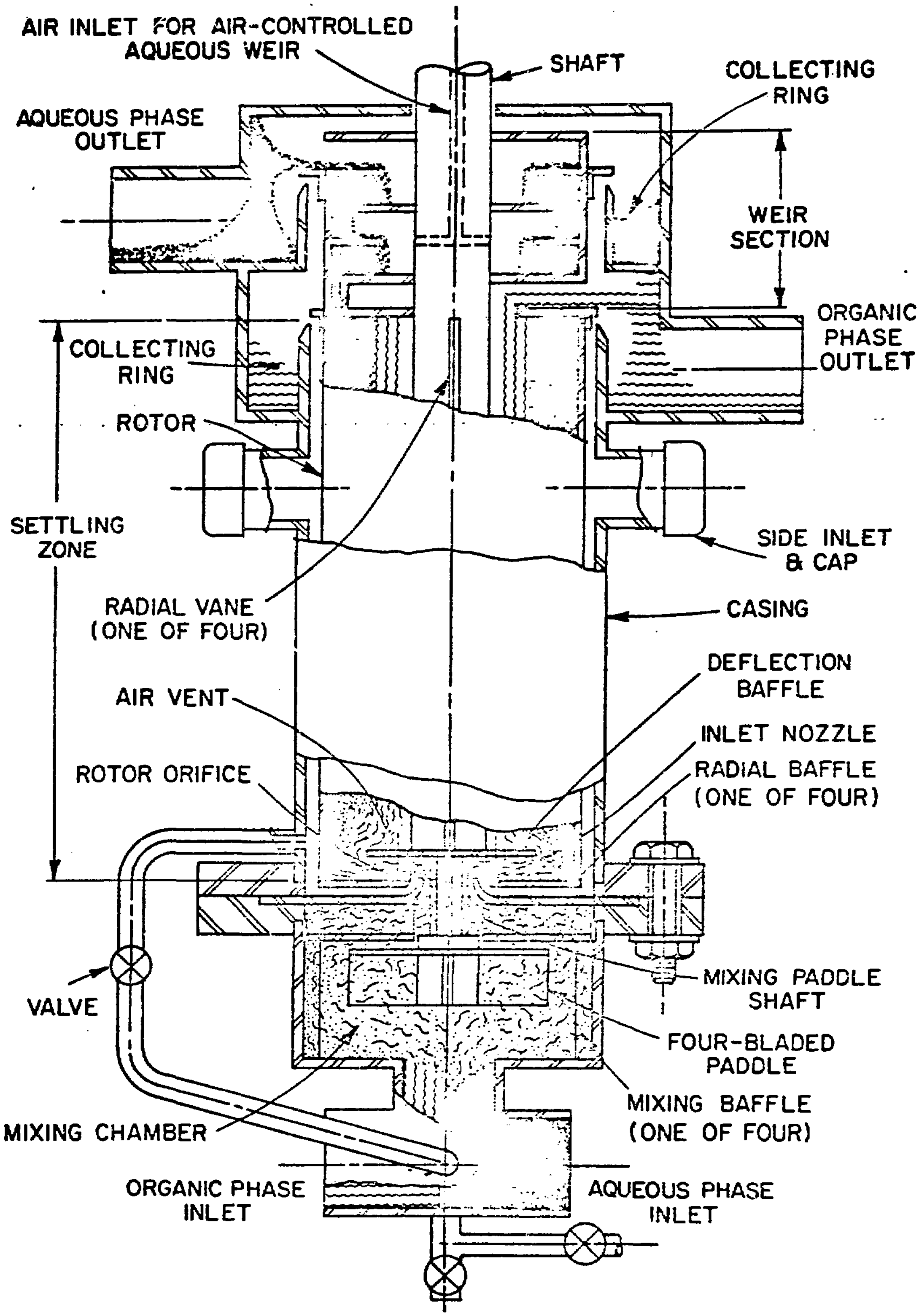

FIG. 2. EXPERIMENTAL LONG-ROTOR CENTRIFUGAL CONTACTOR (SAVANNAH RIVER TYPE)

