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Several Different Gas-Liquid Contactors Utilizing Centrifugal Force*

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Various types of contactors utilizing centrifugal force (centrifugal contactors) have been used commercially especially in the chemical industry for production of petro chemicals, organics, and pharamacenticals, for refining petroleum, and for other purposes. The centrifugal contactors have been known to have characteristics of high efficiency, large gas and liquid through-put, small liquid holdup, and short contact time.

Centrifugal contactors can be classified according to methods of utilizing the centrifugal force as follows (1);

i) Tray type. In this type of contactor, kinetic energy of the gas from the lower tray is used to impart centrifugal motion to the liquid on the upper tray.

ii) Mechanically agitated type. In this type of contactor, gas or liquid in the contactor is mechanically agitated to increase interfacial area by atomizing dispersion of fluid, and to reduce resistance for mass transfer at the interface by disturbance induced in both fluid phases. The column or tank with an agitator, and the apparatus with a rotating part have been invented for this purpose.

iii) Rotating type. This type of contactor consists of multistage concentric cylinders fixed to a rotating shaft. The gas and liquid in the contactor are brought into contact cocurrently or cross currently.

Since it is difficult to give a detailed description of all types of contactors utilizing centrifugal force, emphasis will be placed on the description of the fluid dynamical and mass transfer aspects of several specific types such as the rotational current tray, the rotating concentric column, Piazza type contactor, Podobielniak contactor, and centrifugal contactor of the rotating type, investigated by the first author. These contactors are currently employed for industrial distillation, absorption, and humidification. It is expected that the centrifugal contactor of the rotating type which consists of all rotating parts will be applied in the near future to the life support of men in space crafts, air planes, submarines and civil defense shelters, and to prevention of air pollution because of its compactness and other advantages. It also appears that it can be used as a blood oxygenator.

1. Tray types

Various tray type systems in which mass transfer operations are carried out have been developed and employed industrially. In a plate column, when the gravitational force is the only force affecting phase separation, the vapor velocity and resulting liquid entrainment in the column may set the maximum allowable vapor velocity and liquid velocity. However, if the centrifugal force is used to separate the entrainment, the capacity of such a tray may be increased.

In the system constructed by Manning (2), the column wall is used as the outer cylinder of a cyclone, and the contacting of gas and liquid takes place on a small perforated tray section which receives liquid from the tray above and vapor from the tray below. The two-phase mixture is discharged tangentially into the settling zone. The liquid is forced outward against the column wall by centrifugal force and flows into the downcomer leading to the next lower tray. The vapor enters the tray above through a conduit located inwardly from the column shell. It has been reported that the through-put of this tray is larger than those of many other trays (2).

In contrast to Manning's tray, the Kittel tray (3) and the rotational current tray (4,5) are designed so that the flow of the ascending gas or vapor is directed almost horizontally across the tray surface through the openings.

The Kittel tray consists of a pair of upper and lower grids, and each one is divided into six equal basic parts. The openings in the tray are in the shape of slots inclined at an angle to the horizontal plane of the grids. Thus some of the energy associated with the gas pressure drop is utilized to give centrifugal and centripetal motion to the liquid on the tray. That is, on the upper grid this motion is towards the wall of the column and on the lower grid towards the center. Because of the absence of the overflow weir and downcomer area, the free cross-sectional area of the Kittel tray is more than that of the sieve tray. Detailed review of this tray has been reported (3).

In the following paragraphs, emphasis will be placed on the description of the performance of the rotational current tray. The structure of the tray is shown in Figure 1. The shape of holes in the tray is a half ellipse, and it has a guide inclined at an angle to the surface of the tray. As shown in the figure there are two types of the rotational current tray, the upper guide tray (U.G.T.) and the down guide tray (D.G.T.). The liquid on the tray is carried along by gas and is brought into intimate contact with the gas. For this reason, the tray has many advantages in comparison with other trays.

In Figures 2 and 3, the pressure drop of gas flow through a tray and the liquid holdup on a tray of this type are compared with some trays of the counter current type without downcomer (4). It can be concluded that the pressure drop through the D.G.T. is smaller than those through other trays. It is, therefore, expected that a larger volume of gas can be treated with this type of tray than with other trays. Furthermore, it is interesting to note that the behavior of the tray is similar to that of the Ripple tray, as shown in Figure 2. From Figure 3, it is also evident that the liquid holdup on the D.G.T. is smaller than those of other types. This is probably due to the fact that the falling of liquid through the tray is made easy by the down guide.

