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L. O. Finsterwalder

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# GEOMETRIC SCALING OF STACKED-CLONE CONTACTORS

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# GEOMETRIC SCALING OF STACKED-CLONE CONTACTORS

L. O. Finsterwalder

ABSTRACT

A study of the effect of geometric scale-up on the performance of the stacked-clone contactor, which is a high performance, liquid-liquid, countercurrent solvent extraction device, has been completed. Units 0.5 and 1.4 times the size of the original contactor have been tested. Hydraulic data for these machines showed solution throughput to be 40 and 119% of the original MK X machine respectively. Mass-transfer stage efficiencies were obtained, using uranyl nitrate in the system 1 M $NaNO_3$--18% TBP in Amsco. The results averaged 85% for the smaller, and 74% for the larger, contactor.

The validity of the obtained scale-up factors for other chemical systems was demonstrated with the half-scale unit using the system $HNO_3$--0.8 M $Al(NO_3)_3$--40% TBP in Amsco.

## 1. INTRODUCTION

The stacked-clone contactor is a high-speed countercurrent solvent extraction device based on the inherent flow pattern in hydroclones. In a hydroclone the fast spinning motion created by the tangential feed entry gives rise to high centrifugal and shear fields within the cavity. Because of the decrease of the centrifugal field caused by the drag along the wall, one gets strong secondary flows. The slower-moving boundary layer is squeezed out by the faster-moving inner liquid and travels on a spiral path along the wall out of the underflow port. In a closed system, this outflow is matched by a countercurrent inflow along the axis of the clone.

In a stacked-clone contactor, several hydroclones connected by underflow chambers are stacked axially together to form a countercurrent cascade. Extensive work has been done to optimize the geometrical form of the hydroclones and underflow chambers to achieve high stage efficiencies and liquid throughputs. This work was described in previous reports. Dimensional scale-up was investigated in the work described in this report.

## 2. EXPERIMENTAL RESULTS

In addition to the original full-scale MK X contactor, two new units, which were 0.5 and 1.4 times the size of the original contactor, were tested. A detailed description of these machines is presented in Section 4.

### 2.1 Hydraulic Data

We used water to determine the recycle pressure-flow characteristics for a typical stage for each of the three contactors. The mathematical form of the relations is a parabola,

$$\Delta p = K \cdot F^2.$$

Table 1 gives the values of hydraulic K for the three contactors. The hydraulic K multiplied by the fourth power of the scale factor is essentially the same for all three units, which means that the recycle rates at equal pressures are proportional to the cross sections of the contactors. Recycle rates for water were 4.25 liters/min at 21.4 psi for the 0.5-scale, 17 liters/min at 20 psi for the full-scale, and 32.3 liters/min at 19.5 psi for the 1.4-scale unit.

### 2.2 Flooding Data

Flow capacity and mass-transfer runs were made with the system 1 M $NaNO_3$--18% TBP in Amsco, using uranyl nitrate as a distributing solute. Typical physical properties of this system are shown in Table 2. Flooding data at 40°C for all three contactors are presented in Table 3 and Fig. 1. The throughput of the small unit averages 40%, whereas the throughput of the 1.4-scale contactor is only 119%, of that of the full-scale machine.

### 2.3 Mass-Transfer Data

Mass-transfer data for the above mentioned system are given in Table 4. Four series of runs with the 0.5-scale unit had low efficiencies, apparently caused by swelling of the plastic inserts, which caused underflow gaps to become smaller. After correction, the contactor performed with an average efficiency of 85%.

Table 1. Data Summary

| | 0.5-Scale Unit | Full-Scale Unit | 1.4-Scale Unit |
|---|---|---|---|
| Scale Factor, r | 0.5 | 1.0 | 1.4 |
| Hydraulic K | 16.7 | 0.99 | 0.28 |
| $K \cdot r^4$ | 1.04 | 0.99 | 1.075 |
| Flow Capacity (Flooding) at 40°C and A/O = 3, liters/min | 1.25 | 3.08 | 3.67 |
| Typical Stage Volumes: | | | |
| Hydroclone cavity, underflow chamber, plenums, ports, and ducts, cc | 8.5 | 68.4 | 186.0 |
| Pump impeller cavity and ports, cc | 41.0[a] | 41.0 | 82.0[a] |
| Pump-connecting lines, cc | 50.6[a] | 50.6 | 184.0[a] |
| Total volume per stage, cc | 100.1 | 160.0 | 452.0 |
| Residence time[b] per stage at flooding, sec | 1.0 | 3.1 | 7.2 |
| Average Stage Efficiency, % | 85 | 65 | 74 |
| Performance Index, $P = \frac{FE}{r^2}$ | 4.24 | 2.0 | 1.39 |

[a]Not scaled properly; may be varied depending upon design considerations.

