DP - 137
Engineering

MIXER-SETTLER DEVELOPMENT

CHARACTERISTICS OF THE PUMP-MIX IMPELLER

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ABSTRACT

The characteristics of a mixer-settler impeller were found to be those of a high-capacity, low-head pump. These characteristics are not affected by recirculation from the mixing to the suction sections of the contactor. The discharge coefficient for recirculation of liquid through the annulus around the impeller nozzle is affected by the rotation of the impeller and decreases with increase in area of the annulus.

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INTRODUCTION

In the "pump-mix" mixer-settler[1] used in liquid-liquid extraction processes, the rotating impeller draws liquid up from the suction section and discharges it into the mixing section, thereby moving the phases from stage to stage and creating the turbulence that is required to mix them. Liquid can recirculate from the mixing section to the suction section through the annular space around the suction nozzle of the impeller. The degree of mixing and the net pumping effect can be controlled by varying the impeller speed and by adjusting the area of the annulus.

The tests reported here were made to obtain an understanding of the hydraulic behavior of the mixer-settler through measurement of the head-capacity characteristics[2] of the impeller and the discharge coefficient of the recirculation annulus.

SUMMARY

The relationship between head, capacity, and speed for the impeller of a Savannah River Plant mixer-settler is

$$\frac{H}{n^2} = 0.000079 - 0.0127\left(\frac{q_t}{n}\right)^{1.67}$$

where

H = head, inches

q_t = flow rate through the impeller, gpm

n = impeller speed, rpm

With no imposed head, the capacity varies directly as the impeller speed; with no flow, the head varies directly as the square of the impeller speed.

The discharge coefficient for flow through the recirculation annulus was found to decrease with increase in area of the annulus, apparently owing to the effect of the vortex created by the impeller. The coefficient varied from 0.80 for an area of 0.64 square inch to 0.28 for 5.31 square inches.

This information permits one to calculate the hydraulic performance of the mixing section of a mixer-settler.

DISCUSSION

EQUIPMENT

The tests were run in a "Lucite" box simulating the suction and discharge section of a mixer-settler. The arrangement is shown in Figure 1.

A closed impeller five inches in diameter was tested. The impeller is shown in Figure 2. The lower side of the impeller was set 2-5/16 inches above the plate that contains the recirculation hole, with the suction tube extended through the hole. The impeller was driven by an air motor that was adjusted to give the desired speed as indicated by a stroboscope. The speed was constant within about 5 rpm during a run.

The area of the annulus between the 1-1/2 inch suction tube and the recirculation hole was varied by fitting over the hole any of several discs. The discs had holes of 3, 2-1/2, 2, and 1-3/4 inches in diameter. Recirculation could be eliminated by placing a rubber seal around the shaft so that it covered the annulus.

One side of the discharge section was partly blocked off by a quieting baffle. The liquid discharge level was measured on the quiet side of this baffle, where turbulence and vortex action were at a minimum. The total head developed by the impeller was taken as the difference between this level and that in the suction section. The surfaces fluctuated, but it was possible to measure their levels within ±1/8 inch under even the worst conditions.

The net flow, that portion of the total flow that did not pass down through the recirculation annulus, went up past the quieting baffle, then under the control baffle. The latter served as a flow control gate, allowing adjustment of level in the discharge section.

After passing the control baffle, the water discharged over a 90° triangular weir into the suction section. It was possible to raise or lower the weir by changing rectangular plates beneath it. Crest height over the weir was measured within ±2 mm with a cathetometer. Figure 3 is the calibration for the weir. The accuracy of the weir was poor below a total head of about two inches.

A Pitot tube was used to measure total flow through the impeller. The Pitot tube was placed inside a cylinder 1-3/8 inches in diameter and 1-3/8 inches high in such a way that it could be moved diametrically across the cylinder to obtain a velocity profile. The cylinder was fixed immediately below the impeller suction tube, so that it acted as an extension of the tube. Antiswirl baffles were placed below the cylinder to reduce flow pulsations to ±1/8 inch. Figure 4 is the calibration for the Pitot tube at the point of maximum velocity.

PROCEDURE

Tests were made with and without recirculation. Figure 5 is a diagram of the flow paths in the equipment. In the no-recirculation experiment the annulus around the impeller nozzle was sealed and water was pumped from the suction section through the impeller and thrown out into the mixing section. From the mixing section it passed through the baffles, over the weir, and into the suction section. Under these conditions the net flow, q_n, was equal to the flow through the impeller, q_t. The total head imposed on the impeller was varied by raising or lowering the control baffle and weir. It was necessary to add or remove liquid in order to maintain the discharge level at the standard 10 inches. In a test run the impeller speed was set at the desired value and the discharge level was adjusted. Readings were then made of crest height over the weir, Pitot tube manometer differential, and the levels in suction and discharge sections.

In the recirculation runs the annulus seal was removed and one of the four recirculation control discs was substituted. If the total imposed head was not too great, part of the water went over the weir and part recirculated as indicated in Figure 5. If the passage under the control baffle was closed, no net flow occurred, and all of the water recirculated. A number of runs were made under these conditions.

The discharge coefficients for flow through the recirculation hole decreased as the hole area was increased. This was unexpected, so further experiments were made in an effort to explain the effect. In one set of experiments the discharge coefficients were determined with the impeller not rotating and flow produced by an external pump; in another set the impeller was completely removed.

RESULTS

Head-Capacity Characteristics of Impeller

Head-capacity measurements with no recirculation were made for impeller speeds of 255, 345, and 450 rpm with the Pitot tube and antiswirl baffle in place. The data are shown in Figure 6. Head-capacity measurements were also made for an impeller speed of 345 rpm, without the Pitot tube and antiswirl baffles. These data are shown in Figure 7, with the 345 rpm data from Figure 6 shown as a broken line for comparison. From Figure 7 it is apparent that the Pitot tube and antiswirl baffles caused insignificant additional friction loss.

The data from each run with no recirculation were used to calculate a dimensionless head coefficient, ψ, and a dimensionless capacity coefficient, ϕ,

$$\psi = \frac{H}{12u^2/g_c} \qquad (1)$$

$$\phi = \frac{v}{u} \qquad (2)$$

where

g_c = conversion constant for force units, 32.2 $\frac{(\text{lb mass})(\text{ft})}{(\text{lb force})(\text{sec}^2)}$

H = total static head, inches

u = peripheral velocity of impeller, feet per second

v = radial velocity of fluid at impeller discharge, feet per second

These coefficients appear as the coordinates of Figure 8; the resulting curve may be approximated by the equation

$$\psi = 0.45 - 22.5\phi^{1.67} \tag{3}$$

Substituting in this relation the terms for ψ and ϕ from Equations 1 and 2, and suitably converting velocities to flow rates and impeller speeds, one obtains the characteristic equation for the impeller.

$$\frac{H}{n^2} = 0.000079 - 0.0127\left(\frac{q_t}{n}\right)^{1.67} \tag{4}$$

where

n = impeller speed, rpm

q_t = flow rate through the impeller, gpm

Figure 9 shows the interrelationship of head, capacity, impeller speed, and size of recirculation hole under conditions of total recirculation. The head and total recirculating flow increase with impeller speed at a fixed hole size. Increasing the hole size at a fixed impeller speed increases the flow but decreases the available head. The data are replotted in Figure 10 to show the insensitivity of impeller characteristics to recirculation.