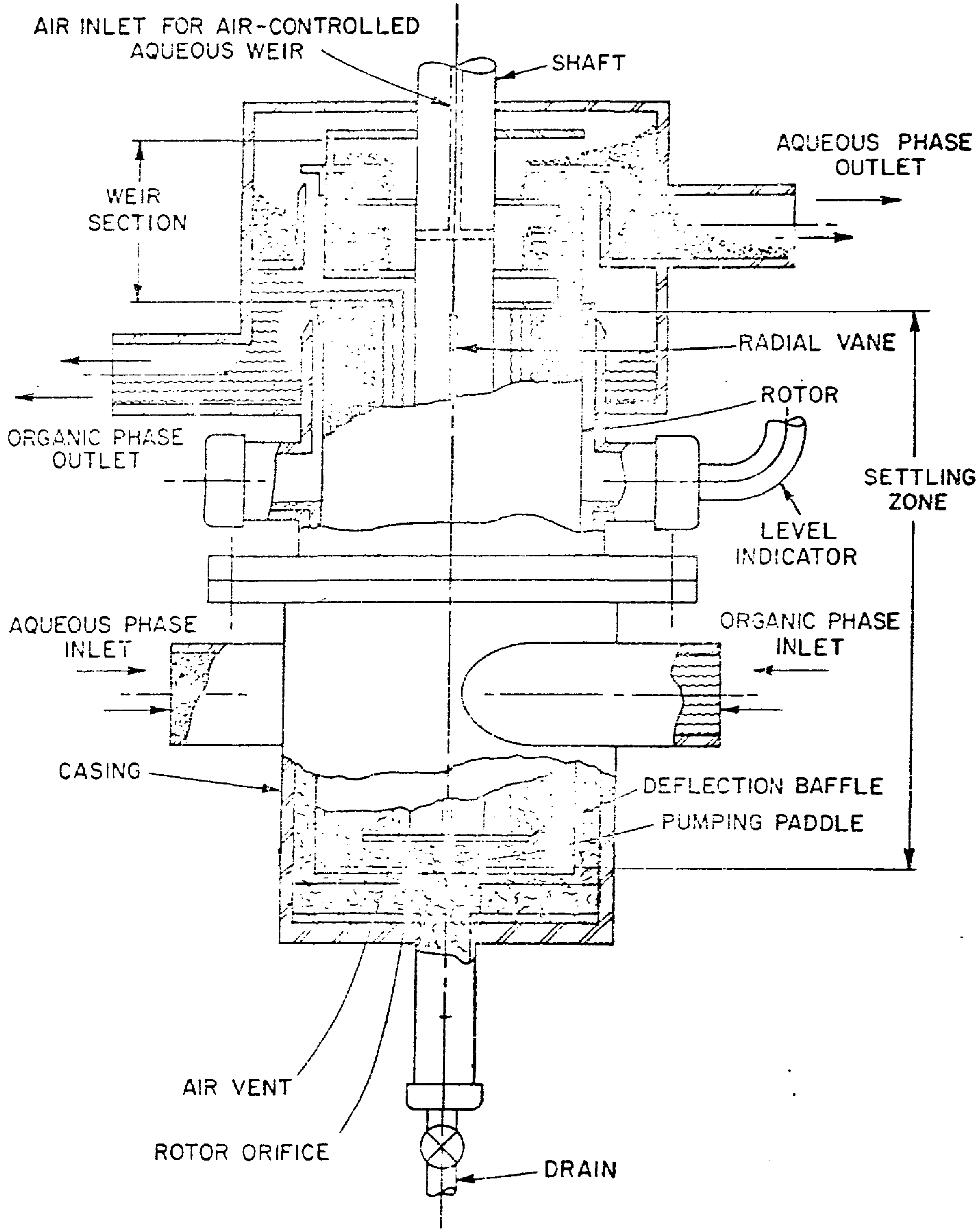

FIG. 3. EXPERIMENTAL ANNULAR CENTRIFUGAL CONTACTOR