[b]Based on flooding data at a flow ratio (A/O) of 3 and on the volumes of the hydroclone, related parts, and appropriately scaled pump and lines.

Table 2. Physical Properties of the System 1 M $NaNO_3$--18% TBP in Amsco, Used in the Extraction of Uranyl Nitrate in the Stacked-Clone Contactor

| Temperature (°C) | Aqueous Phase Density (g/cc) | Aqueous Phase Viscosity (centipoises) | Organic Phase Density (g/cc) | Organic Phase Viscosity (centipoises) | Density Difference (g/cc) | Interfacial Tension (dynes/cm) |
|---|---|---|---|---|---|---|
| 25 | 1.0505 | 0.8705 | 0.7865 | 1.4247 | 0.2640 | 13.00 |
| 30 | 1.0455 | 0.7842 | 0.7825 | 1.3159 | 0.2630 | 13.05 |
| 35 | 1.0410 | 0.7385 | 0.7790 | 1.2094 | 0.2620 | 13.60 |
| 40 | 1.0360 | 0.6995 | 0.7750 | 1.1480 | 0.2610 | 14.10 |
| 45 | 1.0315 | 0.6658 | 0.7715 | 1.1004 | 0.2600 | - |
| 47 | - | - | - | - | - | 14.30 |

Table 3. Flow Capacity of the Contactors at Flooding

Aqueous Phase: 1 M $NaNO_3$, 0.08 M $HNO_3$, trace of uranium

Organic Phase: 18% TBP in Amsco, trace of uranium

Temperature : 40°C

| A/O | Throughput of the Contactors (liters/min) | | |
|---|---|---|---|
| | 0.5-Scale | Full-Scale | 1.4-Scale |
| 0.5 | 0.67 | 1.72 | 2.03 |
| 1 | 0.84 | 2.08 | 2.46 |
| 2 | 1.09 | 2.65 | 3.16 |
| 3 | 1.25 | 3.08 | 3.67 |
| 5 | 1.44 | 3.66 | 4.39 |
| 10 | 1.67 | 4.42 | 5.35 |