The relationship of head to total flow and to flow over the weir during partial recirculation was determined for impeller speeds of 345, 400, and 450 rpm. Liquid was discharged over the weir and was also recirculated through an annulus with an area of 5.3 square inches (3.0-inch diameter recirculation hole with a 1.5-inch suction tube passing through it). The results are shown in Figure 11.

Discharge Coefficients for Recirculation Annulus

Measurements of flow and pressure drop through the recirculation hole permitted calculation of discharge coefficients for the following conditions: impeller rotating, impeller not rotating, and impeller removed. In experiments where the impeller was rotated, and flow was produced by the impeller, coefficients were found to decrease with increasing recirculation hole diameter. Data for an impeller speed of 345 rpm show this trend and are given in the following table.

Discharge Coefficients - Rotation at 345 rpm

D_h, in.	D_s, in.	A_a Area, sq/in.	H, in. of H_2O	gpm	C
1.75	1.50	0.64 (annulus)	5.65	8.7	0.80
2.00	1.50	1.38 (annulus)	3.50	12.8	0.69
2.50	1.50	3.15 (annulus)	2.40	13.5	0.39
3.00	1.50	5.31 (annulus)	1.75	13.9	0.28
3.00	2.50	2.16 (annulus)	2.20	13.2	0.57

Figure 12 is a plot of discharge coefficient against area of the annulus. There was no appreciable change in annulus coefficient with impeller speed, within the speed range covered.

In contrast, when the impeller was not rotated and flow through the annulus was produced by an external pump, discharge coefficients for flow through the recirculation annulus were found to be in the usual range and to be relatively independent of the area of the annulus. The data obtained without impeller rotation are given in the following table. A discussion of the probable causes for the anomalous coefficients is presented in the Appendix.

Discharge Coefficients - No Rotation

D_h, in.	D_s, in.	A_a Area, sq/in.	H, in. of H_2O	gpm	C
2.00	0	3.41 (orifice-impeller out)	0.25	8.3	0.73
2.00	1.50	1.38 (annulus)	1.60	8.3	0.64
3.00	0	7.06 (orifice-impeller out)	0.07	8.75	0.68
3.00	1.50	5.31 (annulus)	0.12	8.75	0.68

CONCLUSIONS

For the hydraulic behavior of the mixer-settler the following conclusions may be drawn:

1) The head-capacity - speed relationship can be expressed by the equation

$$\frac{H}{n^2} = K - K' \left(\frac{q_t}{n}\right)^{1.67}$$

For the 5-inch closed impeller the constants are

$K = 0.000079$

$K' = 0.0127$

Maximum head and capacity coefficients are 0.45 and 0.095, respectively.

2) Head and flow increase with impeller speed for a given size of the recirculation hole. Flow increases, but head decreases, with increase in hole size at a given speed.

3) The head-capacity characteristics of the impeller are independent of recirculation rate.

4) The discharge coefficients of the recirculation annulus decrease with increasing annulus area.

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2. Stepanoff, A. J. Centrifugal and Axial Flow Pumps. New York: J. Wiley Sons, Inc. pp. 27,28 and 176. (1948).

NOMENCLATURE

A_a area of annulus, square inches, $\frac{\pi}{4}(D_h^2 - D_s^2)$

A_i area of opening at discharge (periphery) of impeller, $\frac{\pi D_i h - 4ht}{144}$ = 0.051 square feet for the impeller studied

C orifice and annulus discharge coefficient, $C = 0.139 \frac{q_r}{A_a \sqrt{H}}$

D_i impeller diameter in inches. $D_i = 5$ for impeller studied

D_s outside diameter of impeller suction tube, inches

D_h diameter of recirculation hole, inches

g_c conversion constant for force units, $32.2 \frac{(\text{lb mass})(\text{ft})}{(\text{lb force})(\text{sec}^2)}$

h impeller plate (shroud) spacing, 0.50 inch for impeller studied

H total static head, inches of liquid pumped

K constant in Equation (4), 0.000079

K' constant in Equation (4), 0.0127

n impeller speed, revolutions per minute

q_n net flow over the weir, gallons per minute

q_r flow through the recirculation hole, gallons per minute

q_t total flow through the impeller, gallons per minute

t thickness of vane, inches, t= 0.25 for impeller studied

u peripheral velocity of impeller, feet per second, $\pi D_i n/720$

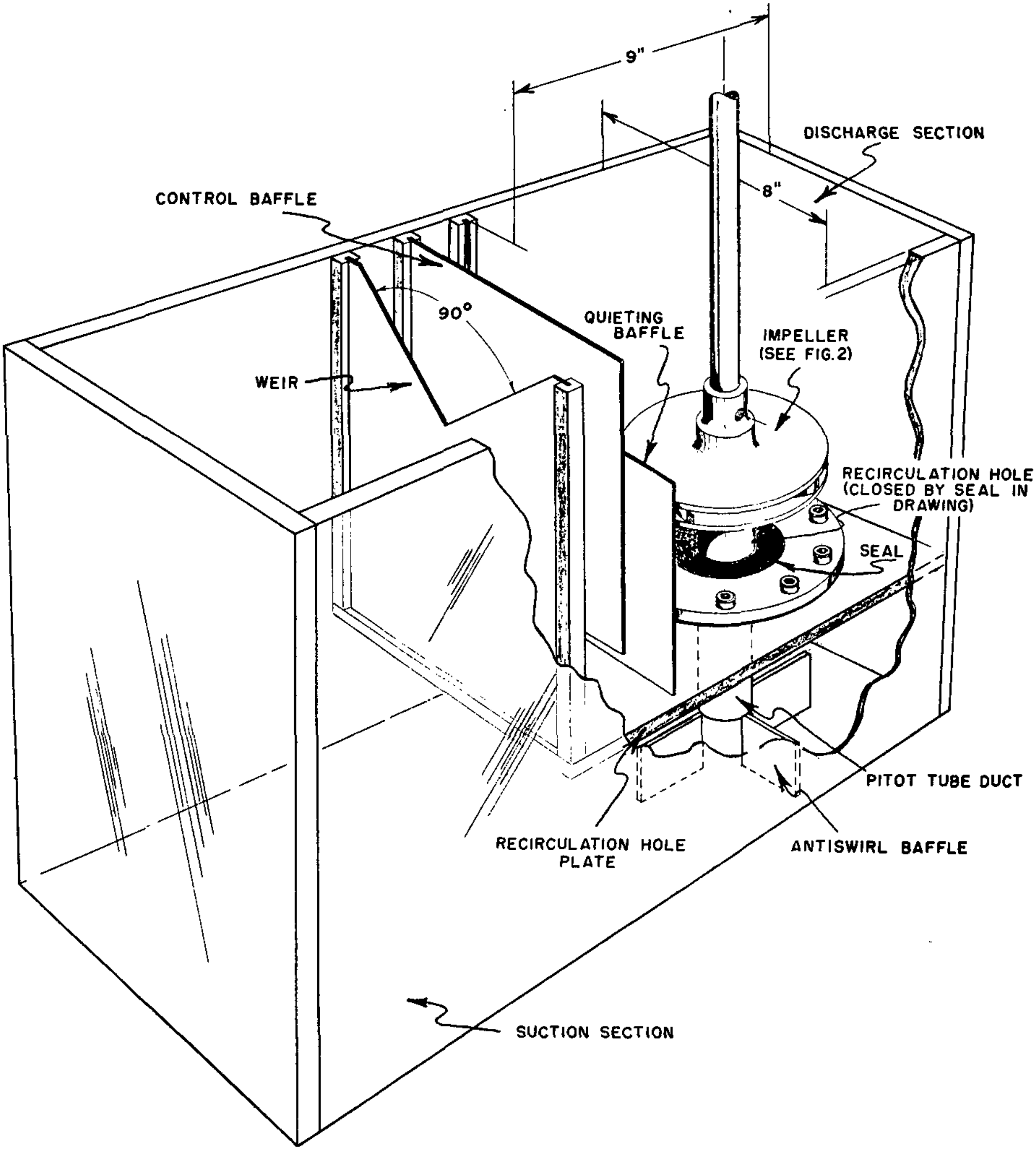
v radial velocity of fluid at impeller discharge, feet per second, $q_t/450\ A_i$