The residence time of liquid on the tray was measured experimentally, and the desorption experiments were carried out by using the water-oxygen-air system to determine the liquid phase resistance to the mass transfer (5). The gas absorption experiments were carried out by using the water-ammonia-air system to determine the gas phase reisitance to the mass transfer (5). The results of these experiments have indicated that the gas flow rate and the residence time of liquid on the tray control strongly the plate efficiency. The Murphree plate efficiency of this tray for gas absorption based on the liquid phase is compared with those of other types of trays as shown in Figure 4. It can be concluded that the rotational current tray can be operated at high efficiency up to large gas flow rate.

The tray type centrifugal contactors are used for gas cleaning and dust collection in air pollution control. One particular tray, the Kettel tray, has been extensively used for air pollution control in Europe.

2. Mechanically agitated types

The rotating cone column (6, 7), the rotating basket column, the rotating flat plate column, and the spinning band column (8, 9, 10) belong to this class of distillation columns, each containing a rotating agitator which disturbs both the gas and liquid phases. The small laboratory scale columns of these types perform excellently and are effective for the separation of components from a mixture with a narrow boiling temperature range, for instance, the separation of isotopes (6). The mechanism of flow of both gas and liquid in these systems is not yet well known and the prediction of the capacity in these systems can not be made accurately. Therefore, it is difficult to design a commercial tower of this type.

The rotating concentric tube distilling column (11) is similar to the rotating cone column, the rotating basket column, the rotating flat plate column, and the spinning band column. The column has the characteristics of the small liquid holdup and the low pressure drop which is similar to that of the wetted wall column, and of the high flow rate. The liquid contacts with the vapor in the narrow annular space between the stationary outer cylinder and the rotating inner cylinder. The mass transfer coefficient increases as the speed of the rotor becomes greater because the flow of vapor is disturbed by the rotation of the inner cylinder. This can be seen from the results of the investigation by Taylor (12) and Lewis (13), who studied theoretically and experimentally the mechanism of fluid flow in an annular space between the rotating double cylinder. It has been theoretically determined that the efficiency of distillation increases with the increase in the degree of turbulence in the vapor phase and with the decrease in the annular space and in the flow rate through the annular space (14). This fact has also been confirmed experimentally (15, 16, 17, 18).

and several stationary cylinders. The liquid fed near the center flows over the periphery of a rotary cylinder by centrifugal action as sprays, sheets, and droplets, and then collides with the wall of a stationary cylinder. After the impact one part of the flow backmixes with the sprays and the other part flows down along the cylinder wall.

On the other hand, one of the authors and his coworkers (30) have designed a centrifugal contactor of the rotating type whose main part consists of multistage concentric perforated cylinders. The schematic diagram of the contactor is shown in Figure 11. The liquid fed near the center of the cylinder is spouted from a small hole drilled through the rotating cylinder wall, and gas is sent cross currently to the liquid in an annular space between the rotating cylinders.

To understand the fluid dynamic and mass transfer aspects of these rotating type contactors, investigations on the gas absorption by the short liquid jets (31) and the droplets issued from a capillary (32) in the gravitational field have been carried out. Furthermore, the fluid flow and mass transfer in the centrifugal field have also been investigated (33, 34, 35, 36, 37).

The distribution of droplets which are broken off from the liquid jet issued from a rotating cylinder and a spinning cup has been studied by Walton and Prewett (39), Adler and Marshall (40), and Hinze and Milborn (41). The photographic observation of the flow pattern of liquid jets injected from a rotating cone cup has indicated that the liquid from such a cup forms a sheet or film, at the periphery of which the liquid jets are formed and break into droplets. Furthermore, Hinze and coworkers (41) have investigated experimentally the effects of the speed of rotor, the flow rate of liquid, and the angular

Willingham and coworkers (11) carried out experiments in a column with a diameter of 9.62 cm and a height of 58.4 cm. The column was provided with a rotor with a diameter of 7.44 cm which was operated at speeds in the range of 0 ∿ 4,000 R.P.M. The feed in liquid form was maintained in the range of 600 ∿ 4,700 cm^3/hr. The pressure drop was lower than those of similar type columns described previously and it increased with the revolution speed of the rotor and with the flow rate of liquid, as shown in Figure 5.