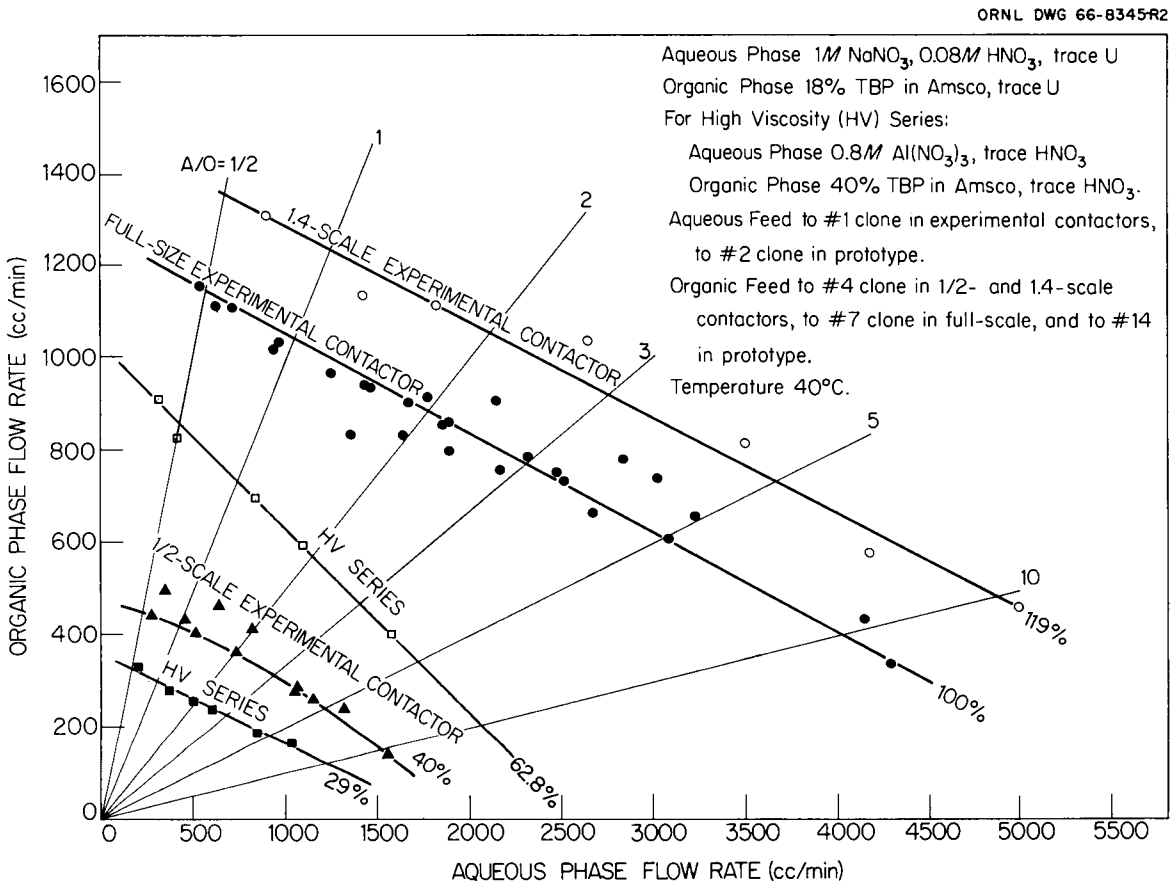


Fig. 1. Comparison of Flow Capacities of Three Stacked-Clone Contactors at Flooding.

Table 4. Performance Data for Three Stacked-Clone Contactors

Aqueous Phase: 1 M $NaNO_3$
Organic Phase: 18% TBP in Amsco
Distributing Species: $UO_2(NO_3)_2$

| Contactor | Run Series | No. of Runs | Average Temperature (°C) | Range of Throughput (% of Flooding) | Range of A/O | Stage Efficiency (%) |
|---|---|---|---|---|---|---|
| Half-Scale | 1 | 12 | 41.7 | 78-98 | 2.79-3.84 | 92 ± 21 |
| | 7 | 12 | 40.4 | 84-99 | 2.74-3.85 | 86 ± 7 |
| | 36 | 10 | 40.0 | 92-97 | 3.0 -3.58 | 80 ± 9 |
| | 41 | 12 | 40.3 | 88-98 | 2.73-3.3 | 90 ± 4 |
| | 47 | 12 | 40.3 | 86-100 | 2.52-3.25 | 79 ± 8 |
| Full-Scale | 958 | 12 | 40.2 | 58-97 | 1.49-4.77 | 64 ± 5 |
| | 964 | 12 | 40.1 | 61-105 | 1.64-4.94 | 65 ± 4 |
| | 1 M 16 | 8 | 41.0 | 64-97 | 2.08-4.58 | 67 ± 4 |
| | 1 M 20 | 8 | 40.0 | 67-92 | 2.06-4.69 | 64 ± 5 |
| 1.4-Scale | 1 | 12 | 39.8 | 68-82 | 3.24-3.97 | 77 ± 9 |
| | 7 | 12 | 40.5 | 80-89 | 2.75-3.31 | 75 ± 5 |
| | 13 | 12 | 40.2 | 89-99 | 2.30-3.32 | 70 ± 8 |
| Half-Scale | HVS 1[a] | 12 | 40.6 | 77-94 | --- | 83 ± 10 |
| | HVS 7[a] | 10 | 40.6 | 82-91 | --- | 80 ± 12 |
| Full-Scale | H1[a] | 9 | 41.4 | 69-93 | --- | 45 ± 7 |
| | H5[a] | 10 | 41.1 | 82-106 | --- | 51 ± 7 |

[a]A system 0.8 M $Al(NO_3)_3$--0.5 M $HNO_3$--40% TBP in Amsco.