θ vane angle (angle that tangent to vane makes with tangent to impeller periphery), 20°

ϕ capacity coefficient, $\frac{v}{u}$

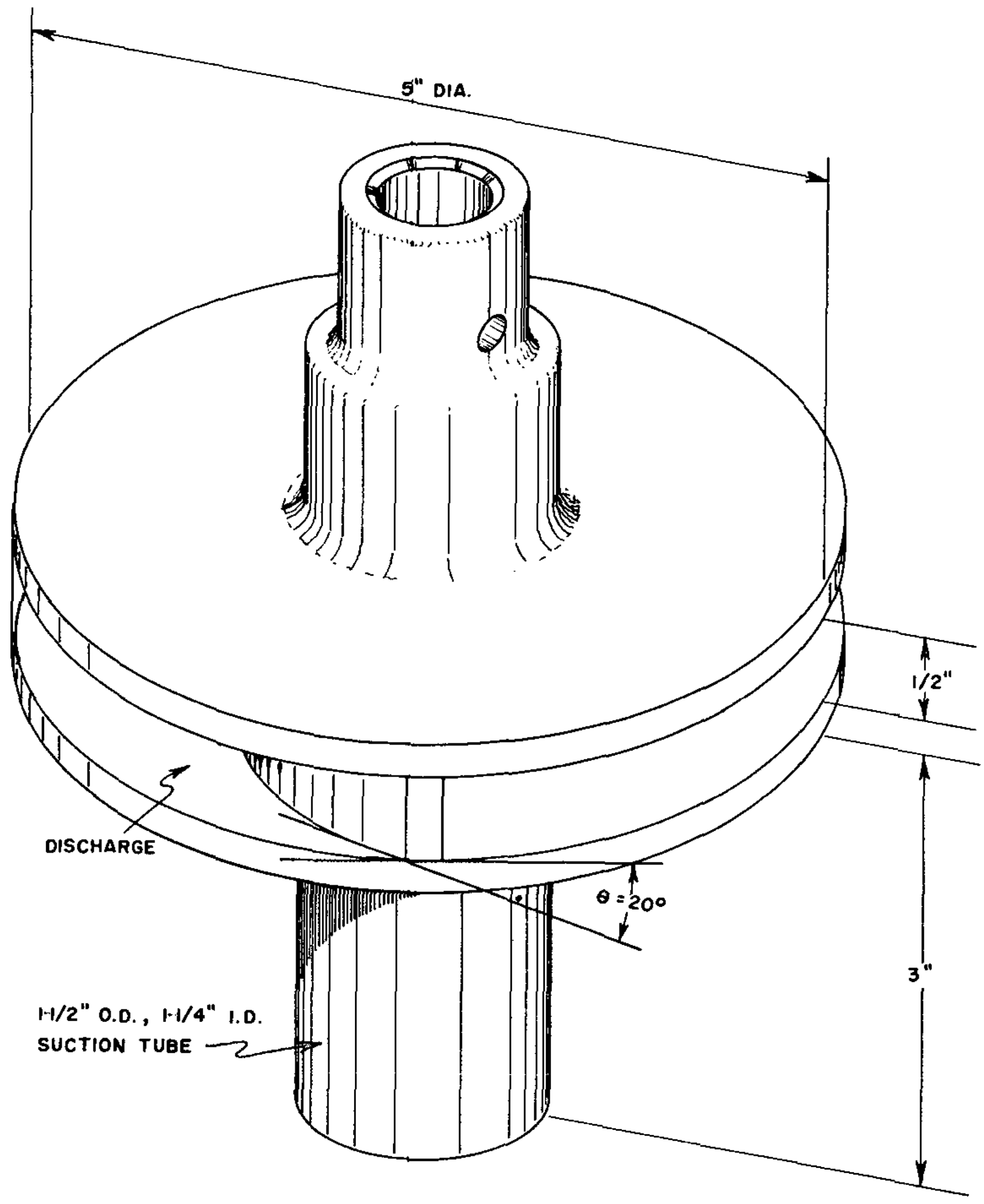
ψ head coefficient, $\frac{H}{12u^2/g_c}$

