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Engineering

MIXER-SETTLER DEVELOPMENT

USE OF A SHROUDED PADDLE

by
W. J. Mottel
Separations Technology Division

August 1955

E. I. du Pont de Nemours & Co.
Explosives Department - Atomic Energy Division
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Work done by
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ABSTRACT

The effects of paddle design and speed on the performance of a shrouded-paddle contactor for two liquid phases were determined. Transfer of heat between the phases was used as a measure of contacting efficiency.

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INTRODUCTION

A turbine-type liquid-liquid contactor is being developed to overcome limitations of other designs of mixer-settlers. Mixer-settlers offer a convenient means of achieving multi-stage liquid-liquid extraction, and are finding increasing use in carrying out chemical separations.(1)(6)

The mixer-settlers described by Coplan et al.(1) are used as a basis of comparison in this work. These mixer-settlers are satisfactory, but are limited in capacity by the necessity for the light phase to flow by gravity from stage to stage. They are limited in mixing efficiency by the lowering of adjacent stage interfaces and eventual reversal in the direction of the light phase flow at high agitator speeds.

The new contactor utilizes a shrouded paddle that pumps as well as mixes both organic and aqueous phases. A wider range of impeller speeds is made possible by weirs that control interface levels and allow the attainment of high impeller speeds and accompanying high efficiencies.

In this first phase of the work the pumping and mixing characteristics of the shrouded paddle were investigated. The thermal efficiency or heat transfer ability of the system was used as a measure of its mixing efficiency.

SUMMARY

Effective mixing and circulation of two immiscible liquids were achieved by means of rotating, flat-blade paddles operated within shrouds of flat, tangential vanes. The pumping and mixing characteristics of the device were determined by the size and number of blades of the paddles and their speed and direction of rotation. Mixing efficiency increased with increased paddle speed, and was greatest for a four-blade paddle with a ratio of two for the shroud height to paddle height. The suction head increased with either the number of blades or the blade height. Paddles with two, four, and six blades and blade heights of 1/8 to 3/8 inch were tested.

The measurement of the transfer of heat rather than of material was developed as a convenient and effective means for evaluating the effectiveness of mixing the two liquid phases.

This work was the first under a program to develop a turbine-type contactor. Work is continuing on the effects of other design and operating variables, including direction of paddle rotation, clearance between paddle and shroud, and flow rates and ratios of the two liquid phases. A correlation is being developed between the transfer efficiencies of heat and of mass.

DISCUSSION

EXPERIMENTAL METHOD

The mixing efficiencies of flat paddles were determined in the middle stage of a three-stage turbine contactor unit, shown in Figures 1 and 2. The effectiveness of the contactor in transferring heat was used as a convenient measure of its relative efficiency in mass transfer. The organic phase entering the middle stage was heated to about 2°C above the temperature of the entering aqueous phase. An immersion-type electrical heating element was used. The extent to which the temperatures of the effluent streams approached the common equilibrium temperature, expressed as a percentage, was taken as the thermal efficiency. The thermal efficiency is defined as follows:

$$\text{Thermal Efficiency} = \frac{(T_i-t_i) - (T_o-t_o)}{(T_i-t_i)}$$

where T_i = temperature of organic phase entering the stage

T_o = temperature of organic phase leaving the stage

t_i = temperature of aqueous phase entering the stage

t_o = temperature of aqueous phase leaving the stage

Inlet and outlet temperature differences were measured by iron-constantan thermopiles and were recorded on a potentiometer. The temperature differences as recorded in microvolts were used directly to give the thermal efficiency.

At high efficiencies (95 to 99 per cent) it was necessary to determine effluent temperature differences of 0.1 to 0.01°C. In this range a Type K_1 Leeds and Northrup potentiometer was used.

Aqueous and organic phases were fed by gravity to the contactor. The outlet streams were recirculated. The aqueous flow was one gpm and the organic flow 0.6 gpm, as indicated by calibrated rotameters. Tap water was used as the aqueous phase, and "Ultrasene," a highly refined kerosene, as the organic phase.

The tests covered two, four, and six-blade paddles, one inch in diameter and from 1/8 to 3/8 inch high. In all tests the shroud was 1-1/8 inches in inside diameter and 1/2 inch high.

HYDRAULIC PERFORMANCE

Because of the alignment of the shrouds relative to the paddle, the direction of paddle rotation greatly influences the characteristics of the contactor (Figure 3). Flow discharge normal to the shrouds suppresses the pumping action of the paddle and allows the achievement of high paddle speeds and good mixing while avoiding organic recirculation. Organic-phase recirculation occurs when the organic phase leaving the stage re-enters through the aqueous-phase inlet. Flow discharge parallel to the shrouds increases the pumping action and causes recirculation at a somewhat lower paddle speed. The work covered in this report was done with normal discharge only.

The suction head developed by a paddle increases as the number of blades increases and as the blade height increases. The suction head is the vertical distance from the interface to the crest of the aqueous weir (Figure 2). A plot of suction head versus paddle speed is shown in Figure 4. When the blade height is reduced to 1/8 inch, pumping is reduced to zero. This inability to pump results from recirculation within the shrouds caused by the large ratio of shroud height to blade height (a factor of four). Pumping is also reduced as the clearance between the paddle tip and the inner edges of the shrouds is increased.