If it is assumed that the surface of rotating cylinder is not wetted and that the rate of reflux which flows down along the inner wall of a stationary cylinder is independent of the rotation of the cylinder, the liquid holdup can be calculated by the following equation (19).

$$w = \left(\frac{3\,Q\,\mu_\ell}{\rho_\ell\, g}\right)^{1/3} \qquad (1)$$

where w is the thickness of liquid film, Q is the volume flow rate per wetted perimeter, μ_ℓ and ρ_ℓ are the viscosity and density of liquid respectively, and g is the acceleration of gravity.

The values of holdup calculated from equation (1) for the rotating concentric tube distilling column are shown in Table 1. The number of theoretical plates decreases with the increase in flow rate and increases with the speed of revolution, which is illustrated in Figure 6. A high efficiency is obtained above the speed of about 2,300 R.P.M., as shown in Figure 7. The reason may be due to the fact that the vapor phase becomes highly disturbed above this critical velocity.

In a plate column, the gas bubbles are passed into a liquid holdup through the submerged openings in the tray to increase the contacting area of the gas and liquid. The amount of agitation that can be obtained in this way is limited essentially by the rate of gas flow.

The tank with an agitator is a more efficient device than the plate column for agitation of the liquid on the tray regardless of the gas throughput. The tank, therefore, may have to be used for the agitation of viscous liquids or slurries. Since the agitation also increases the residence time of the bubbles in the liquid, the tank may be an efficient device where absorption is accompanied by a chemical reaction especially a slow reaction (20).

It has also been reported that a horizontal cylinder with an agitator can be used for the absorption operation (21). The agitator consists of several discs fixed to a rotary shaft placed in the center of a horizontal cylinder. The structure of the disc is shown in Figure 8. The liquid fed near the end of the cylinder flows through the discs in the form of sprays, sheets, and droplets by centrifugal action. The gas is sent through the cylinder cocurrently or countercurrently to the liquid. According to the studies by Ganz and coworkers (22), this absorber is highly efficient, but its performance and efficiency for industrial scale operation are unknown.

These systems with agitators have been reported in detail (23, 24).

3. Rotating types

Recently centrifugal contactors consisting of all rotating parts have been developed for mass transfer operations. Many of these contactors have been described in detail (21).

The Podobjelniak centrifugal rectifier used in the distillation operation belongs to this class of contactors (25). The main part of the rectifier is a rotating drum made of a spiral metal sheet. The liquid fed near the center flows in radial direction by the centrifugal action as a thin film along the metal sheet. The apparatus can be operated at a relatively large flow rate without any entrainment which decreases the distillation efficiency. It has been reported (26) that when a small apparatus with a rotating drum made of a metal strip, 1/4 inch in width, 100 feet in length, and 1/8 inch for distance between coil of spiral, is run at a speed of 1,200 R.P.M., the approximate feed rate is 12 liter/hr, the liquid holdup is 30 liter/hr, the pressure drop ranges from 10 to 20 mm Hg, and its efficiency corresponds to that of a 80 plate column.

The rotary surface vapor compression still whose main part consists of the conical disc was fabricated in 1952 by Hickman (27). This apparatus has been further developed for application to sea water distillation (27). The schematic diagram of the apparatus is shown in Figure 9. Feed water is supplied to the inside surface of the rotor and vapor is condensed on the outside surface. The industrial scale rotary surface vapor compression stills have been in operation for several years. To be able to design this system intelligently, however, the mechanism of the evaporation and condensation on a rotating heat transfer surface must be known.

The penetration theory (28) and the surface renewal theory (29) predict that the absorption rate on the renewed surface of liquid is excellent. These theories may be employed generally for the design of contactors by utilizing the centrifugal action. For example, these theories can be applied to the Piazza type centrifugal absorber. As shown in Figure 10, the absorber consists of several concentric cylinders fixed to a rotating shaft velocity of the cup on the flow mechanism. Figure 12 shows the distribution of the drop diameter as a function of the rotating velocity. These experimental results were obtained with a cup having a diameter of 10 cm operated at the liquid rate of 80 liter/hr. Walton and coworkers (39) have found that the drop diameter goes through the maximum value when the angular velocity is increased and that the drop diameter is given by the equation,

$$d = \frac{K}{\omega}\sqrt{\frac{\sigma}{D\,\rho_{\ell}}} \qquad (2)$$

where d and D are the diameter of the drop and that of the cup, respectively, ω is the angular velocity, σ is the surface tension of the liquid, and K is a constant. Although equation (2) agrees with the experimental results of Hinze and coworkers (41), it does not contain the effect of the viscosity of liquid.