The 1.4-scale machine operated with an average efficiency of 74%, compared with 65% for the full-scale experimental unit. All mass-transfer efficiencies were calculated with a computer and are based on a distribution coefficient that was adjusted by using an iteration method to obtain equal efficiencies in both the stripping and the extraction modes of operation.

The effect of a viscous aqueous phase was studied in the small contactor by extracting $HNO_3$ from 0.8 M $Al(NO_3)_3$ with 40% TBP in Amsco. The throughput was 73% of that obtained for the standard $NaNO_3$--18% TBP system, and mass-transfer runs yielded a stage efficiency of 81%. This is superior to the performance of the full-scale unit in a similar study. With the viscous system, the full-scale unit ran at 63% of its throughput with the $NaNO_3$--TBP system and had a stage efficiency of 48%.

## 3. DISCUSSION

We can compare the performances of geometrically scaled units by using a performance index, P, which is defined as:

$$P = \frac{F \cdot E}{r^2},$$

where

F = the total flow,

E = the stage efficiency, and

r = the scale factor.

In contactors where stage efficiencies vary little with size and where the total flow capacity depends only on cross section, this number should be constant for all sizes.

Table 1 shows that the performance indexes for the three contactors tested increased markedly as the size was reduced. A log-log plot exhibits a $P \sim r^{-1.08}$ relation.

In a properly designed unit, the stage volume, $V_s$, is proportional to the third power of the scale factor, r. The contact time, T, per theoretical stage can be defined as:

$$T = \frac{V_s}{E \cdot F} = \frac{V_s}{P \cdot r^2} \sim r^{2.08} .$$

# 4. EXPERIMENTAL SETUP

## 4.1 Contactors

Two new contactors, 0.5 and 1.4 times the size of the original MK X machine (a stage of which is schematically shown in Fig. 2), were designed and fabricated. The original feed plates, as well as the 1/8-hp Eastern pumps, were used in both instances. Clone bodies and feed plate inserts were made of Lucite. Pump connections were made of 5/8-in.-diam stainless steel tubing.

The 0.5-scale machine (Fig. 3) consisted of four extraction and four polishing stages, each driven by an Eastern pump. The pumps were arranged in two levels. The settling section at the organic solvent discharge consisted of a 5-in. section of 1.5-in.-diam tubing, which was packed with 1/4-in.-diam by 1/4-in.-long polyethylene sections, joined to a 30°-inclined, 1.5-in.-diam settler. The aqueous phase was withdrawn from the lower end of this settler, 4 in. from the mixed-phase inlet. The upper 12 in. of the inclined section was made of glass pipe. The 1.4-scale machine (Fig. 4) had four extraction and three polishing stages. Each stage was driven by two Eastern pumps connected in parallel to supply the double flows. A Y-shape manifold kept the flow resistance of these connections to a minimum. The end section from the original MK X contactor was used, but the length of the 3-in.-diam glass pipe was extended to 24 in.

## 4.2 Auxiliary Equipment

A flow diagram of the stacked-clone contactor test facility is shown schematically in Fig. 5. The rates of all four streams to and from the contactor were monitored by rotameters. Temperatures were adjusted by using heat exchangers. Aqueous and organic feed pressures were provided by booster pumps or gravity. The constant flows--organic feed and aqueous raffinate--were controlled using orifice meters and checked by volume displacement in sight glasses. The aqueous feed was introduced into the bottom of the gravity settler at a rate governed by the pressure signal from the first-stage recycle pump, which senses the position of the interface in the settler. The organic feed was introduced into the