THERMAL EFFICIENCY

The thermal efficiencies of 3/8-inch high paddles at various speeds are shown in Figures 5, 6, and 7. Data for a 1/4-inch high four-blade paddle are shown in Figure 8. Figure 9 is a summary of the thermal efficiency data. The dotted portions of the curves represent the transition from nonrecirculation to recirculation of the organic phase. Within this range the slight pulsing action of the shrouded paddle causes intermittent recirculation of the organic phase. An abrupt change in slope appears at the speed at which organic recirculation starts. The rate of increase of efficiency with paddle speed diminishes after the transition to organic-phase recirculation has occurred.

Maximum efficiency was obtained with the four-blade paddle and a shroud height to paddle height ratio of two. The effect of the shroud diameter to paddle diameter ratio on mixing efficiency was not studied.

It was desirable to correlate the efficiency data obtained in terms of the operating variables, namely paddle speed and paddle height.

The thermal efficiency of a system can be expressed by Equation (1). The equation is derived in the Appendix.

$$\ln (1-E) = -UA\left[\left(\frac{1}{C_pV\rho}\right)_{org} + \left(\frac{1}{C_pV\rho}\right)_{aq}\right] \qquad (1)$$

where:

E = thermal efficiency

U = over-all heat transfer coefficient

A = heat transfer area

C_p = heat capacity

V = volume of flow/unit time

ρ = density

All quantities should be in consistent units.

Under constant flow conditions,

$$\ln(1-E) = -UAK \tag{2}$$

It has been shown that the interfacial area, A, generated by a flat paddle should be proportional to $L^{1.5}N$ if other conditions are held constant[4]. L is the paddle diameter and N is the paddle speed. With constant paddle diameter,

$$A = K'N \tag{3}$$

The experimental data can be represented by the equation,

$$\ln(1-E) = -K''N^2 \tag{4}$$

in the range where no organic-phase recirculation occurs. Correlations in the recirculation range have not been successful.

From equations (2), (3), and (4) it appears that U is also directly proportional to N.

