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February 19, 1981

M E M O R A N D U M

TO: J. F. ORTALDO

FROM: B. V. CHURNETSKI *BVC*

EFFECTIVE CLEANING RADIUS STUDIES

Summary

Results of testing done in the Savannah River Laboratory half tank and full tank mockup facilities using kaolin clay slurries indicate a relationship between cleaning radius and pump and slurry characteristics of the form:

$$ECR \propto DV_o \left(\frac{\rho}{\tau_o}\right)^{\frac{1}{2}}$$

This can be used to predict the slurry pump requirements for sludge removal during waste tank retirement.

Background

Waste is to be removed from 22 older type I, II, and IV tanks and placed in new, stress relieved type III tanks. The waste consists of approximately seven million gallons of salt and two million gallons of sludge. The salt will be removed by dissolution in water. The high specific gravity solution will then be transferred to the new tanks for storage. The sludge will be hydraulically resuspended. This pumpable slurry will then be transferred to the new tanks.

Storage in type III tanks is the interim solution. Long range plans call for removal of the waste from these tanks for feed to the Defense Waste Processing Facility where the waste will be immobilized in glass and placed in permanent storage.

Access to any of the waste tanks is limited to existing riser locations (Figure 1). The technology developed for waste removal under this restriction includes the use of long shaft, centrifugal pumps. This technology was proven in the Tank 16H cleaning demonstration where about 98% of the sludge was removed using 3 slurry pumps.[1] Initial testing done in a half tank facility predicted 85% sludge removal using five pumps.[2] This conservatism required further definition of the cleaning mechanism of the pump and the slurry rheology.

Purpose

The slurry pump development program includes the definition and optimization of hydraulic cleaning procedures for waste removal. The two thrusts of this program are (1) to determine the rheological relationship between the actual sludge and the kaolin clay simulant and (2) to correlate the cleaning parameters to both slurry and pump characteristics.

Test Equipment and Facilities

Initial testing was done in a half tank facility (Figure 2 and 3). As larger capacity pumps were developed the geometric configuration of the half tank facility began to interfere with the measurements of pump cleaning ability.

Present testing is done in a full tank mockup (Figure 4). The tank is 85' in diameter and 8' high. The overhead gantry has six pump locations to model type I, II and IV tanks. To simulate two feet of waste in the mockup tank approximately 130 tons of kaolin clay are required.

Kaolin clay slurries are used to simulate the actual sludge in tanks because (1) it has rheological properties similar to chemically simulated sludge, (2) different rheology can be simulated by varying the water content of the slurry, and (3) the large quantities necessary for testing make the kaolin clay both cost effective and ecologically acceptable. The radioactive sludge consists mainly of insoluble oxides and hydroxides of manganese, aluminum, and iron. It is a sticky, brown, gelatinous material with particle size between 1-80μ. It is characterized as a Bingham plastic, a material with a yield stress. Kaolin clay slurries above ten weight percent exhibit the same characteristic. The yield stress of a sample can be measured using a Haake viscometer, an instrument that produces shear stress versus shear rate curves.

The recirculating, centrifugal pump (Figure 5) has a top mounted 150 hp motor. It's long shaft is enclosed in a 16" O.D. casing. Seven water lubricated bushings keep the shaft aligned. The pump has a bottom suction with two opposing discharge nozzles. The immersion of the pump in the sludge layers allows a recirculating mixture of sludge to serve as feed for the pump. The entire pump can be rotated between 1/5 and 1/2 rpm. This creates a circular cleaning pattern defined as the effective cleaning radius (ECR). This effective cleaning radius is a measure of the cleaning ability of a pump.

The ECR is the distance from the center of the pump to the point where there no longer exists slurried sludge layers (Figure 6). The ECR is an important factor in effective and efficient tank cleaning.

The pump action extends beyond the ECR. The distance from the pump to the outer most visible reach of the pump is called the surface radius (SR). This is the observable action in the actual waste tank during inspections. The surface radius is not a good indication of the pump cleaning capacity since (1) there is unslurried sludge below the last portion of the jet and (2) the SR increases much more rapidly with the amount of liquid on the surface than does the ECR.

Background Theory

Initial studies [3,4] emphasized the velocity of the jet. The two design factors considered potentially important for a liquid jet to be able to resuspend sludges were the turbulence level of the jet stream and the impact of the stream on the sludge. Both of these design parameters are dependent on the velocity of the stream. The ability to keep the solids fluidized is also directly related to the velocity. Therefore, the velocity of the jet at any distance from the nozzle was taken as the measure of the slurrying efficiency of the jet. With this emphasis, submerged jet theory was applied to the nozzle of the pump.

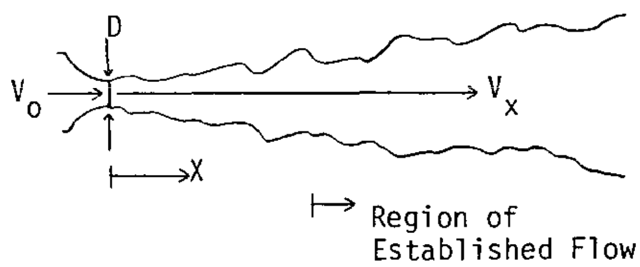

FIGURE 7: CONFIGURATION OF A TURBULENT FREE JET

This theory states that when a turbulent, high velocity, free jet of fluid is discharged from a round opening, it both entrains fluids and expands (Figure 7). Most of the slurrying action and entrainment takes place in the region of established flow which begins at approximately 8 nozzles diameters. The distribution of velocity along the axis in this region for a single phase jet with no density gradients is given by:[5]

$$V_x = \frac{C_1}{X} V_o D e^{-C_2 (r/x)^2} \qquad (1)$$

using $r/x = \tan(\frac{1}{2}\theta)$.

$$V_x = \frac{C_1}{X} V_o D e^{-C_2 [\tan(\frac{1}{2}\theta)]^2} \qquad (2)$$

where C_1 is a constant (equal to approximately 6.2)[5]

C_2 is a constant (equal to approximately 40.)[5]

x is the distance from nozzle

V_o is the initial discharge velocity

V_x is the velocity at point x

D is the nozzle diameter

θ is the jet angle

This shows that the velocity at any point in the region of established flow is directly proportional to the D V_o product. Thus, two pumps with the same D V_o product, should have the same velocity distribution and therefore the same cleaning ability.