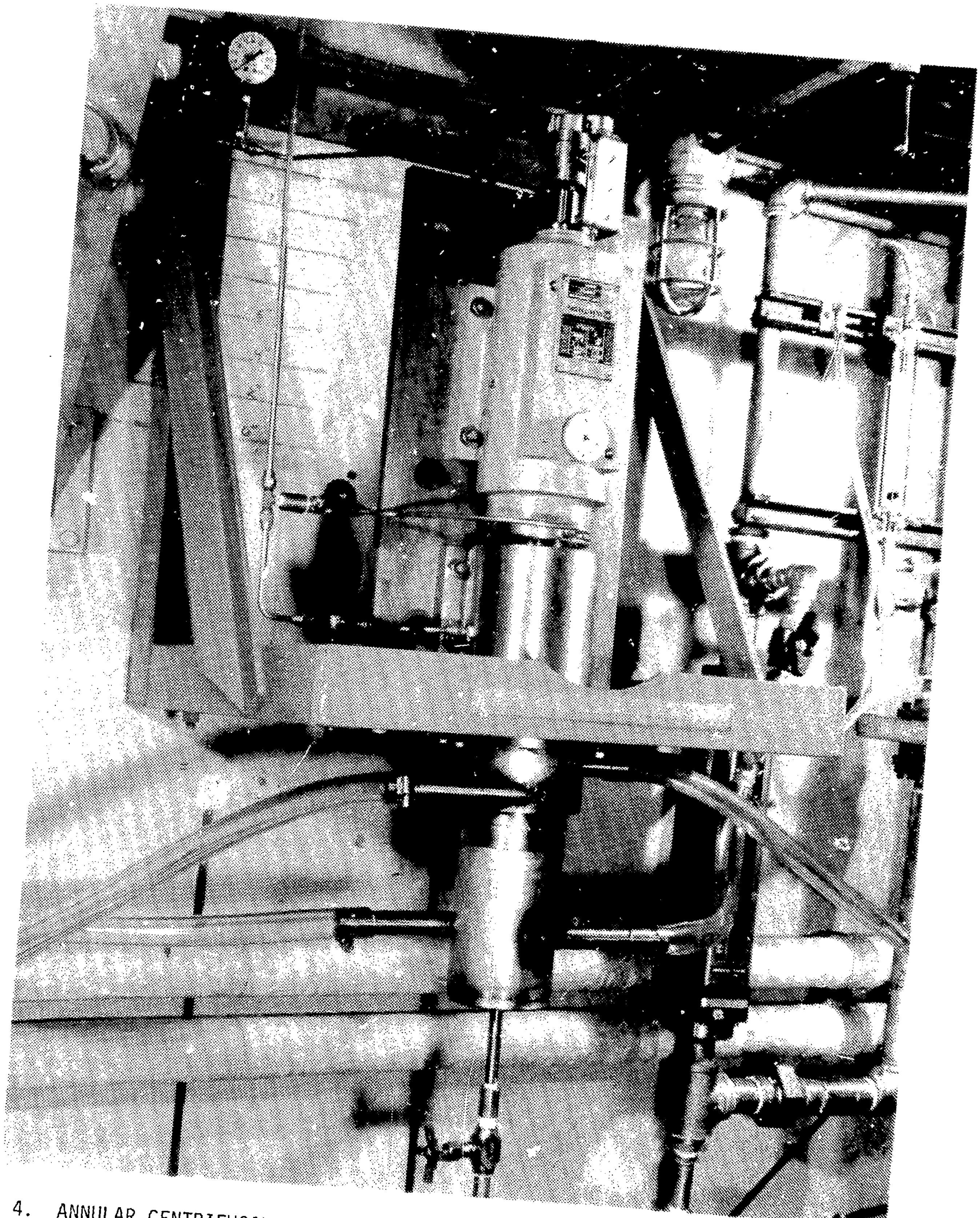

Fig. 4. ANNULAR CENTRIFUGAL CONTACTOR AND MOTORIZED SPINDLE (ANL Photo No. 308-78-30)