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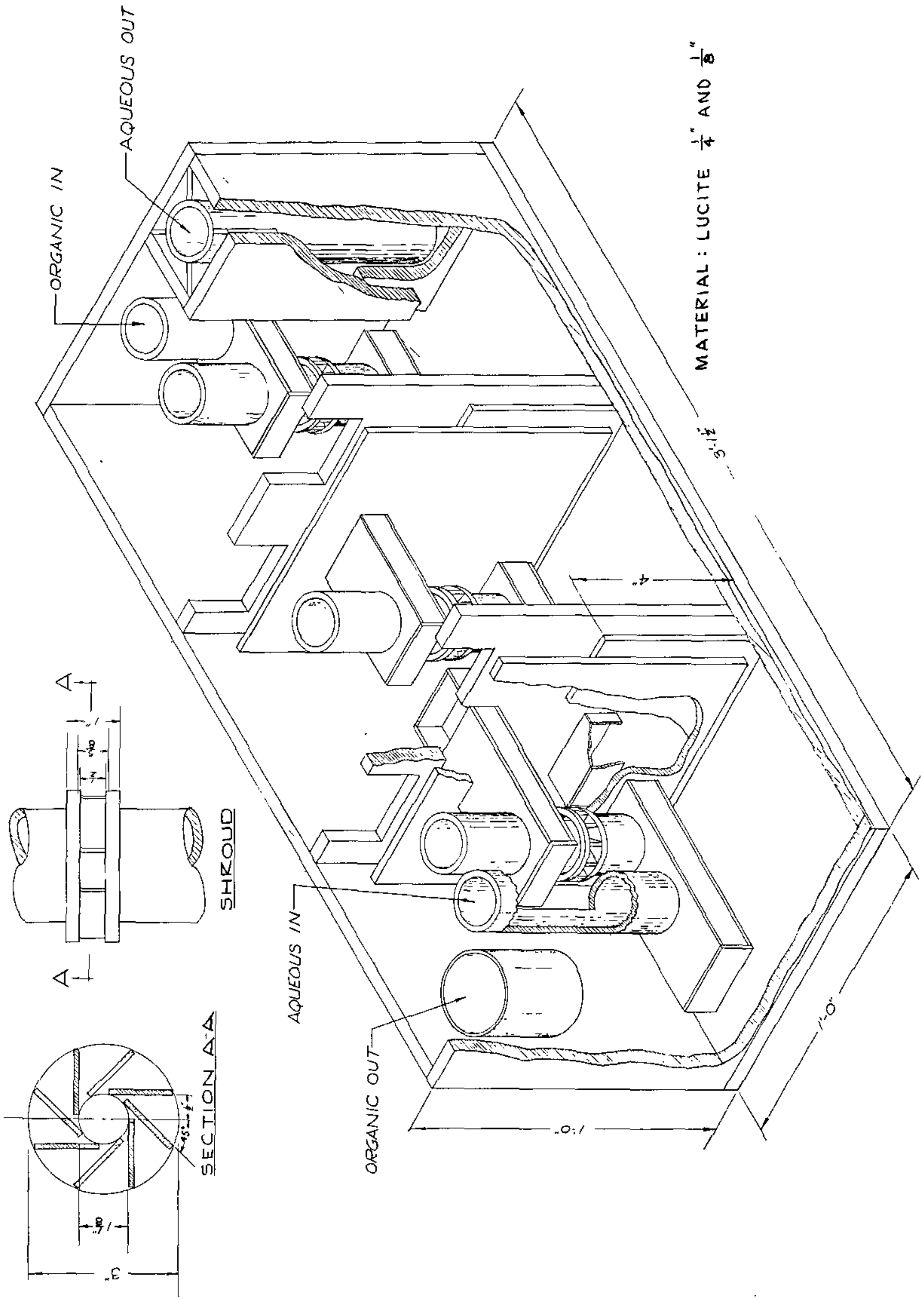
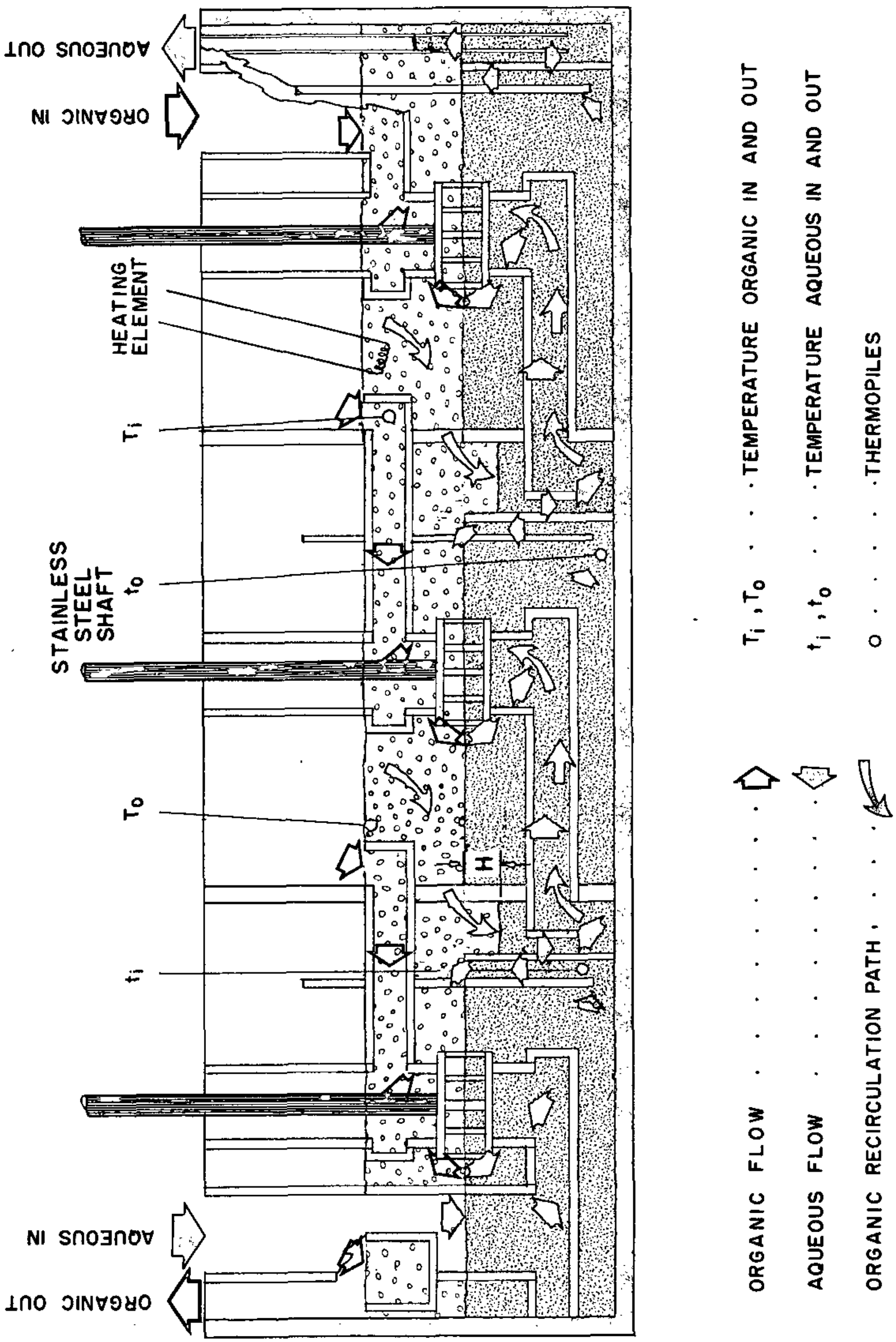
FIGURE 1