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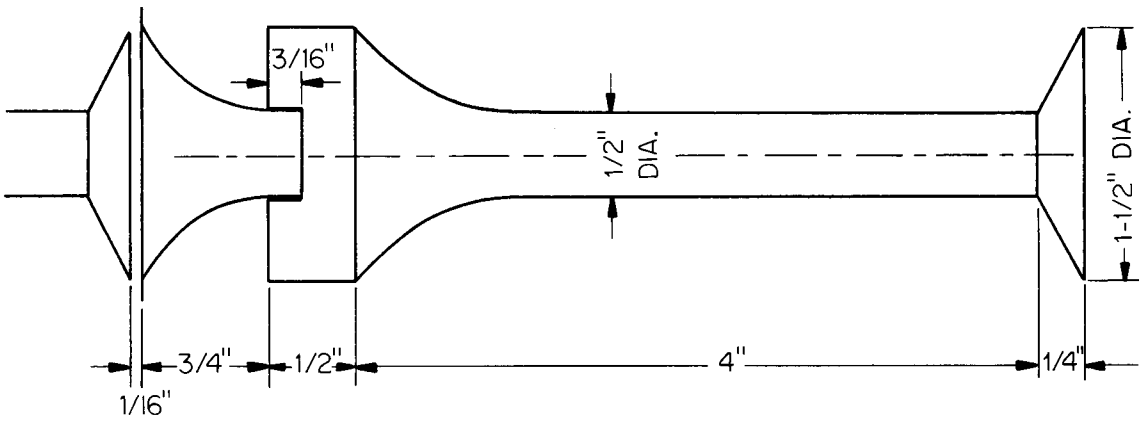


Fig. 2. Full-Scale MK-X Extraction Stage.