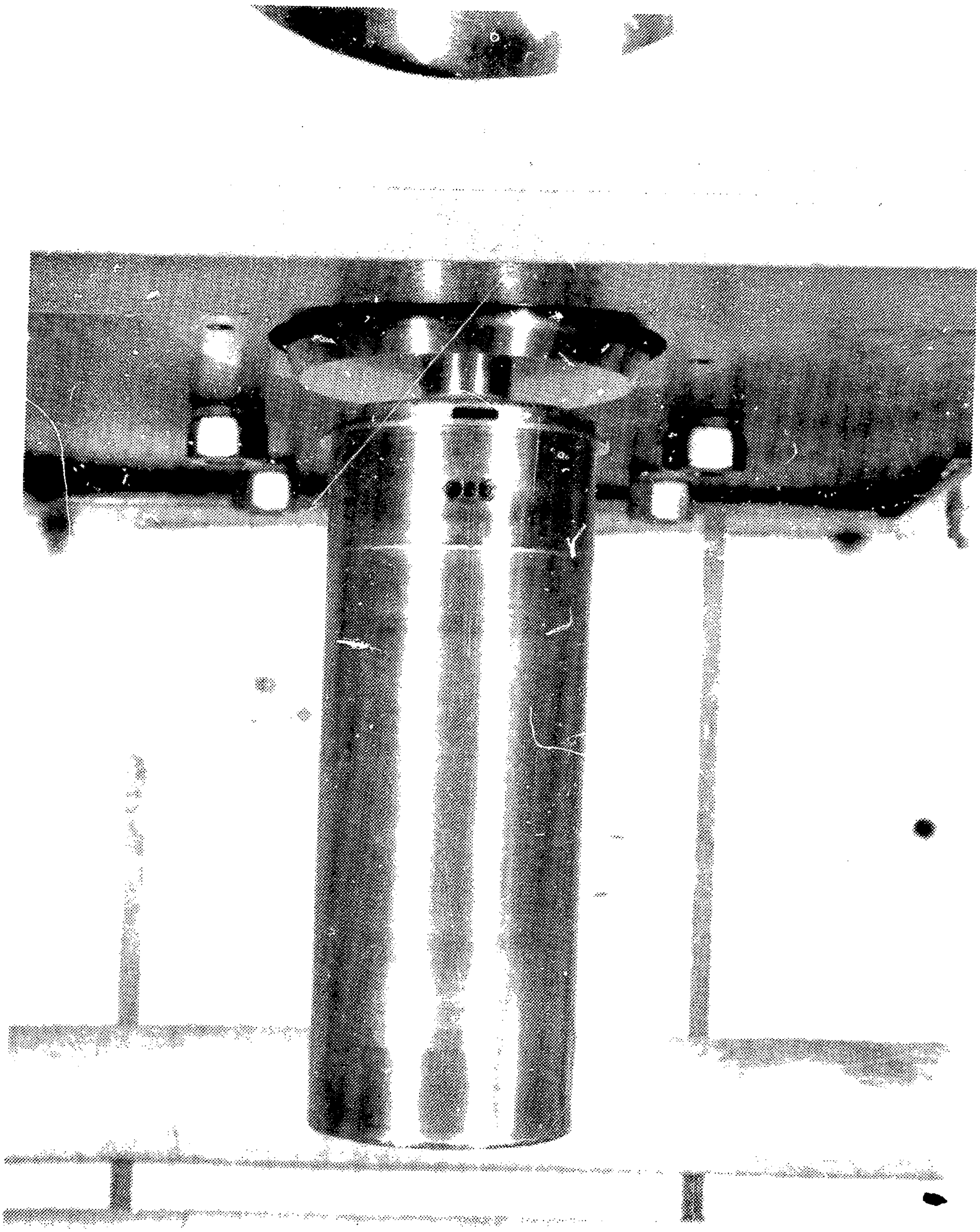

Fig. 5. CONTACTOR ROTOR (ANL Photo No. 308-78-26)