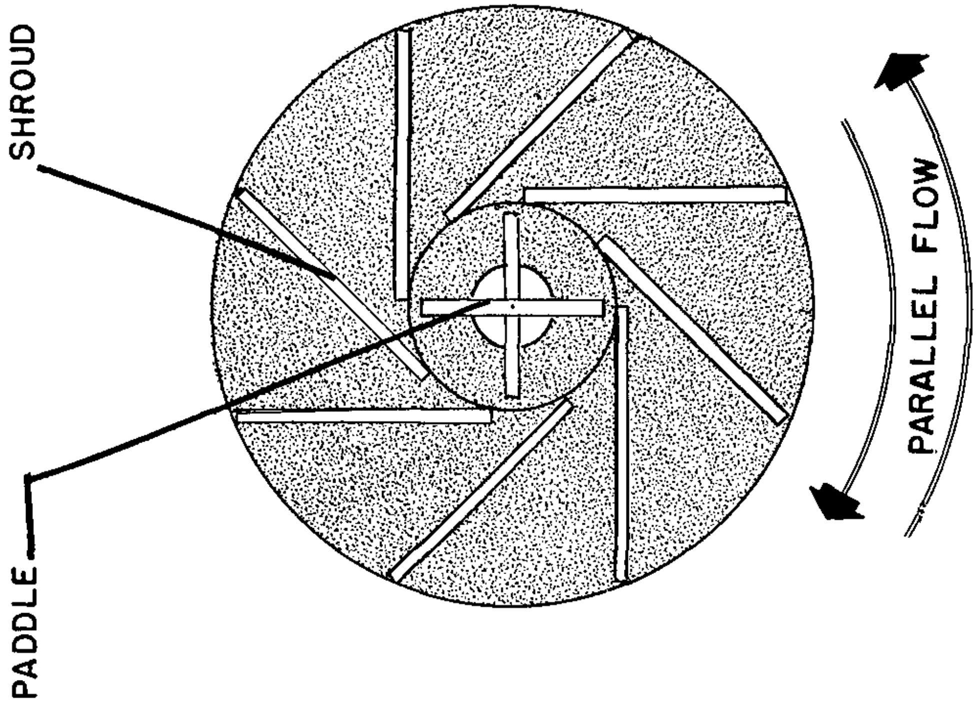
THREE-STAGE TURBINE CONTACTOR

FIGURE 2



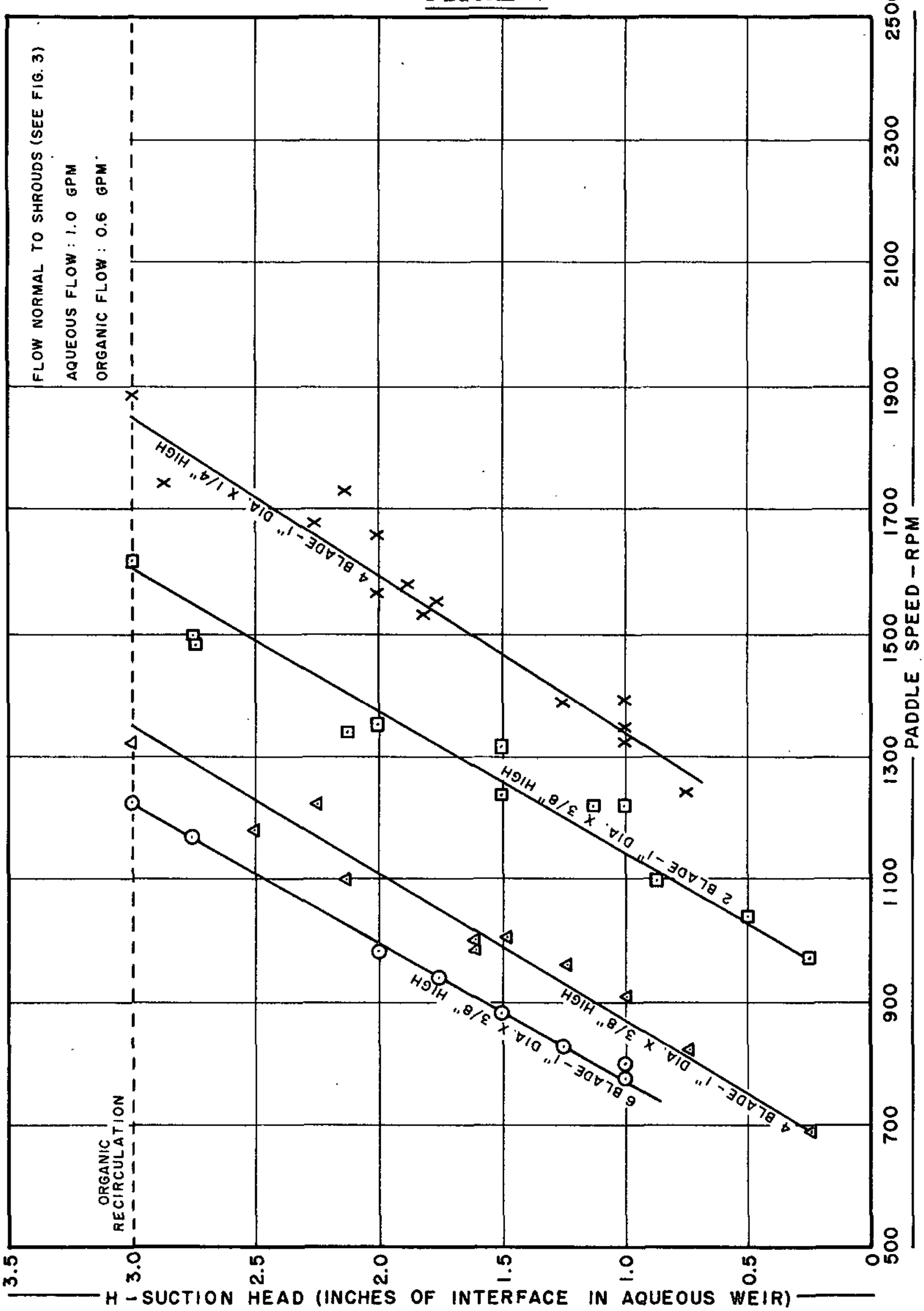