FIGURE 1



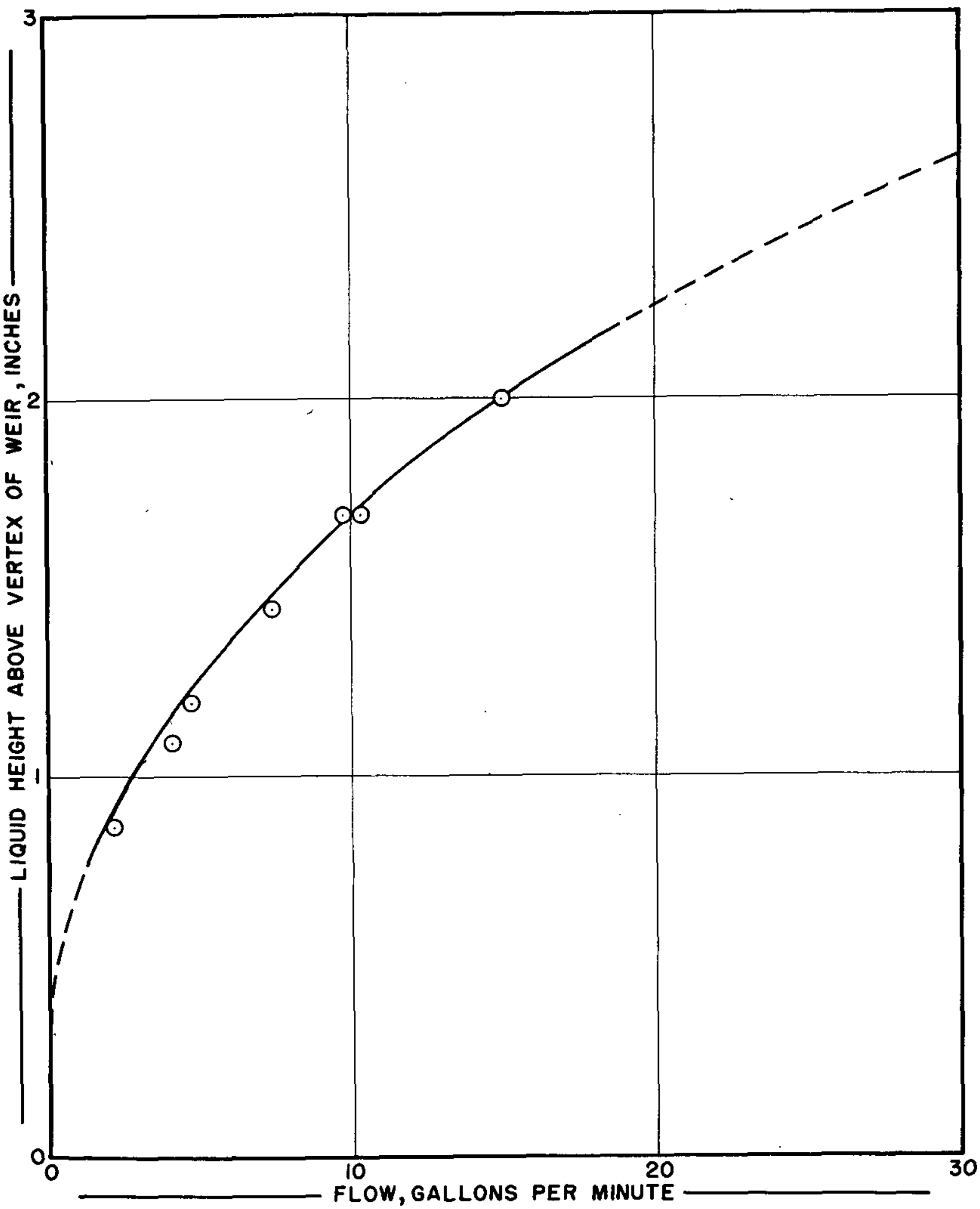
TEST BOX AND IMPELLER

FIGURE 2



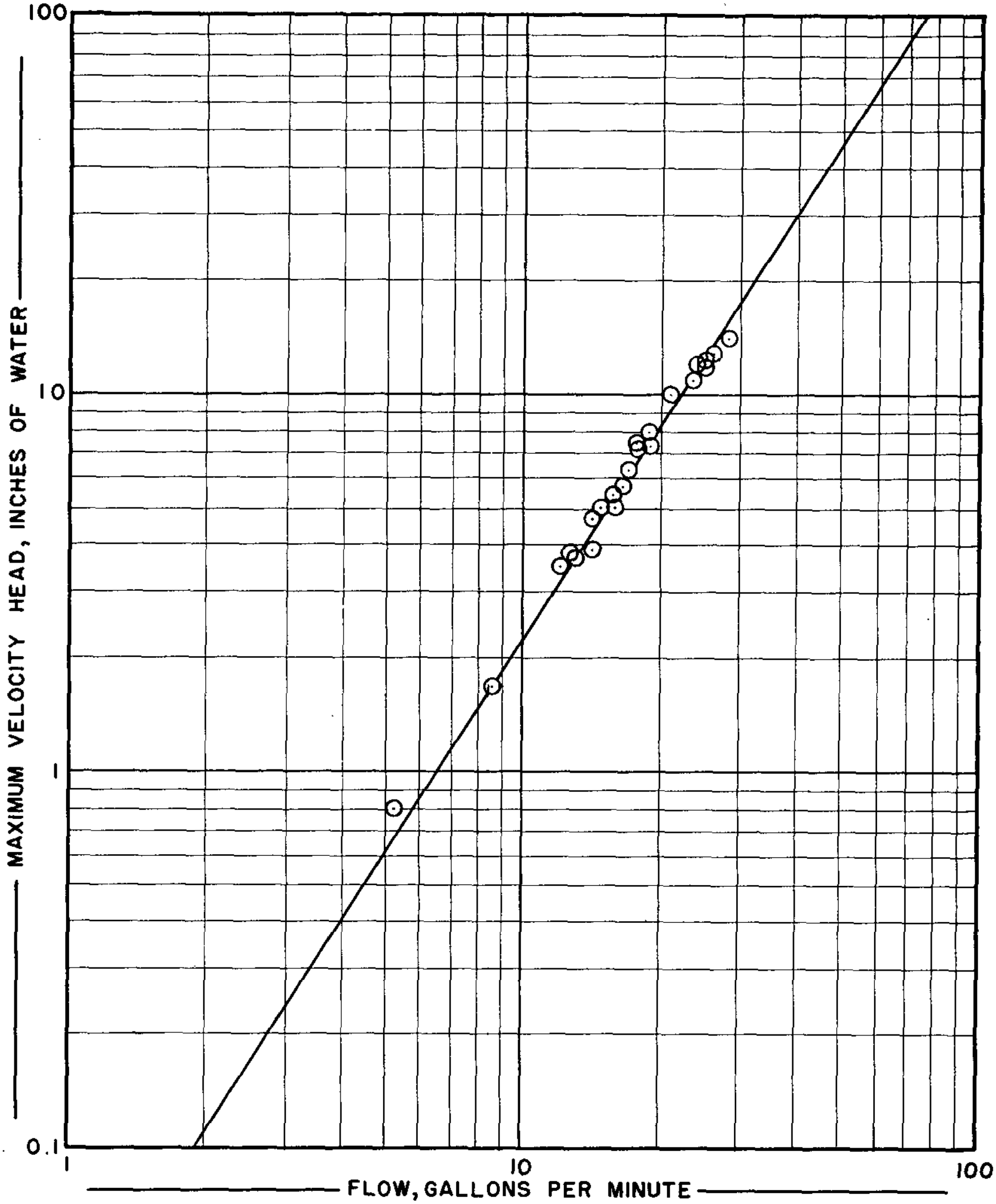
PUMP-MIX IMPELLER

FIGURE 3



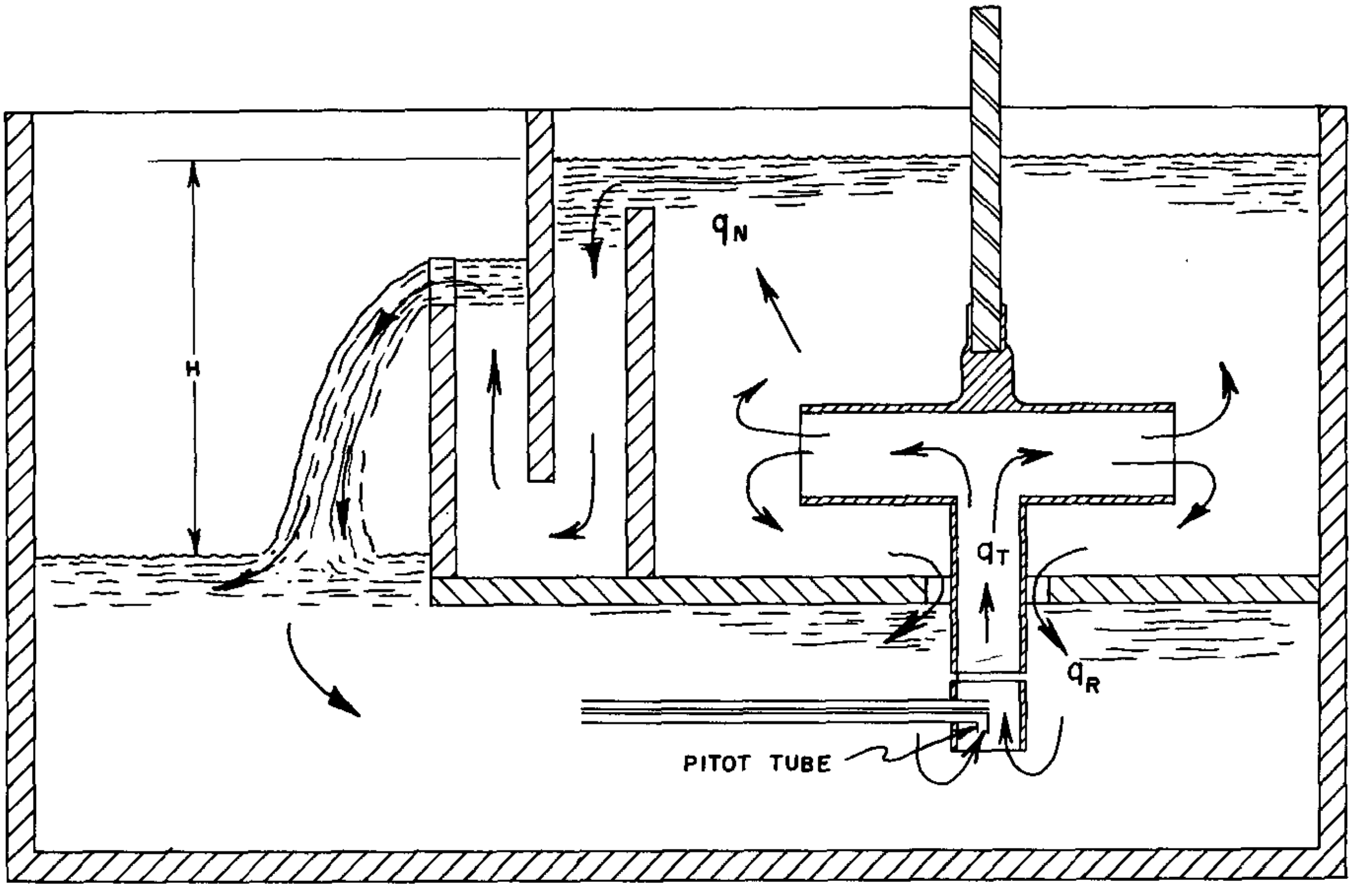