Results

The direct proportionality relationship of the cleaning radius on the D V_o product was verified using a tank 16 type pump and a 'quad volute' pump. The 'quad volute' pump was designed for a 57% larger D V_o product - 20 vs 12.75 ft^2/sec. Specifications for the two pumps are given in Table 1. Testing was done in the half and full tank facilities using concentrations between 17 and 22 weight percent kaolin. The pumps were operated at 65,80, and 100% of their rated capacity.

To prepare the full mockup tank for testing, the pump was operated in five feet of water. Approximately 130 tons of dry kaolin clay was gradually added via two clay augers (Figure 8). This slurry was agitated until it was shear stabilized, approximately 48 hours. Initially the action of the pump (shearing) causes the properties of the kaolin slurry to change, the consistency and yield stress increase with shear. Once the maximum value of these properties is achieved, they do not change with further agitation. At this point the kaolin is shear stabilized.

The initial slurry is approximately 12 weight percent. After settling two weeks and decanting of the excess water, a 20 weight percent kaolin slurry can be obtained.

A probe type device to measure the cleaning radius without emptying of the tank was developed and tested by L. R. Austin and D. L. Kiser. The probe is a 3" stainless steel disc attached to a 3 ft. long 1/4" diameter rod. The probe will go through the slurried material but will rest on the unslurried material. This method was tested in the half tank facility. Cleaning radii were measured using the probe. Then the tank was emptied to determine the actual cleaning radii. The cleaning radii found via probing accurately determined the actual cleaning radii.

Samples of the slurry were taken near the expected cleaning radius before testing and during pump operation. These were analyzed for weight percent solids, volume percent solids, yield stress and consistency.

Between tests, water was added and the tank was reslurried to prevent packing of the kaolin and to obtain an even distribution for measurement. The slurry was then allowed to settle until approximately a 20 weight percent slurry was obtained.

Results of the testing and sample analysis are given in Tables II and III. From this study the following theory was developed:

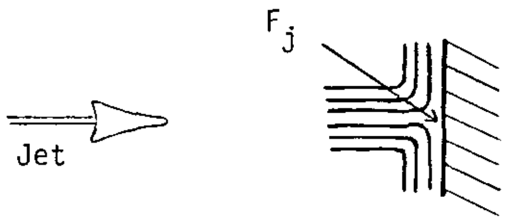

FIGURE 9: IMPACT OF A JET ON A SURFACE

When a jet impacts on a surface normal to its flowpath (Figure 9), the force of the jet-F_j- on the surface is given by:[5]

$$F_j = \frac{\rho V_x^2 A}{2g_c} \tag{3}$$

where F_j = force of jet
ρ = density
V_x = velocity of jet at point of impaction.
g_c = constant
A = area

If the force of the jet is greater than the force of the surface, the jet would either break or move the surface. In relating this to cleaning radius determinations, the force of the surface becomes the force of the sludge. The point where the force of the jet equalled the force of the sludge would be the cleaning radius. For a Bingham plastic material the major components for the force of the sludge would be the τ_o A product, where τ_o is the yield stress and A the area.

Equating the two forces:

$$F_j = F_s \quad (4)$$

$$\frac{\rho V_x^{\,2} A}{2\, g_c} = \tau_o A \quad (5)$$

Substituting V_x from equation (2) and solving for the distance x :

$$X = K\, D\, V_o \left(\frac{\rho}{2\, \tau_o g_c} \right)^{\frac{1}{2}} \quad (6)$$

where $K = C_1 e^{-C_2 [\tan(\frac{1}{2}\theta)]^2}$

Data from tests with initial concentrations between 17 and 22 weight percent kaolin and 1/3 rpm pump rotation are plotted in Figure 10. This represents data from the half tank facility done by D. L. Kiser as well as data from the full tank facility. The line drawn is from equation (6) for a twenty weight percent kaolin slurry. The correlation factor, r, for the fit of this line to the data is approximately 0.92. This is largely due to the fluctuation in concentration of the data.

Figure 11 represents data taken in the half tank facility.[4] Testing was done with a 30 weight percent kaolin slurry. The line drawn represents substitution of the values for a 30 weight percent kaolin slurry into equation (6). This correlation factor for this set of points is 0.98. The deviation of the concentration from 30 weight percent was minimal because the tank was emptied after each test.

Initial studies of the effect of pump rotational speed on the effective cleaning radius indicate that the lower the pump rotational speed the larger the radius. In three tests at 1/5 rpm pump rotational speed a decrease in variation from theory was noted. (Table III). However, more testing will be required to specify the effect of the rotational speed on the cleaning radius.

Conclusion and Recommendation

The equation:

$$ECR = K\ D\ V_o \left(\frac{\rho}{2\,\tau_o g_c} \right)^{\frac{1}{2}}$$

relates both sludge and pump characteristics to the cleaning radius. With the installation of the Haake rotoviscometer in the High Level Caves, the yield stress of a sludge sample can be determined. This data with density measurements and the pump characteristics complete the information required for prediction of the effective cleaning radius. Utilization of this theory can aid in the selection and placement of pumps for efficient waste removal.

BVC:dhw

TABLE I

SPECIFICATIONS OF
SLURRY PUMPS TESTED

	Tank 16 Type	Quad Volute
Capacity - GPM	1200	4000
Nozzle Diameter - in	1½	3.0
RPM	1760	2200
Pump OD - in	22½	33-3/4
Cleaning Radius- ft (in 20 weight percent slurry)	25	40
D V_o Product-Ft²/Sec	12,75	∿20

TABLE II

CLEANING RADIUS TEST RESULTS AT 1/3 RPM ROTATIONAL SPEED

DENSITY (LB/FT^3)	YIELD STRESS (LB_f/FT^2)	INITIAL VELOCITY (FT/SEC)	NOZZLE DIAMETER (FT)	EXPERIMENTAL ECR (FT)	PREDICTED ECR (FT)	PER CENT DIFFERENCE
70.52	0.395	102	0.125	27	29.0	+ 7.5
71.39	0.669	29	0.25	12	12.8	+ 6.7
71.26	0.564	39	0.25	18	18.7	+ 3.8
71.14	0.491	51	0.25	25	26.2	+ 4.8
69.90	0.372	80	0.25	40	46.7	+16.8