THREE-STAGE TURBINE CONTACTOR

FIGURE 3



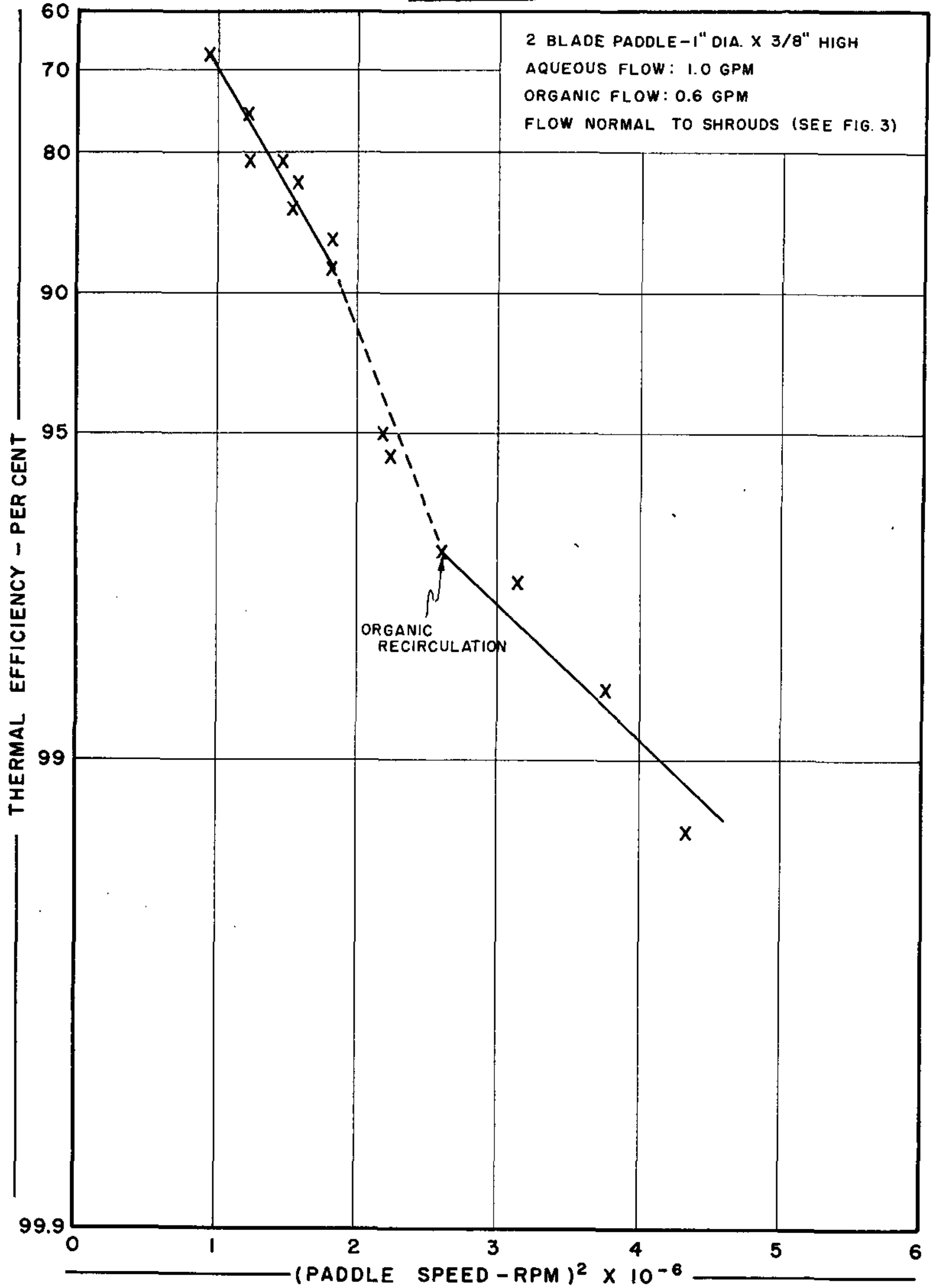
TOP VIEW OF TURBINE SHOWING STATIONARY SHROUDS