Dixon, Russel, and Swallow (42) have investigated the effect of the density, viscosity, and surface tension of the liquid. Furthermore, they have carried out a theoretical analysis, by assuming that the different behavior of the formation of sheets in the different liquid is due to the trajectory of the liquid flow from a feed tube to the periphery of a cup.

As a part of the fundamental studies of fluid dynamics of the centrifugal contactor of the rotating type (30), the first author defined theoretically the discharge coefficient in the centrifugal field, neglecting the effects of the physical properties of liquids but taking into account the effects of hole diameter, wall thickness, cylinder diameter, revolution speed of the cylinder, and discharge pressure of liquid (33). Eventually, the effects of viscosity and surface tension of discharged liquids were taken into account and the equations applicable to the liquids of various viscosities and surface tensions in the centrifugal field were derived (33). Other studies on the flow pattern of a round liquid jet in the centrifugal field are a study of the discharge from a rotating pipe (43), a study of the discharge from an orifice (37), and a study of the atomizing pattern of liquids spouted from a cylindrical nozzle (44).

The flow pattern of the liquid jet spouted from a rotating small hole is very complex. However, it is known that the jet travels due to the combination of the circumferential velocity and the radial velocity (37). Therefore, it is clear that these give rise to the relative velocity against the surrounding gas. As the discharge velocity of liquid is increased, it undergoes transition consecutively through the stages of drops, laminar flow, turbulent flow, and spray. Figure 13 shows the most typical forms of liquid jet spouted from a rotating small hole (38). In this figure, (a) is the dripping flow, (c) and (d) are the laminar flow, (e) is the turbulent flow, and (g) is the spray. It can be seen that these flow patterns in the centrifugal field are similar to those in the gravitational field.

According to the experimental results of Tanazawa, Kurabayashi, and Saito (43), the flow pattern of liquid jet in the gravitational field can be divided as follows:

$Je < 0.1$	dripping
$Je \cong 0.1 \sim 10$	laminar flow
$Je \cong 10 \sim 500$	turbulent flow
$Je > 500$	spray

where the Jet number of liquid stream, Je, is defined by

$$Je = \left(\frac{d\, w^2\, \rho_g}{\sigma}\right)\left(\frac{\rho_\ell}{\rho_g}\right)^{0.45} \qquad (3)$$

and d is the diameter of hole, w is the discharge velocity of liquid, and ρ_g is the density of gas.

Furthermore, from the available experimental results (35), it can be seen that the flow pattern of the liquid jet in the centrifugal field must be defined by the Jet number based on the resultant velocity as mentioned previously.

The diameter of the liquid jet gradually becomes smaller due to the increase in the rotation of speed. Figure 14 shows the relation between the jet length and the ratio of jet and hole diameters, d_j/d, when the radius of cylinder is 2.5 cm (37). From the figure, it is obvious that the diameter of liquid jet decreases as the jet lengthens. The diameter of the jet when the discharge velocity is slow and angular velocity is high becomes remarkably small immediately after the liquid is spouted from a hole. Hereafter, the continuous length of liquid jet becomes short although the flow of jet is laminar, as shown in Figures 13(c) and (d). This phenomenon can not be found in the liquid jet spouted from a small hole in the gravitational field.

In these rotating type gas-liquid contactors, mass transfer takes place at the surface of the rotating liquid jets, sheets, droplets, and liquid film along the inside wall of the cylinder. It is important to know which one of these controls the mass transfer rate so as to design an apparatus of high efficiency and to determine the optimum condition for operation.

When a small scale Piazza absorber with two rotary cylinders as shown in Figure 10 was operated cocurrently, the following results were obtained (45). The absorption rate was independent of the interfacial area which was provided by the liquid films along the inside wall of the cylinders when the interfacial area of the sprays from the rotating cup was maintained constant. However, when the interfacial area due to the sprays was reduced to half and that due to the films was maintained constant, the absorption rate became half. can be seen from the results that the spray from the rotating cup cont the overall absorption rate.