TABLE III

CLEANING RADIUS TEST RESULTS AT 1/5 RPM ROTATIONAL SPEED

DENSITY (LB/FT^3)	YIELD STRESS (LB_f/FT^2)	INITIAL VELOCITY (FT/SEC)	NOZZLE DIAMETER (FT)	EXPERIMENTAL ECR (FT)	PREDICTED ECR (FT)	PER CENT DIFFERENCE
74.88	0.955	102	.125	19	19.25	+ 1.3
73.88	0.520	66	.125	17	16.75	- 1.4
74.07	0.491	81½	.125	21.5	21.3	- 0.9

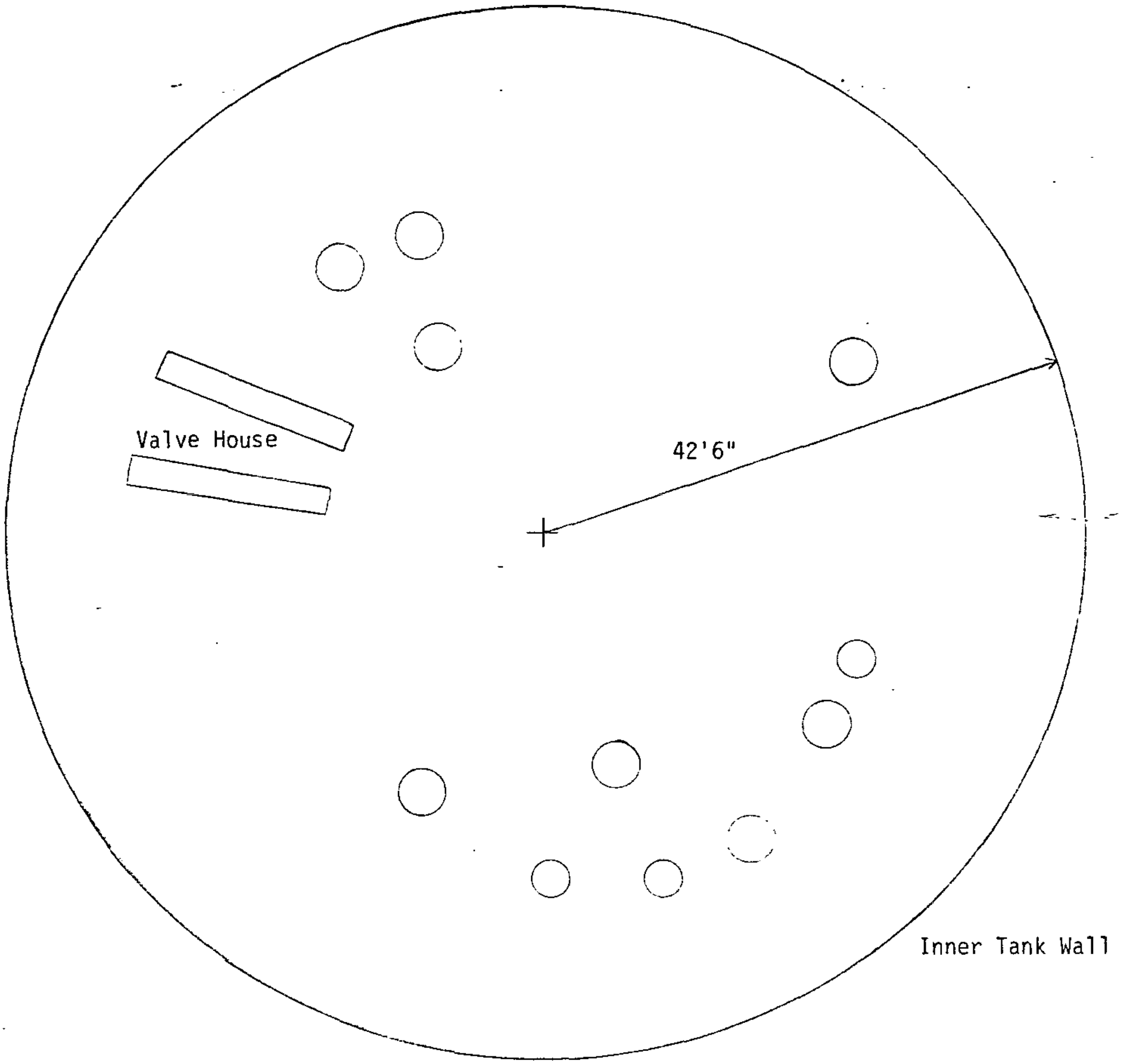

FIGURE 1. TYPE II TANK RISER LOCATIONS

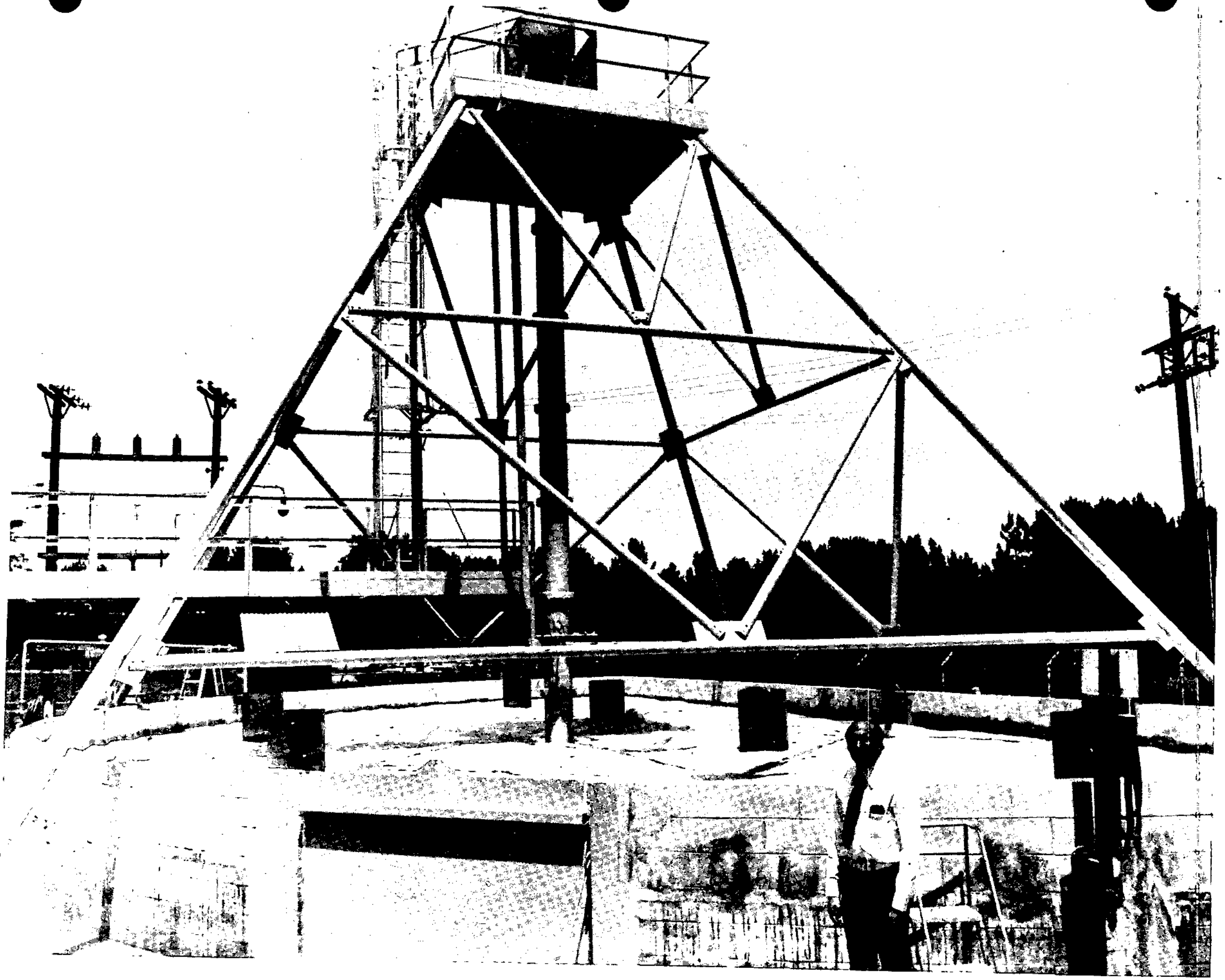

FIGURE 2. HALF TANK MOCK-UP

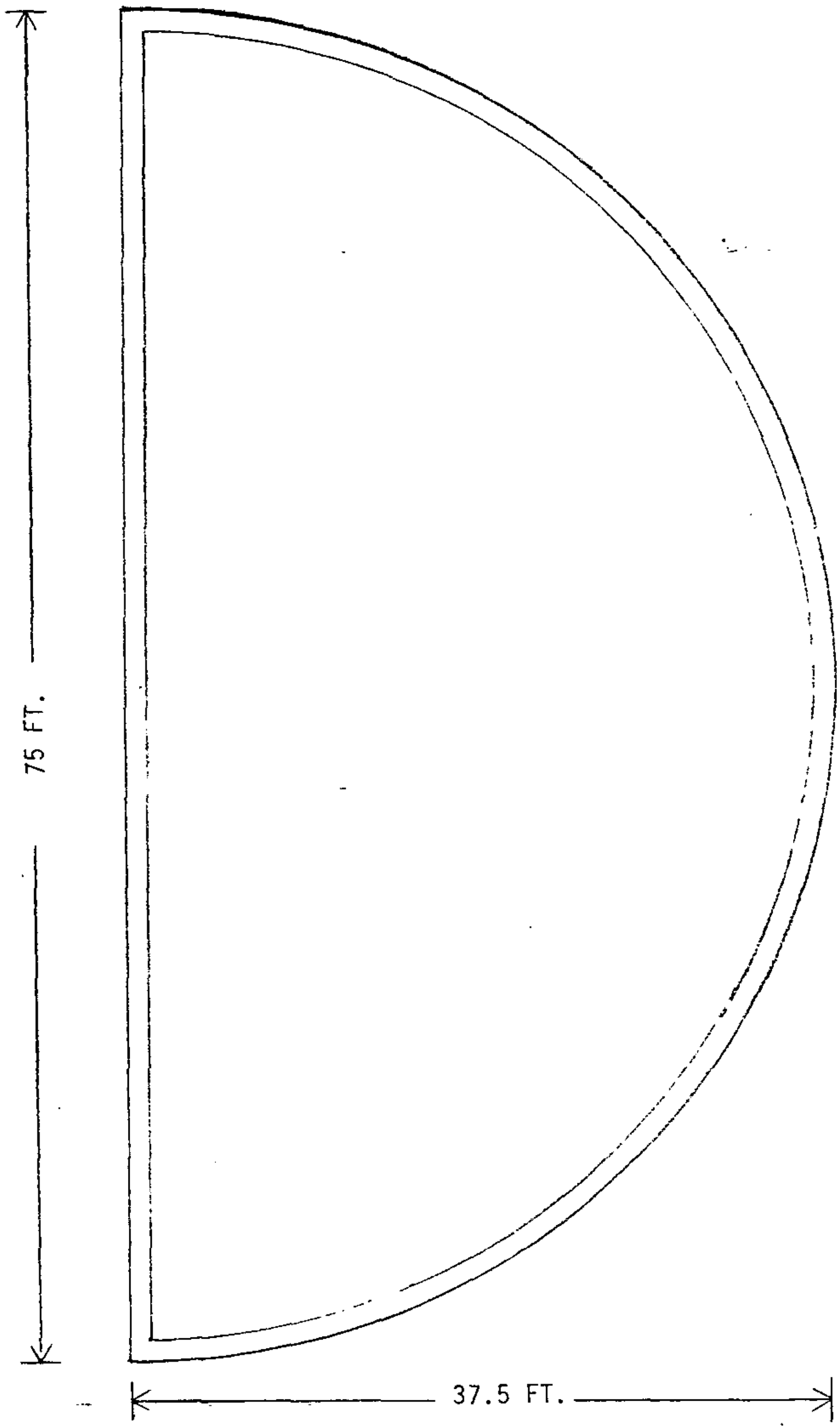

FIGURE 3. HALF TANK MOCK-UP

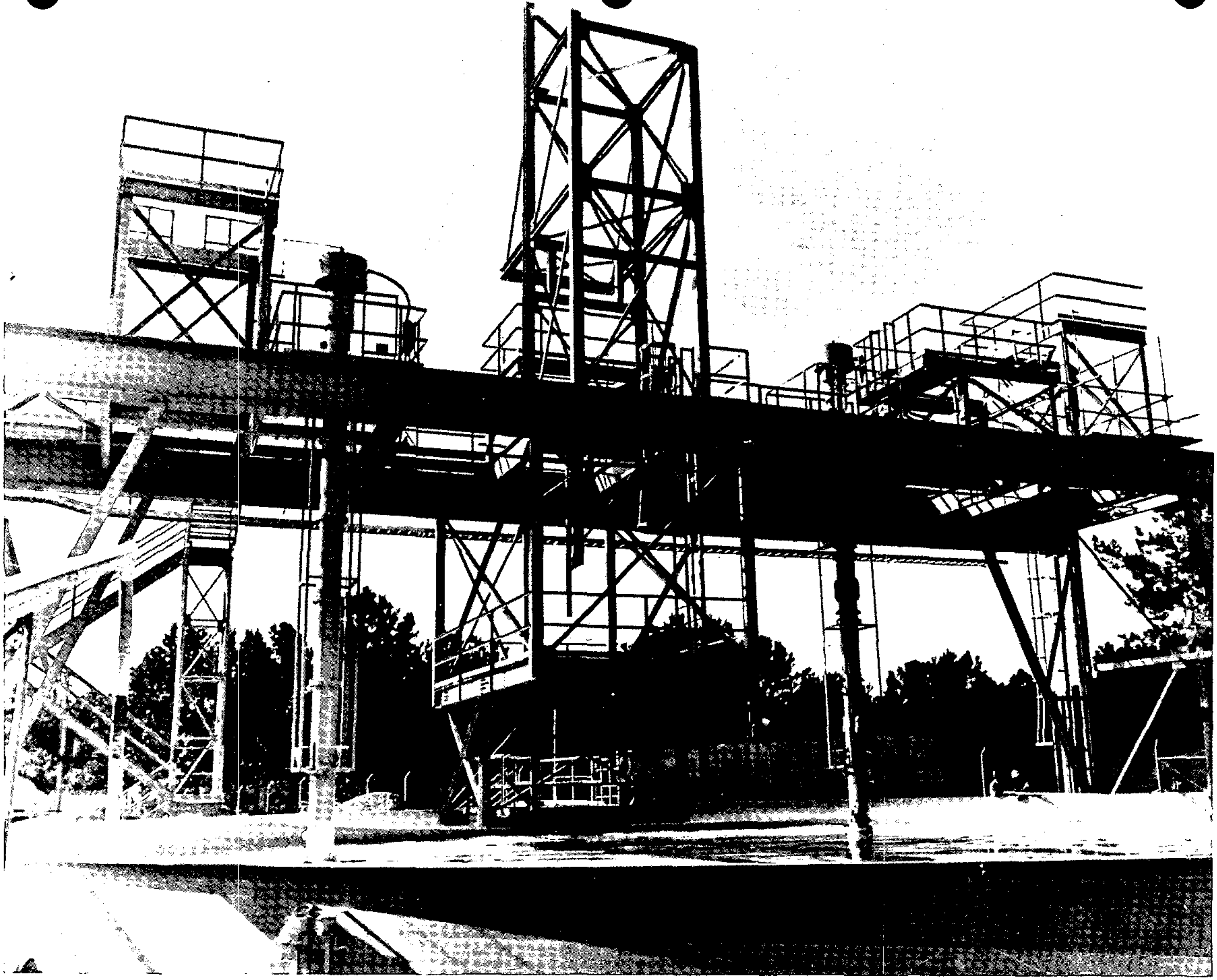

FIGURE 4. FULL TANK MOCK-UP

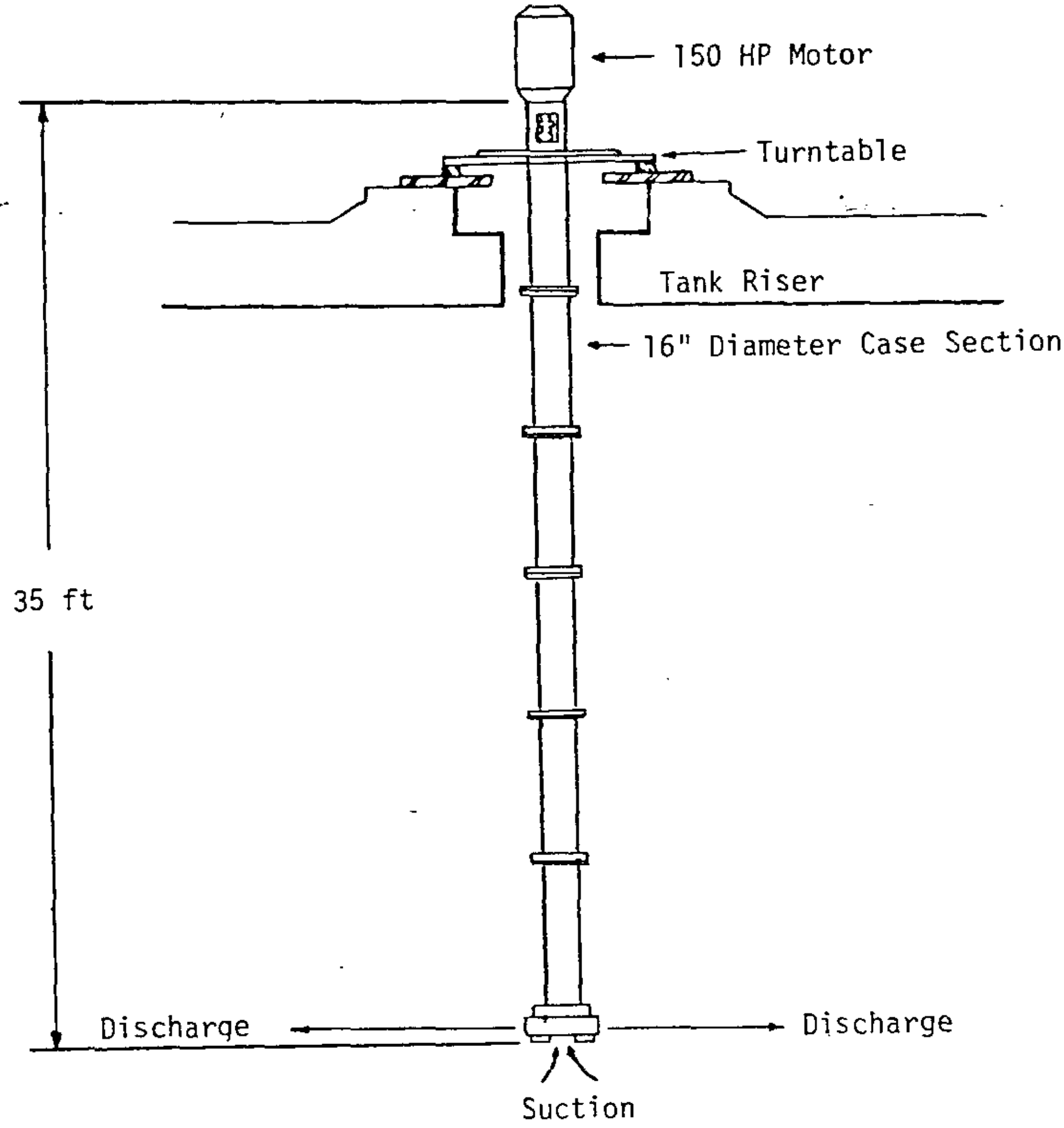