FIGURE 4



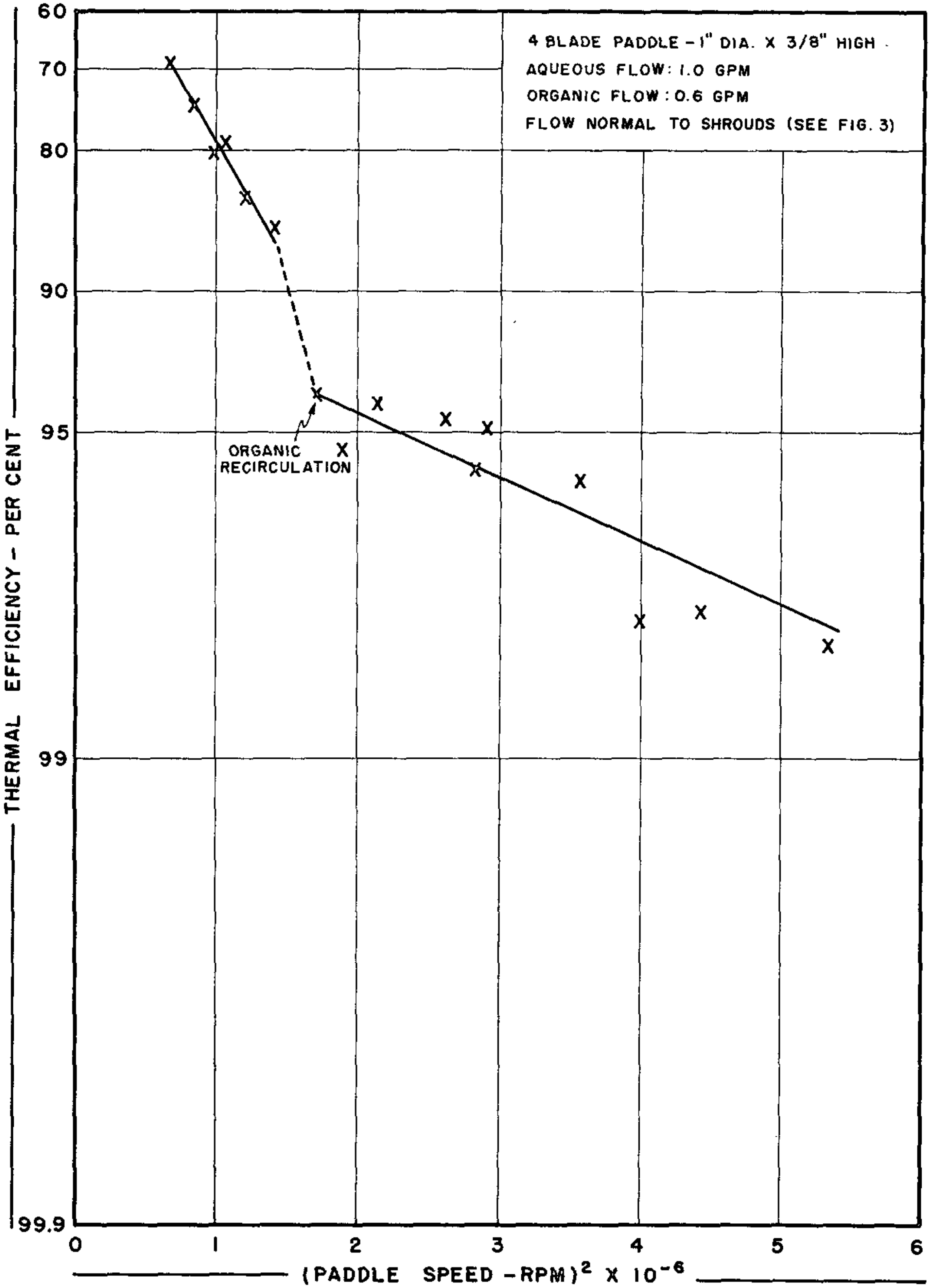
EFFECT OF PADDLE SPEED ON SUCTION HEAD

FIGURE 5



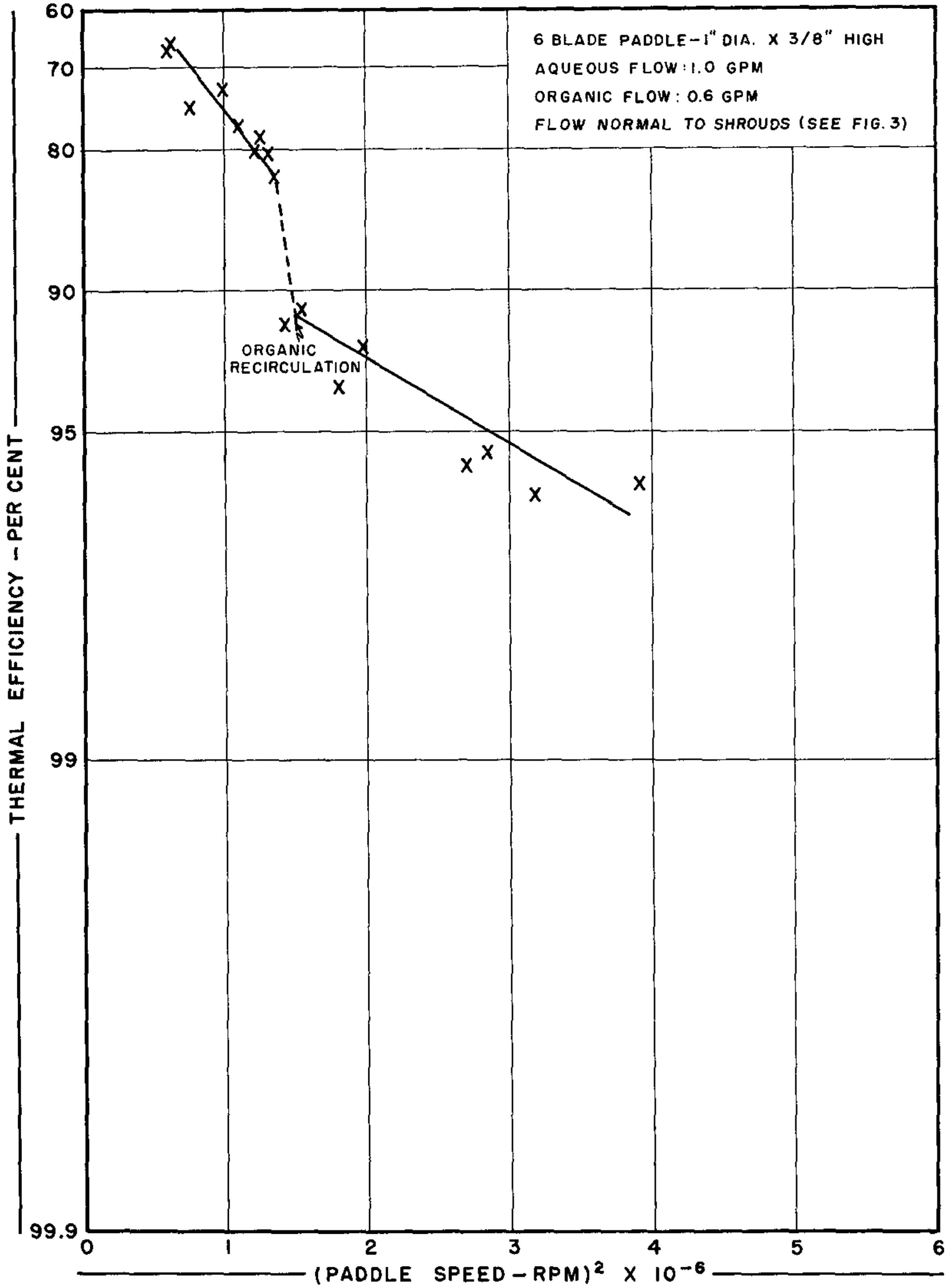
EFFECT OF PADDLE SPEED ON THERMAL EFFICIENCY