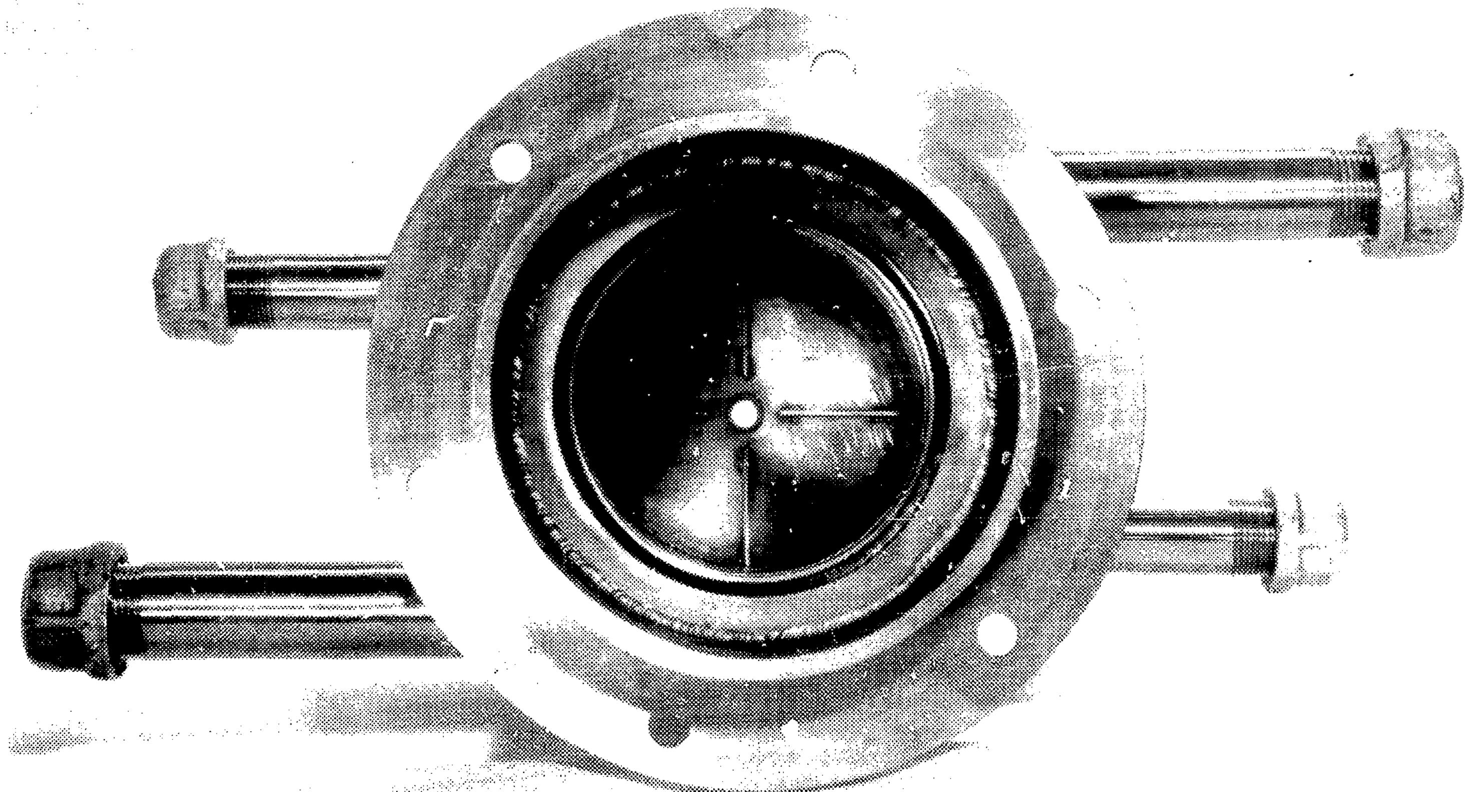

Fig. 6. CONTACTOR CASING (ANL Photo No. 308-77-603)