FIGURE 5. POSITIONING OF SLURRY PUMP IN WASTE TANK RISER

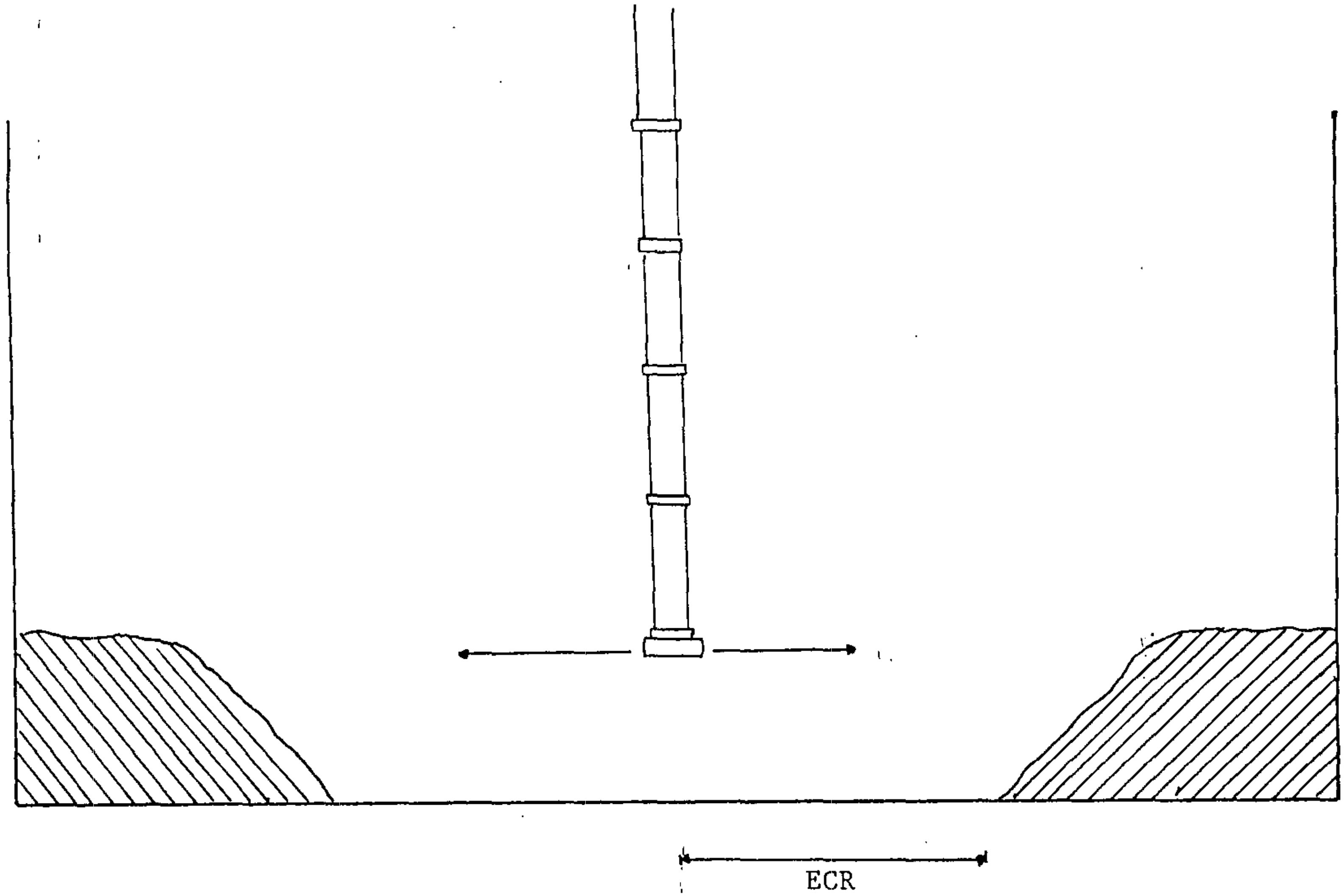

FIGURE 6. CLEANING PATTERN OF SLURRY PUMP

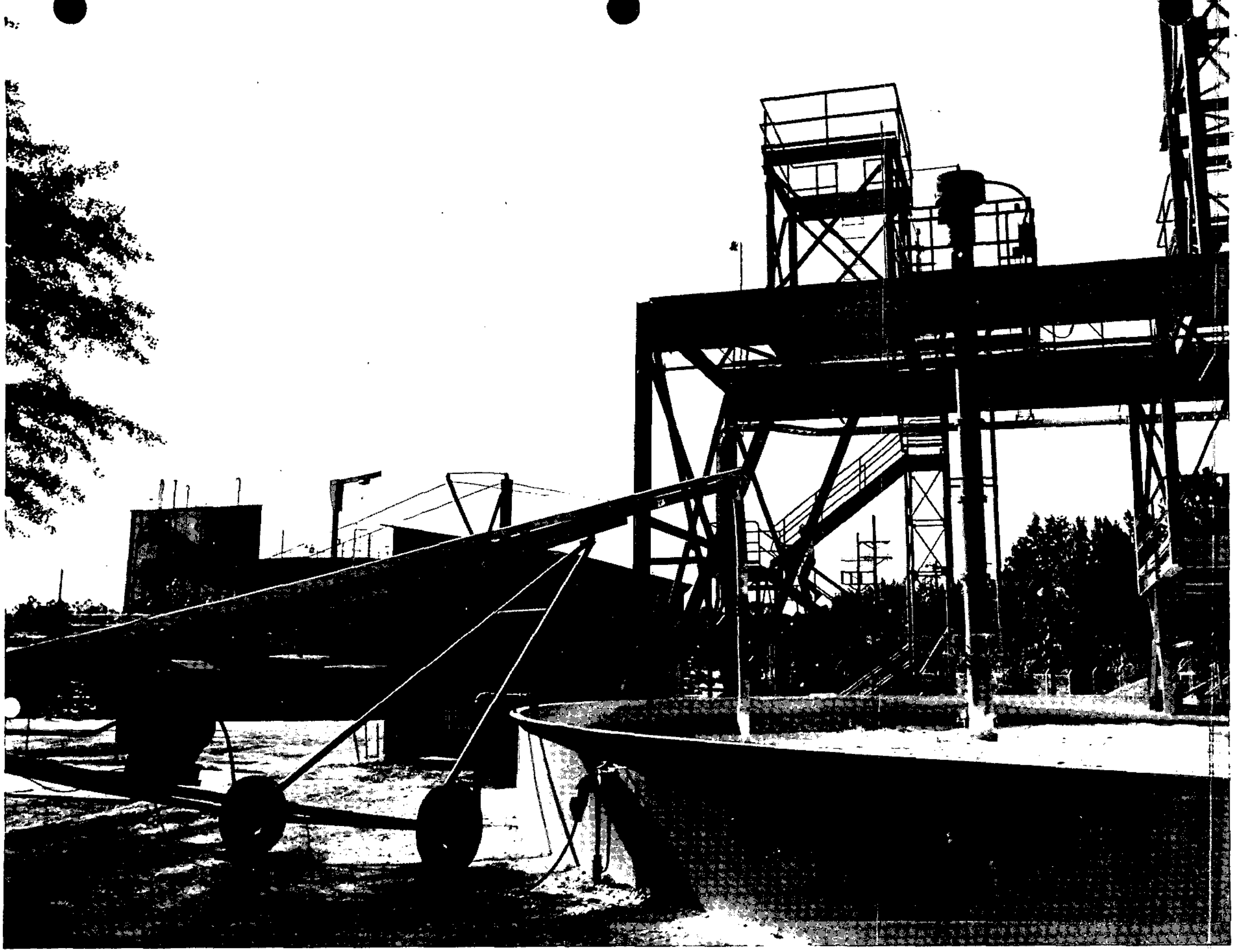

FIGURE 8. ADDITION OF KAOLIN CLAY TO FULL TANK MOCK-UP

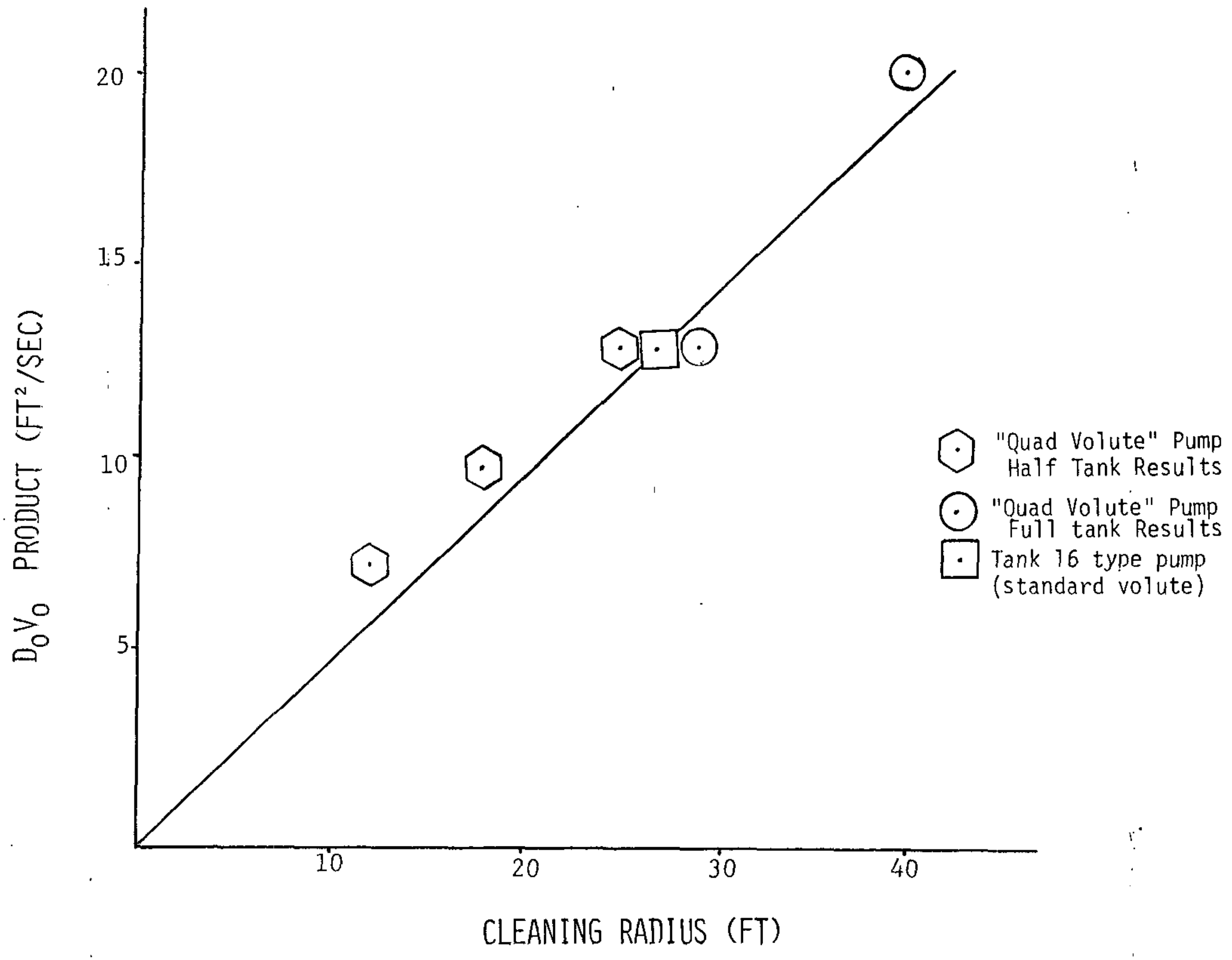

FIGURE 10. ECR vs D V_0 PRODUCT