FIGURE 6



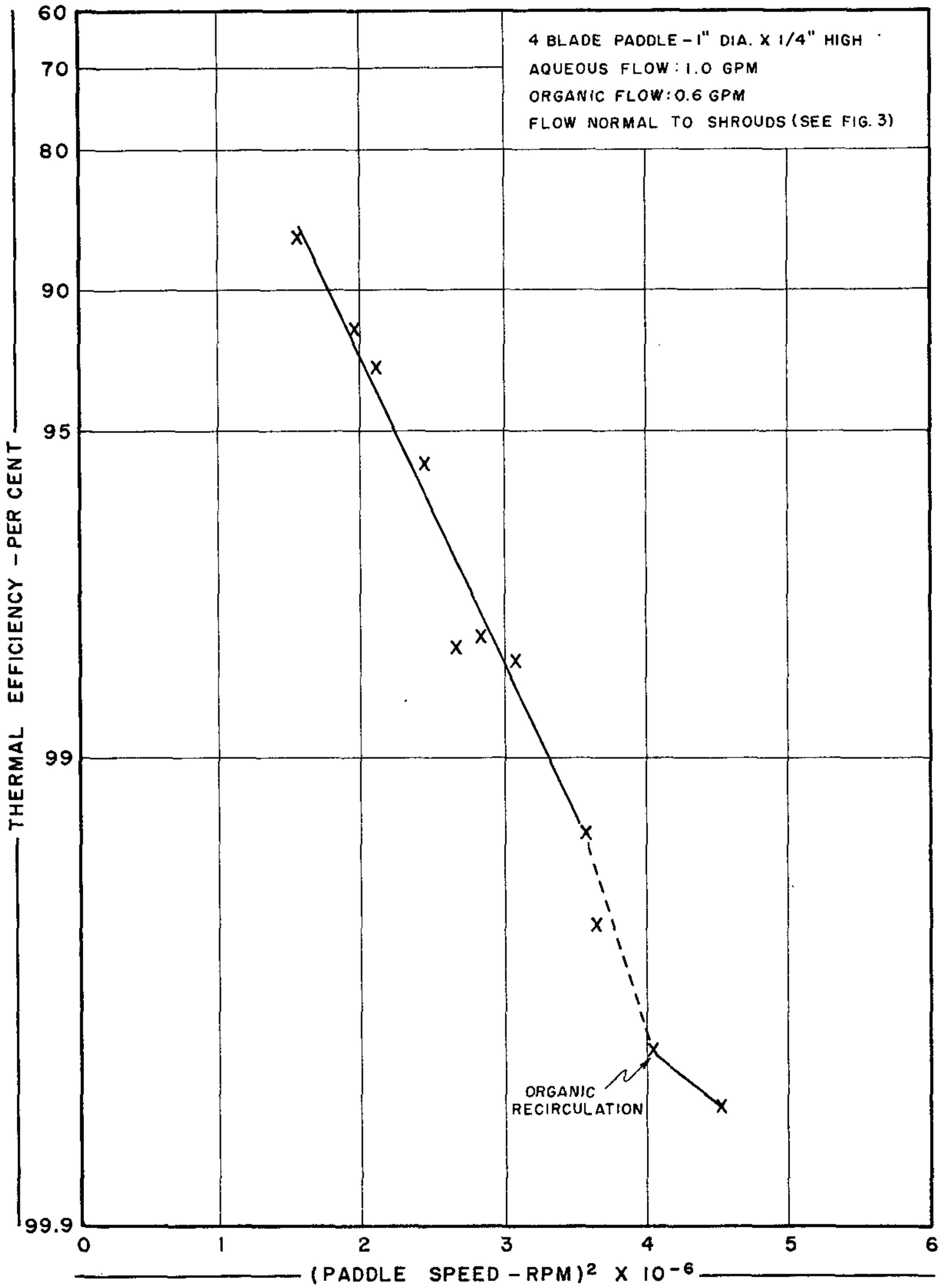
EFFECT OF PADDLE SPEED ON THERMAL EFFICIENCY