WEIR CALIBRATION

FIGURE 4



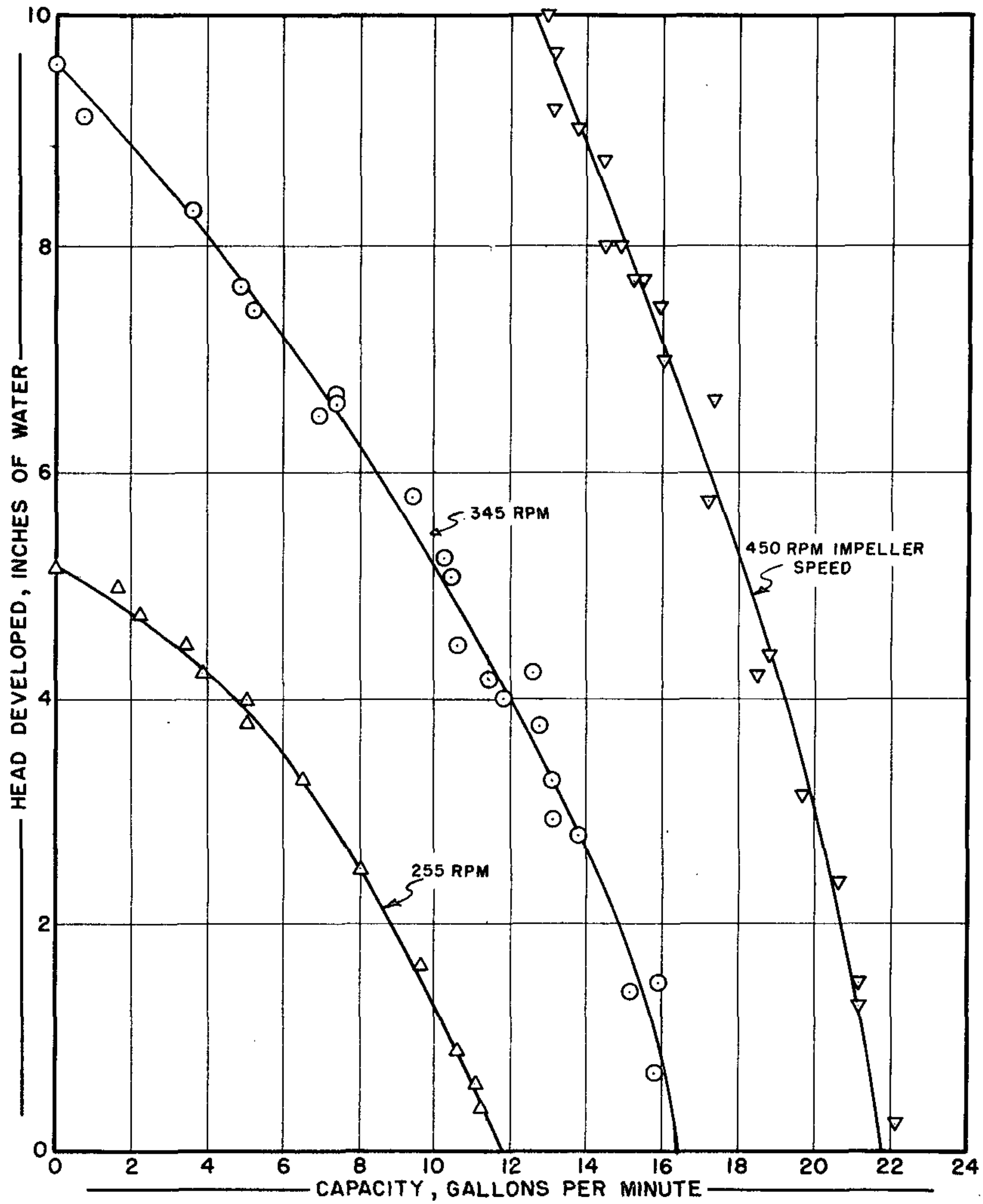
PITOT TUBE CALIBRATION

FIGURE 5



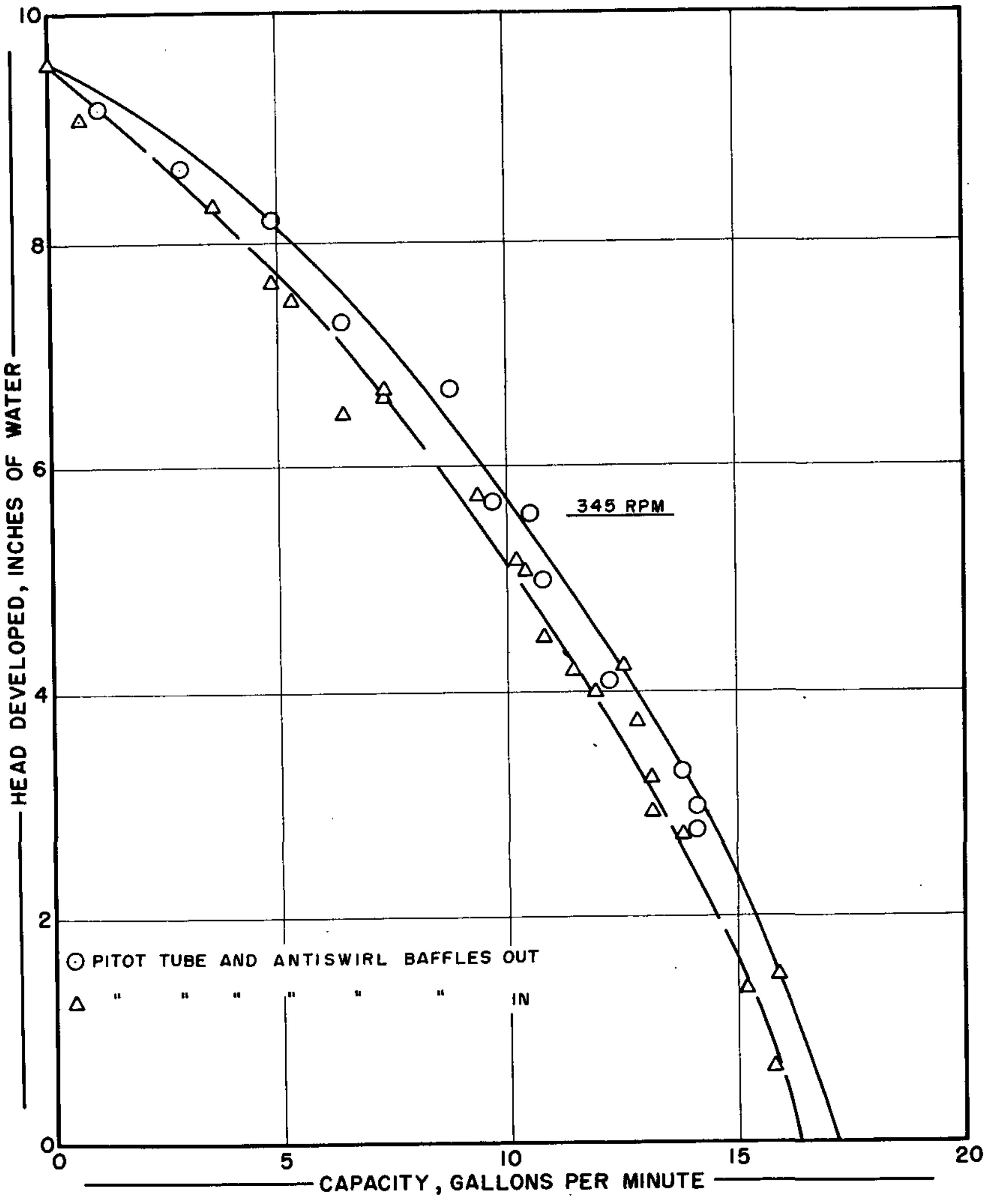
FLOW DIAGRAM OF MIXING SECTION

FIGURE 6