On the other hand, in the rotating type contactor (30), mass transfer between gas and liquid takes place as a result of contact between gas and a liquid jet or gas and a liquid film along the inside wall of the cylinder. In order to evaluate the rate of mass transfer from rotating liquid jets, the contact area of gas and liquid per unit volume of a continuous liquid jet spouted in an annular space from a small rotating hole has been determined theoretically and experimentally (37). Furthermore, the absorption of pure carbon dioxide by a liquid jet issuing from a rotating hole (35) and that by a flowing liquid film along the inside wall of the rotating cylinder (36) have been studied. It can be concluded from the results that the amount of mass transfer into the liquid film on the wall of the rotating cylinder is much less than that into the liquid jet issuing from a rotating hole. However, the absorption efficiency increases as the liquid depth on the inside wall decreases.

The pressure drop under the condition of the cocurrent flow of gas and liquid in the Piazza absorber is affected by both the rotating velocity and the liquid flow rate. The liquid holdup in this apparatus increases when the speed of revolution is lowered. This increase in the liquid hold-up tends to obstruct steady flow of gas and consequently increases the pressure drop steeply. This is the so-called flooding phenomenon. The point of flooding depends on the flow rate of liquid but is almost independent of the gas rate. In the countercurrent operation of this apparatus, these relations are complex.

As mentioned previously, it is desirable to make cylinders as large as possible for the purpose of increasing efficiency of absorption. For absorption the space between cylinders must be narrow. However, this tends to increase the pressure drop. To solve this problem a number of holes is often provided in the bottom of the rotating cylinder. Even with this improvement, the liquid throughput in radial direction cannot be maintained smoothly because the main part of the absorber consists of the rotary cylinders and stationary cylinders, which are overlapped. As a result, the consumption of power is enormous, flooding tends to occur and the countercurrent operation becomes difficult. To avoid these difficulties Alcock and Millington (46) designed the double rotor contactor. The experimental results (46, 47) indicate that the pressure drop for the double rotor type is 1/2 to 1/3 of that of the rotor stator type. The double rotor type is more desirable than the rotor stator type for the treatment of viscous liquid. However, the behavior of liquid flow into the contactor has not yet been investigated. In the centrifugal contactor of the rotating type (30), the pressure drop is much smaller than that of the Piazza type because the gas is sent crosscurrently to the liquid jet in an annular space between the rotating cylinders.

Rumford and Rae (47) have investigated experimentally the effects of the water rate, the gas rate, the concentration of the solute gas, and the revolution speed and structure of cylinders on the absorption rate in the Piazza absorber of the double rotor type operated cocurrently. They have employed three systems, namely, carbon dioxide-water, ammonia-water, and acetone-water. Table 2 shows the experimental results obtained at various flow rates of the liquid and gas. If the total volume of the centrifugal absorber is V ft^3, and if G_m moles of gas flow cocurrently with L_m moles of liquid, the following equation can be obtained from the material balance (47).

$$-G_m \, dy = L_m \, dx = k_\ell \, a(C_e - C_\ell)dV \qquad (4)$$

where $k_{\ell}a$ is the liquid phase coefficient on the volume basis, C_e is the concentration of solute in liquid stream which is in equilibrium with gas, C_{ℓ} is the concentration of solute in the main body of the liquid stream, and x and y are mole fraction of solute in liquid and gas, respectively. The number of liquid phase transfer unit, N_{ℓ}, is

$$N_{\ell} = V \cdot c \cdot K_{\ell}a/L_m \tag{5}$$

where c is the average molal density of the liquid. Then, the volume of a liquid phase transfer unit, V/N_{ℓ}, is

$$V/N_{\ell} = L_m/c \cdot k_{\ell}a \tag{6}$$

This is often denoted as $V.T.U._{\ell}$. And alternatively the volume of a gas phase transfer unit, $V.T.U._g$ or V/N_g, defined as

$$V.T.U._g \equiv V/N_g \equiv G_m/P \cdot k_g a \tag{7}$$

where P is the total pressure of the system. Then the volume of an overall liquid phase transfer unit, $V.T.U._{0\ell}$ is given by

$$V.T.U._{0\ell} = V.T.U._{\ell} + (L_m/G_m \cdot M)(V.T.U._g) \tag{8}$$

where M represents C/H.P., in which H is the Henry's law constant. On the other hand, the volume of an overall gas phase transfer unit, $V.T.U._{0g}$, is

$$V.T.U._{0g} = V.T.U._g + (G_m \cdot M/L_m)(V.T.U._{\ell}) \tag{9}$$

As mentioned previously, values of these quantities are given in Table 2.