FIGURE 7



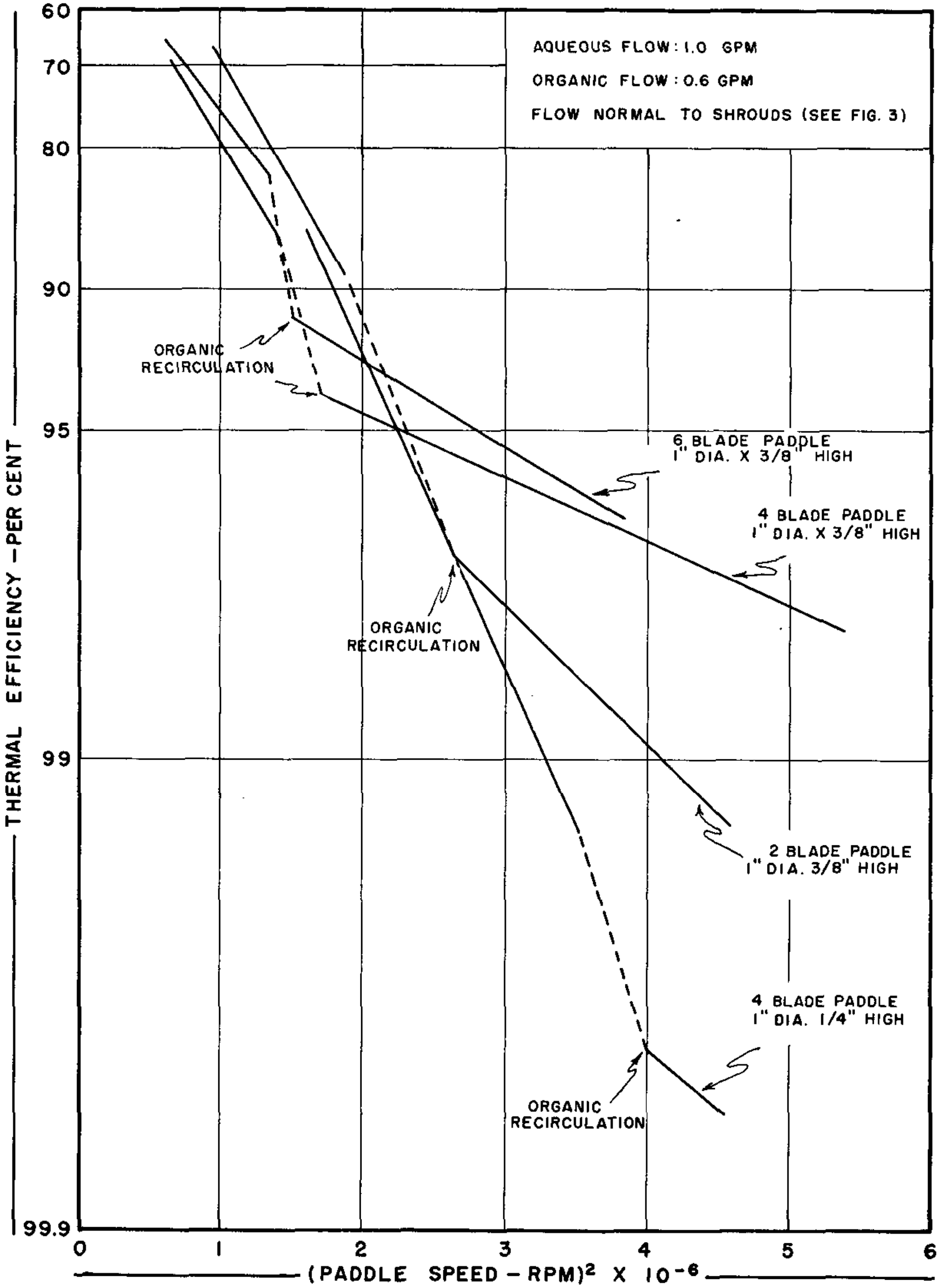
EFFECT OF PADDLE SPEED ON THERMAL EFFICIENCY

FIGURE 8



EFFECT OF PADDLE SPEED ON THERMAL EFFICIENCY

FIGURE 9

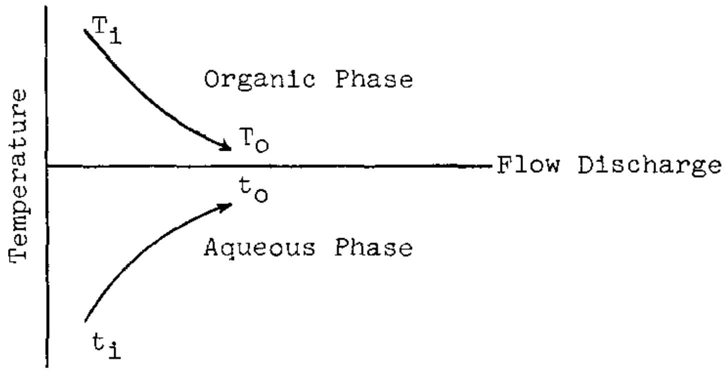


SUMMARY OF PADDLE SPEED - THERMAL EFFICIENCY DATA

APPENDIX

THERMAL EFFICIENCY PRINCIPLE

If warm organic and cooler aqueous phases are contacted in parallel flow, the temperature distribution through the mixing zone would be:



If heat losses are neglected, the heat balance is:

$$q = -\left[C_pV\rho(T_o-T_i)\right]_{org} = \left[C_pV\rho(t_o-t_i)\right]_{aq} \tag{1}$$

where:

q = heat transferred per unit time	T = organic temperature
V = volume of flow per unit time	t = aqueous temperature
ρ = density	i = inlet temperature
C_p= heat capacity	o = outlet temperature

Solving in terms of T,t and rearranging, one obtains

$$q = \frac{(T_i-T_o) + (t_o-t_i)}{\left(\frac{1}{C_pV\rho}\right)_{org} + \left(\frac{1}{C_pV\rho}\right)_{aq}} \tag{2}$$

Also, by Fourier's equation,

$$q = UA\left[\frac{(T_i-t_i) - (T_o-t_o)}{\ln\frac{T_i-t_i}{T_o-t_o}}\right] \tag{3}$$

Equating (2) and (3) and rearranging, one obtains

$$\ln\frac{T_i-t_i}{T_o-t_o} = UA\left[\left(\frac{1}{C_pV\rho}\right)_{org} + \left(\frac{1}{C_pV\rho}\right)_{aq}\right] \tag{4}$$

The thermal efficiency, E, is defined by the relation

$$1 - E = \frac{T_o-t_o}{T_i-t_i} \tag{5}$$

Inverting the T,t ratio in (4) and substituting, one obtains

$$\ln(1-E) = -UA\left[\left(\frac{1}{C_pV\rho}\right)_{org} + \left(\frac{1}{C_pV\rho}\right)_{aq}\right] \tag{6}$$