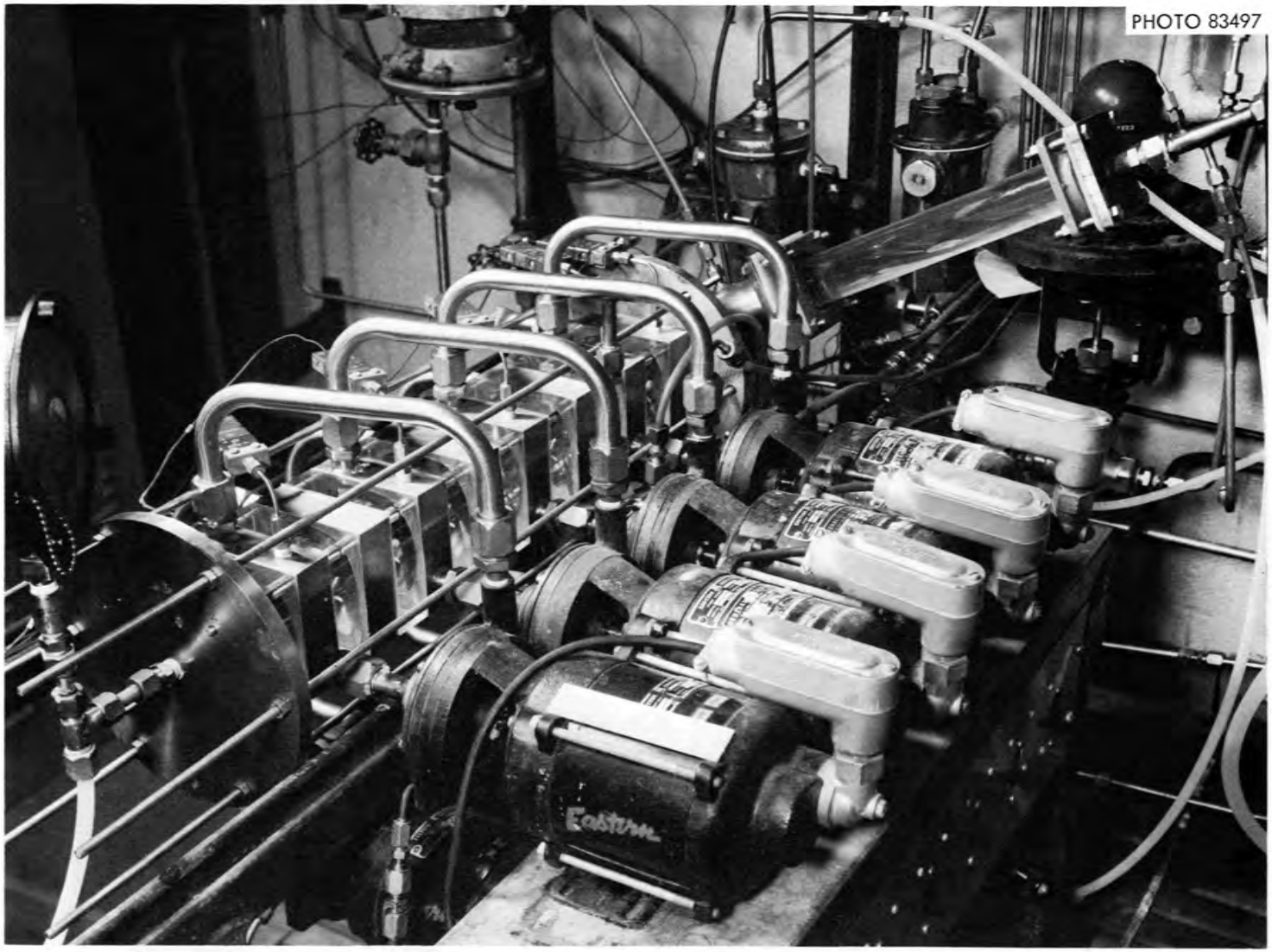


Fig. 3. 0.5-Scale Machine.

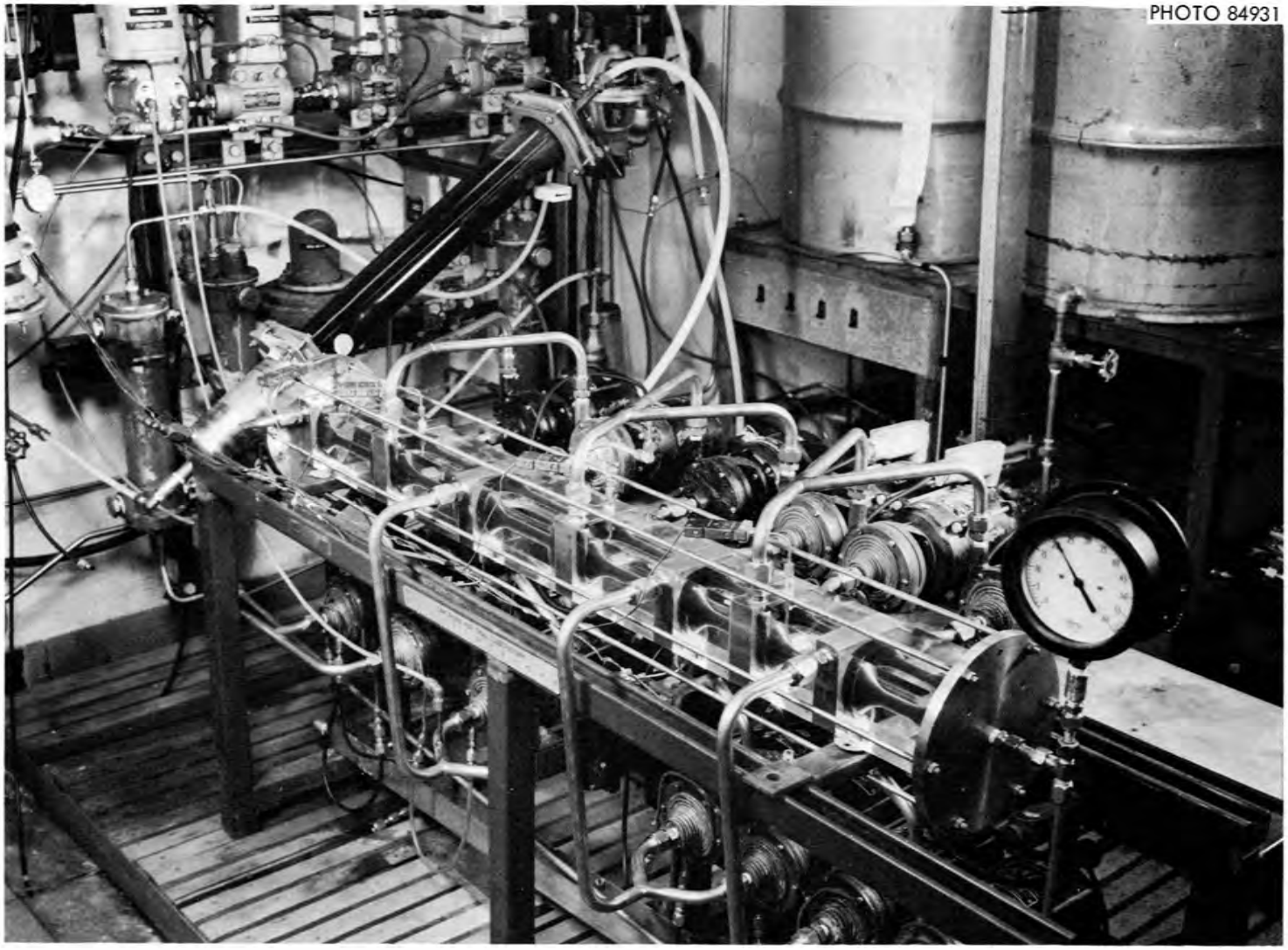


Fig. 4. 1.4-Scale Machine.