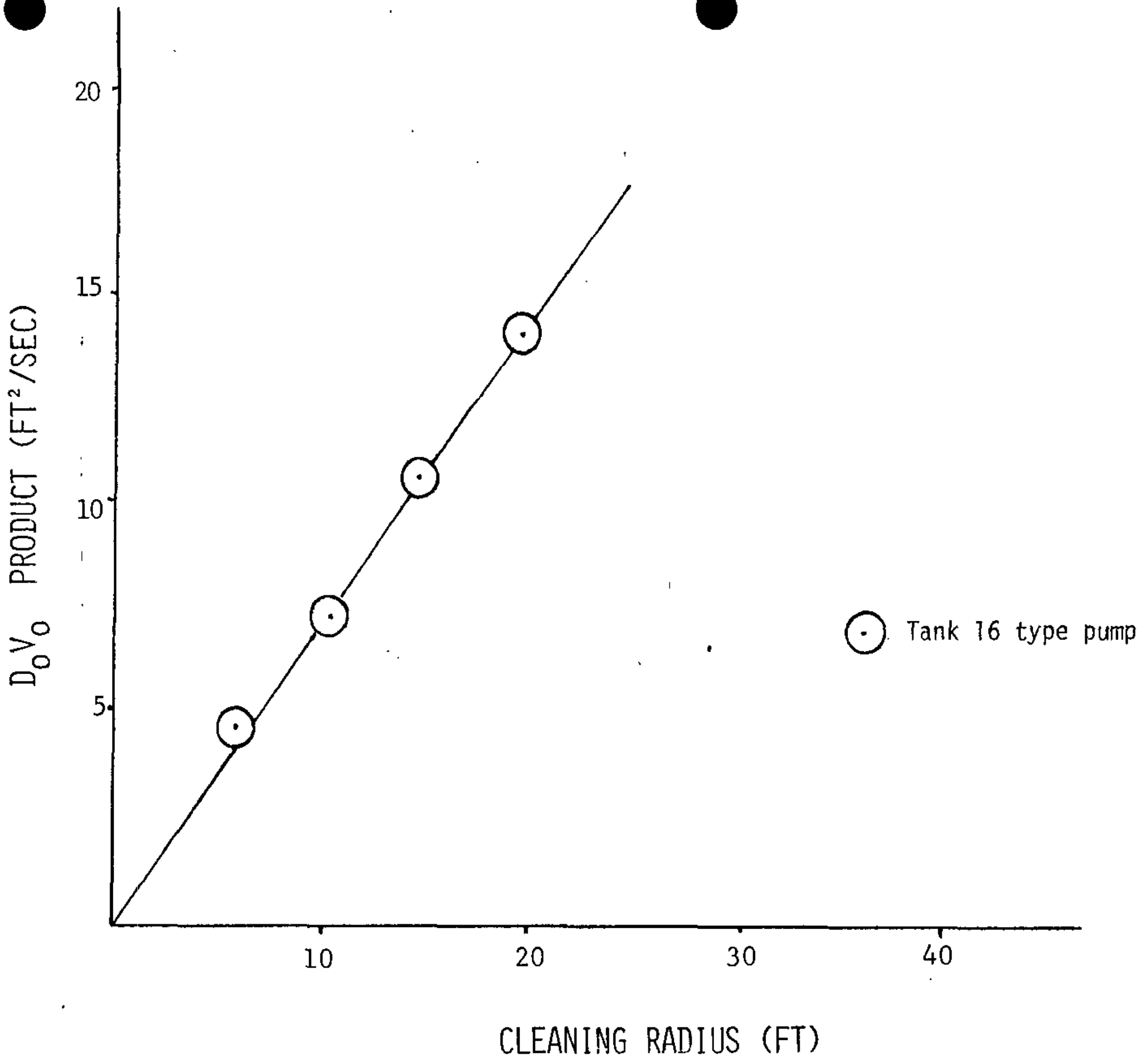

FIGURE 11. ECR vs D V_o PRODUCT HALF TANK RESULTS

REFERENCES

1. C. E. Comly to O. M. Morris, *Tank 16 Demonstration Multi-pump Test Results*, DPSP-79-17-17, June 29, 1979.

2. A. J. Hill, Jr and F. A. Parsons, *Removal of Sludge and Chemical Cleaning of Tank 16-H*, DPSTD-241-TK-16H, February 15, 1977.

3. H. H. Elder, *Demonstration of Radioactive Sludge Removal from SRP Storage Tanks*, DPSPU-79-30-11, September, 1979.

4. R. F. Bradley et al., *A Low Pressure Hydraulic Technique for Slurrying Radioactive Sludges in Waste Tanks*, DP-1468 November, 1977.

5. J. H. Perry, Ed. *Chemical Engineer's Handbook, 5th Edition*, pp 5-19, McGraw Hill Company, New York, 1973.

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May 3, 1984

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- (See descriptions in Letter, S. W. O'Rear to W. R. Lindsey, Rockwell - Hanford, May 3, 1984)

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