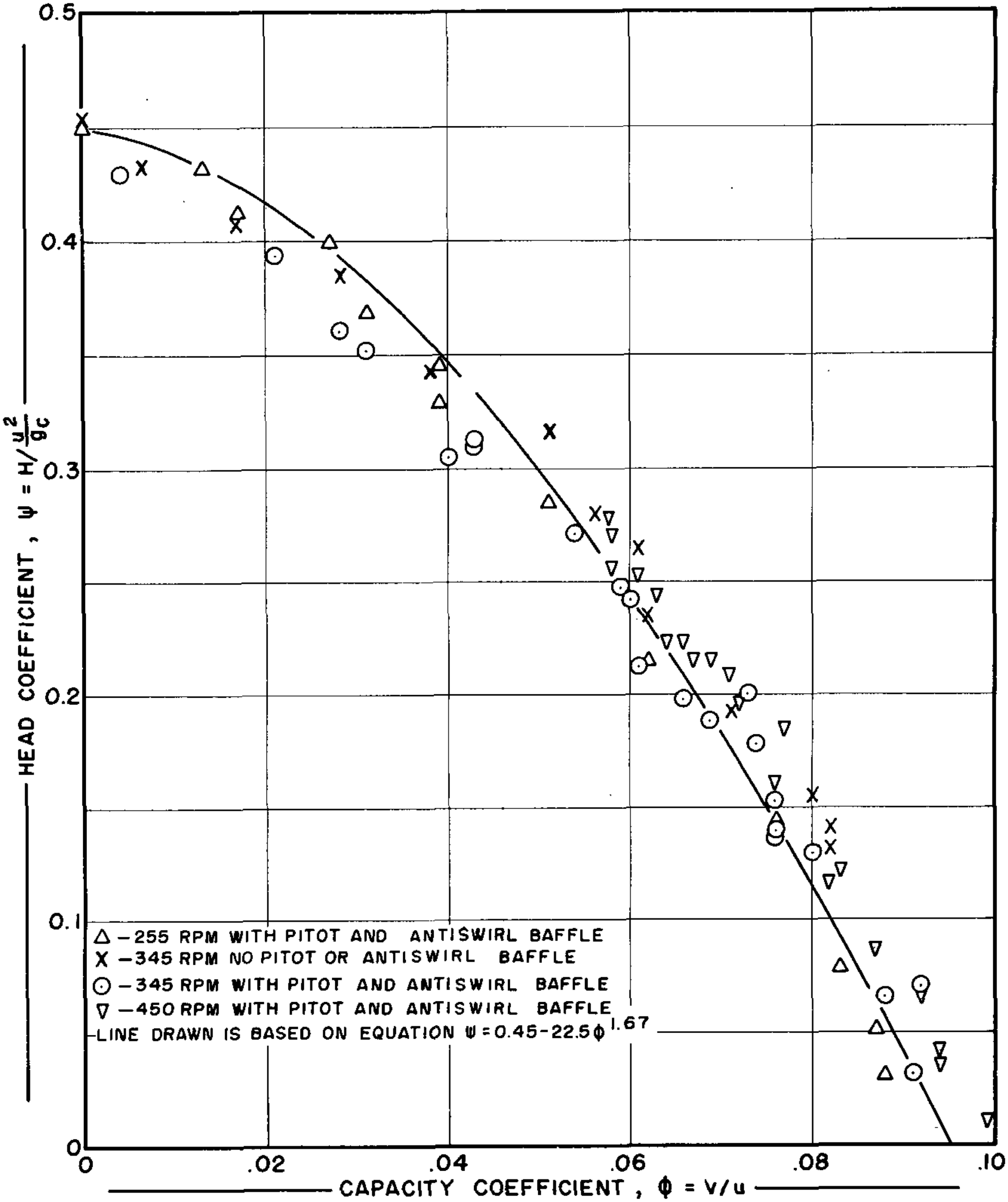
CHARACTERISTICS-NO RECIRCULATION

FIGURE 7



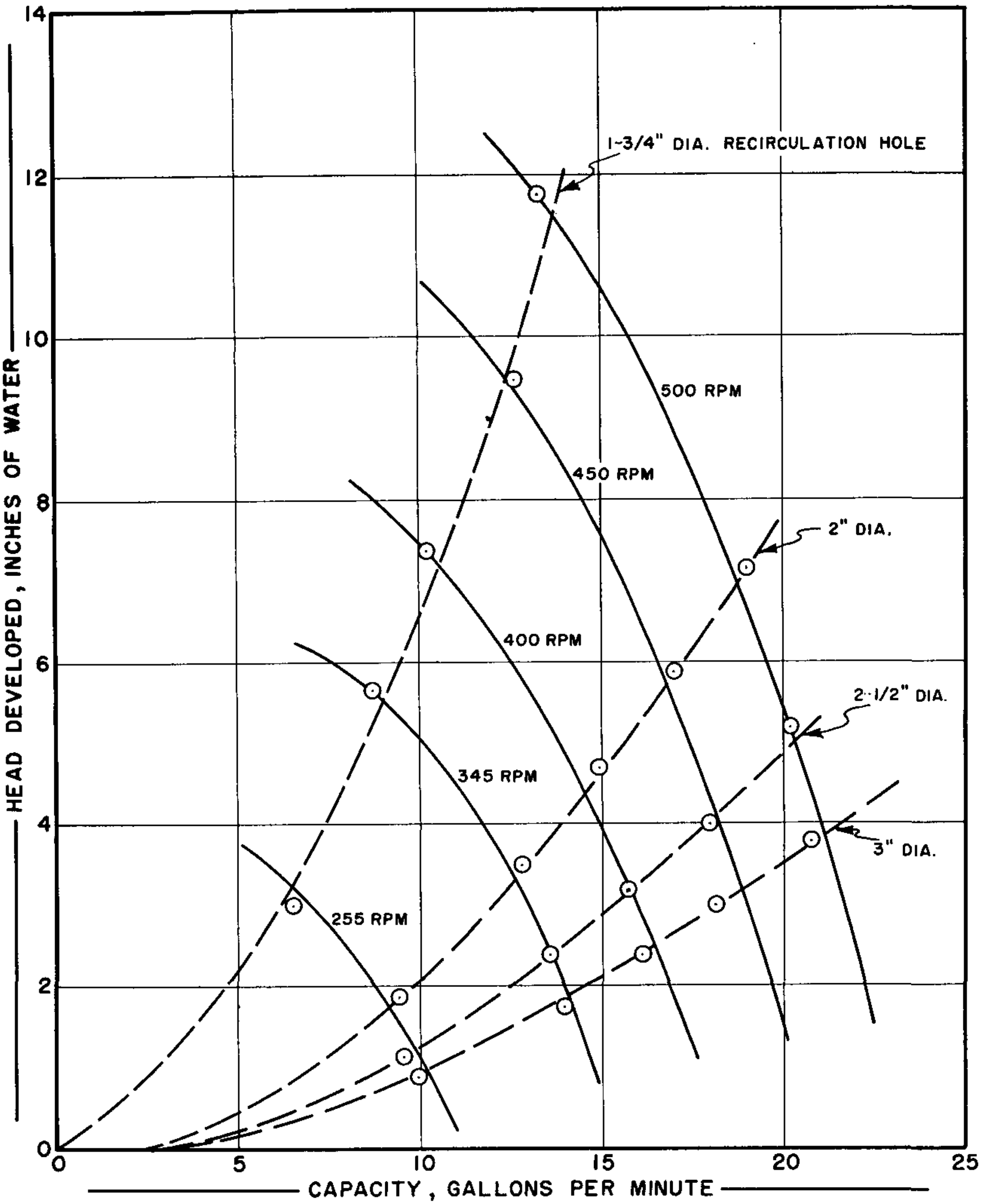
CHARACTERISTICS - NO RECIRCULATION
EFFECT OF PITOT TUBE AND ANTISWIRL BAFFLES

FIGURE 8