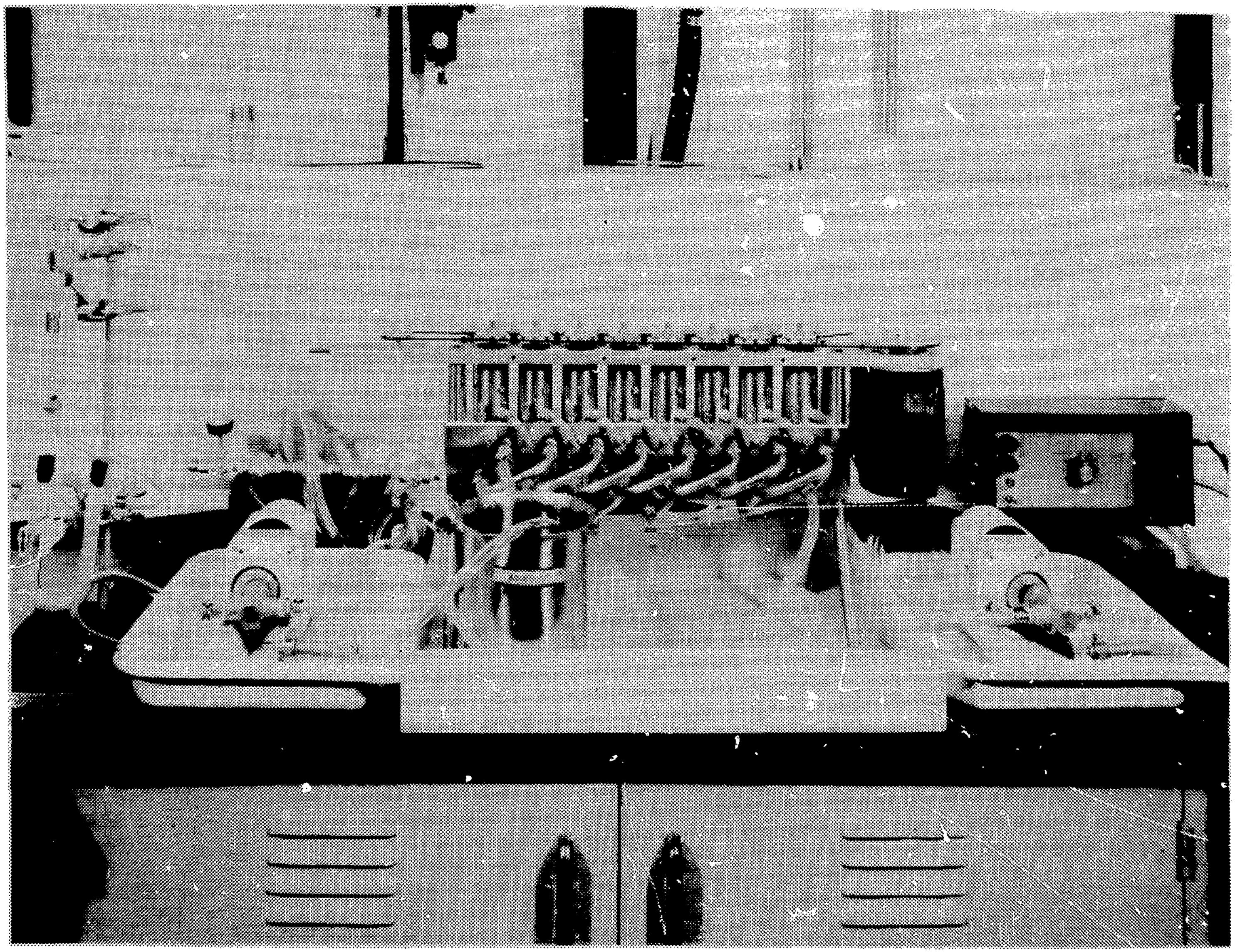

Fig. 7. EIGHT-STAGE MINIATURE CONTACTOR (ANL Photo No. 308-77-598)