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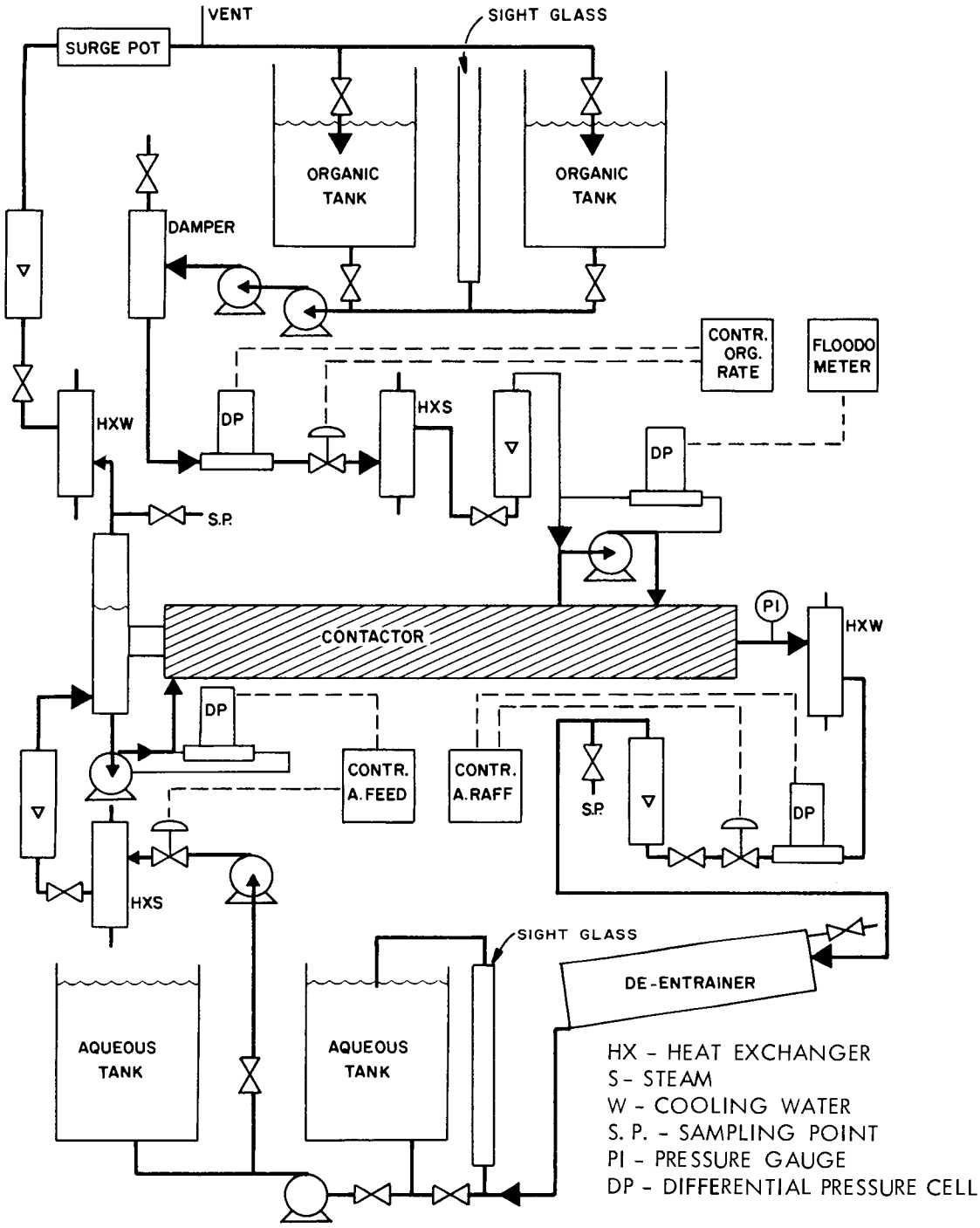


Fig. 5. Schematic Flowsheet of the Stacked-Clone Contactor Test Facility.

suction side of the fourth-stage pump. The organic product was withdrawn over a weir approximately 7 ft above the contactor to prevent pump-cavitation of the first stage. A differential-pressure cell connected across the organic feed-stage pump sensed the organic holdup of the stage, which increases sharply as the unit approaches its maximum throughput.