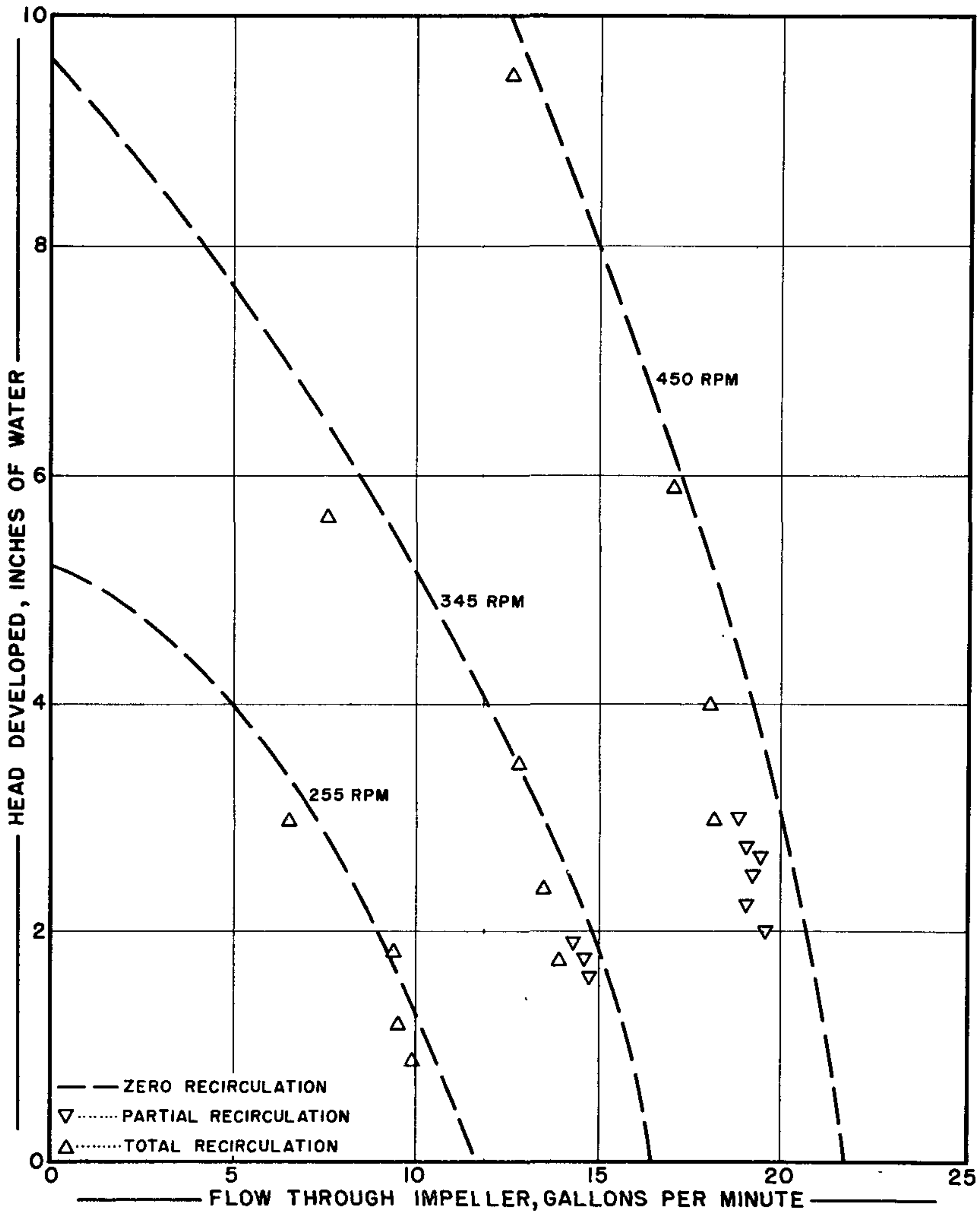
HEAD-CAPACITY COEFFICIENT

FIGURE 9



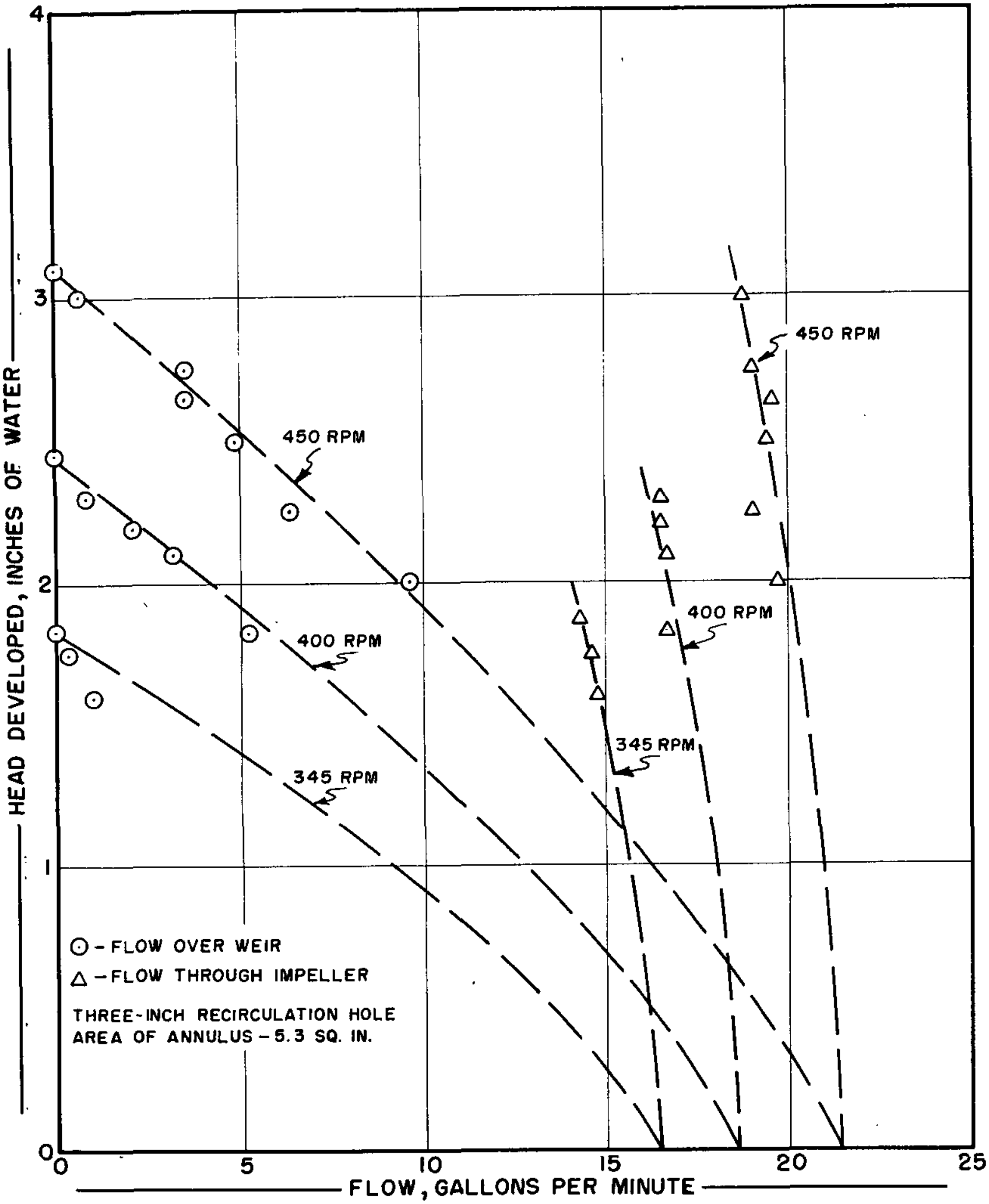
CHARACTERISTICS-TOTAL RECIRCULATION

FIGURE 10



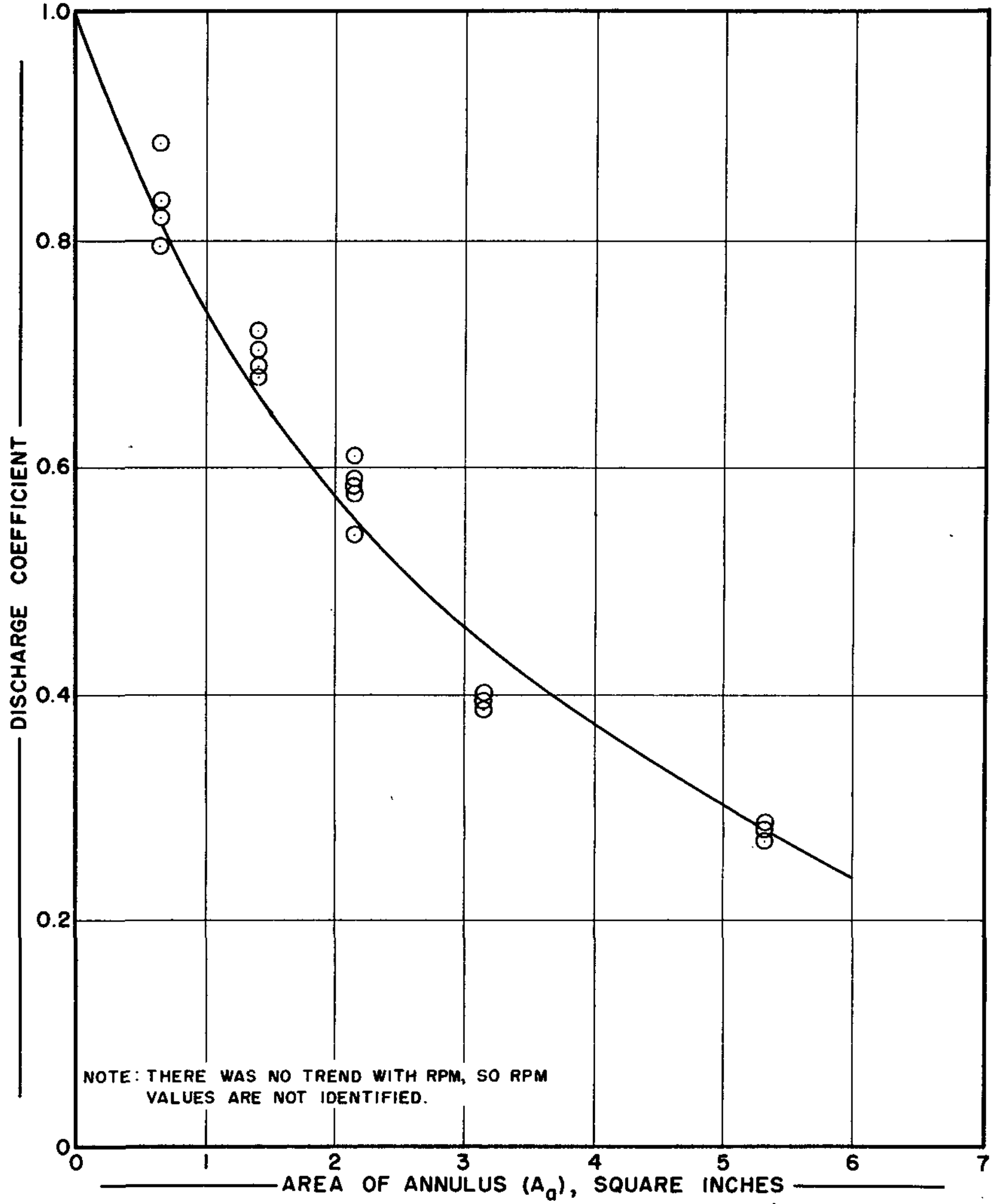
CHARACTERISTICS-EFFECT OF RECIRCULATION ON TOTAL FLOW

FIGURE 11



CHARACTERISTICS - EFFECT OF RECIRCULATION ON FLOW DISTRIBUTION

FIGURE 12



DISCHARGE COEFFICIENT FOR RECIRCULATION ANNULUS