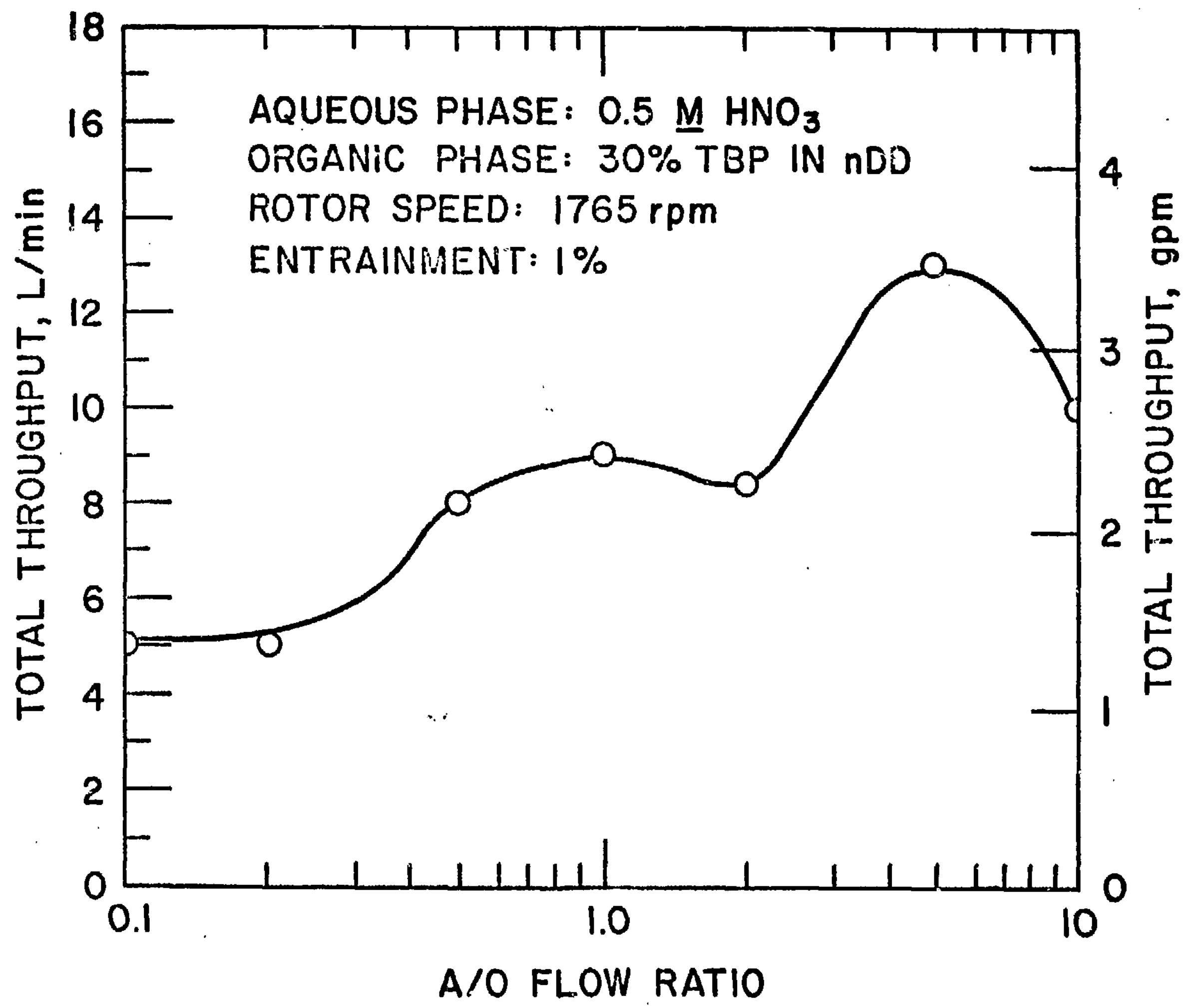

FIG. 8. SEPARATING CAPACITY OF 9-CM ANNULAR CENTRIFUGAL CONTACTOR