Special care was taken to keep the temperatures constant in the contactor. Thermocouples were installed in every stage and in the end section, and readings were plotted by a 12-point Honeywell recorder. The recycle pumps were equipped with cooling coils, which were located on the face of the pump housings, to dissipate the energy introduced by the pumps. Cooling water rates, as well as steam rates for the heat exchangers, were set manually. A warmup operation time of approximately 20 min without flows of process streams helped the system attain steady-state temperatures.

## 5. CONCLUSION

Our results indicate that the superior performance of the small clone units can be attributed to the higher induced gravity fields in the clones. Subsequent prototype contactors for hot cells should, therefore, have several parallel cascades of small clones arranged around the centrally located recycle pumps. Increasing the capacity of stacked-clone contactors by geometric scale-up should be avoided until all techniques for manifolding have been exploited and practically exhausted.

## 6. BIBLIOGRAPHY


1. M. E. Whatley and W. M. Woods, Jr., U. S. Patent No. 3,052,361, assigned to AEC, U. S. Government (filed December 6, 1960; issued September 4, 1962).
2. F. L. Culler, Jr., et al., Chemical Technology Division Annual Progress Report for Period Ending May 31, 1963, ORNL-3452, pp. 221-25.
3. F. L. Culler, Jr., et al., Chemical Technology Division Annual Progress Report for Period Ending August 31, 1960, ORNL-2993, pp. 194-96.
4. F. L. Culler, Jr., et al., Chemical Technology Division Annual Progress Report for Period Ending June 30, 1962, ORNL-3314, p. 205.
5. F. L. Culler, Jr., et al., Chemical Technology Division Annual Progress Report for Period Ending May 31, 1961, ORNL-3153, p. 125.
6. F. L. Culler, Jr., et al., Chemical Technology Division Annual Progress Report for Period Ending May 31, 1964, ORNL-3627, pp. 235-39.
7. M. E. Whatley et al., Unit Operations Section Monthly Progress Report, March 1962, Chemical Technology Division, ORNL-TM-222, pp. 7-25.
8. M. E. Whatley et al., Unit Operations Section Monthly Progress Report, August 1962, Chemical Technology Division, ORNL-TM-355, pp. 12-38.
9. M. E. Whatley et al., Unit Operations Section Monthly Progress Report, May 1963, Chemical Technology Division, ORNL-TM-613, pp. 6-13.
10. M. E. Whatley et al., Unit Operations Section Monthly Progress Report, May 1964, Chemical Technology Division, ORNL-TM-937, pp. 7-19.
11. M. E. Whatley et al., Unit Operations Section Monthly Progress Report, December 1964, Chemical Technology Division, ORNL-TM-1091, pp. 6-17.
12. M. E. Whatley et al., Unit Operations Section Quarterly Progress Report, April-June 1965, Chemical Technology Divison, ORNL-3868, pp. 8-21.

13. M. E. Whatley et al., Unit Operations Section Quarterly Progress Report, July-September 1965, Chemical Technology Division, ORNL-3916, pp. 3-9.

14. M. E. Whatley et al., Unit Operations Section Quarterly Progress Report, October-December 1965, Chemical Technology Division, ORNL-3958, pp. 6-11.

15. M. E. Whatley et al., Unit Operations Section Quarterly Progress Report, January-March 1966, Chemical Technology Division, ORNL-3995, pp. 4-20.

16. M. E. Whatley and W. M. Woods, The Performance of An Advanced Experimental Stacked-Clone Contactor: A High-Performance Solvent Extraction Machine with Potential for Application to Very Highly Radioactive Solutions, ORNL-3533 (April 1964).

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