Figure 15 shows one example of the effect of the rotating velocity on the absorption rate. This result was obtained at the gas rate of 1,100 ft^3/hr. The concentration of carbon dioxide in the inlet gas was 17% and the concentration of monoethanol amine and that of carbon dioxide in the inlet solution were 80% and 3.5% respectively. Furthermore, Alcock and Millington (46) found the optimum condition from their experimental results obtained by using a 6 cylinder unit and designed a large scale absorber in which 15 cylinders were fixed to a rotor, 12 inches in diameter, and have examined it with the monoethanol amine-carbon dioxide systems. The experimental result obtained with both equipment are compared in Table 3.

The absorption rate of pure carbon dioxide gas by a rotating round water jet was measured in an annular space between the rotating cylinder and a stationary concentric outside cylinder (35). Figure 16 shows an example of the relation between the gas-liquid contact time, θ, and the Murphree absorption efficiency, E_{ML} when the hole is 0.9 mm in diameter. θ was evaluated by the theoretical equation (35, 38). From this figure it can be seen that the plot of E_{ML} versus $\sqrt{\theta}$ leads to a straight line through an origin, and also that the pure carbon dioxide gas absorption by a water stream issuing from rotating jet holes conforms to the unsteady-state diffusion theory (28). Furthermore, the gas absorption rate by a water jet spouting from a rotating small hole was observed to be large immediately after the liquid was spouted from the hole. Therefore, for practical purposes, it is desirable to employ a multi-rotor type contactor in order to make as many jets of liquid as possible.

In addition to the experimental mass transfer study mentioned previously, mechanisms of fluid flow and the mass transport of the liquid film on the inside wall of a rotating wetted cylinder were theoretically investigated (36). The effects of various factors such as the gas and liquid velocities, the depth of liquid layer, the number of revolutions, and gas-liquid contact time etc. on the mass transfer rate were examined.

The centrifugal contactor of the rotating type (30) has been extensively developed in Japan as absorbers, humidifiers, rectifiers, etc. based on the fundamental and applicative studies by the first author and his coworkers (33, 34, 35, 36, 37, 38, 40).

Some of the special features of gas-liquid contactors utilizing the centrifugal force are discussed in this report. These contactors have come into general use only in the last ten years and there is as yet no literature that deals with design features and fundamental studies, and many problems are yet to be solved. However, it is expected that these contactors will be employed widely by several industrial fields in the near future because of the generally favorable mass transfer characteristics in the centrifugal field. Some contactors mentioned in this report allow treatment of a viscous solution, and also can be operated without flooding and at a large flow rate. Furthermore, they can be employed where pitching and rolling of the systems cannot be avoided.

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Table 1. Holdup

Liquid flow rate [ml/hr]	Holdup / Column height [ml/m]	Holdup / Number of theoretical Plate [ml]
1,000	12.8	0.10
1,500	14.5	0.14
2,000	15.9	0.19
2,500	17.2	0.24
3,000	18.2	0.29
3,500	19.2	0.36
4,000	20.1	0.40

Table 2.

L_m	G_m	$N_{O\ell}$	N_{Og}	$V.T.U._{O\ell}$	$V.T.U._{Og}$	
22.2	3.66	0.825	0.00352	0.04	9.4	6% CO_2 in gas
44.4	3.66	0.825	0.00704	0.04	4.68	
66.6	3.66	0.825	0.01056	0.04	3.12	
88.8	3.66	3.850	0.01450	0.039	2.28	
111.0	3.66	0.870	0.01850	0.038	1.79	
44.4	1.83	0.56	0.0095	0.059	3.48	9% CO_2 in gas
44.4	2.45	0.56	0.0072	0.059	4.60	
44.4	3.06	0.56	0.00575	0.059	5.75	
44.4	3.66	0.56	0.0048	0.059	6.89	

Table 3. Comparison of 6 Cylinder and 15 Cylinder Absorbers

	6 Cylinder Absorber			15 Cylinder Absorber		
Liquid flow rate [gal/hr]	$k_g a$	Absorbed CO_2 [lb / hr]	Pressure drop [in-W.C.]	$k_g a$	Absorbed CO_2 [lb/hr]	Pressure drop [in-W.C.]
20	7,700	13.1	5.5	31,000	17.6	12
30	10,500	16.9	5.5	41,000	19.6	14
40	12,700	18.3	5.5	47,300	20.5	16

Concentration of inlet liquid	85% M.E.A. 2.5% CO_2
Temperature of inlet liquid	60°C
Gas flow rate	1,200 ft^3/hr
CO_2 concentration of inlet gas	16%
Number of revolution	2.300 R.P.M.

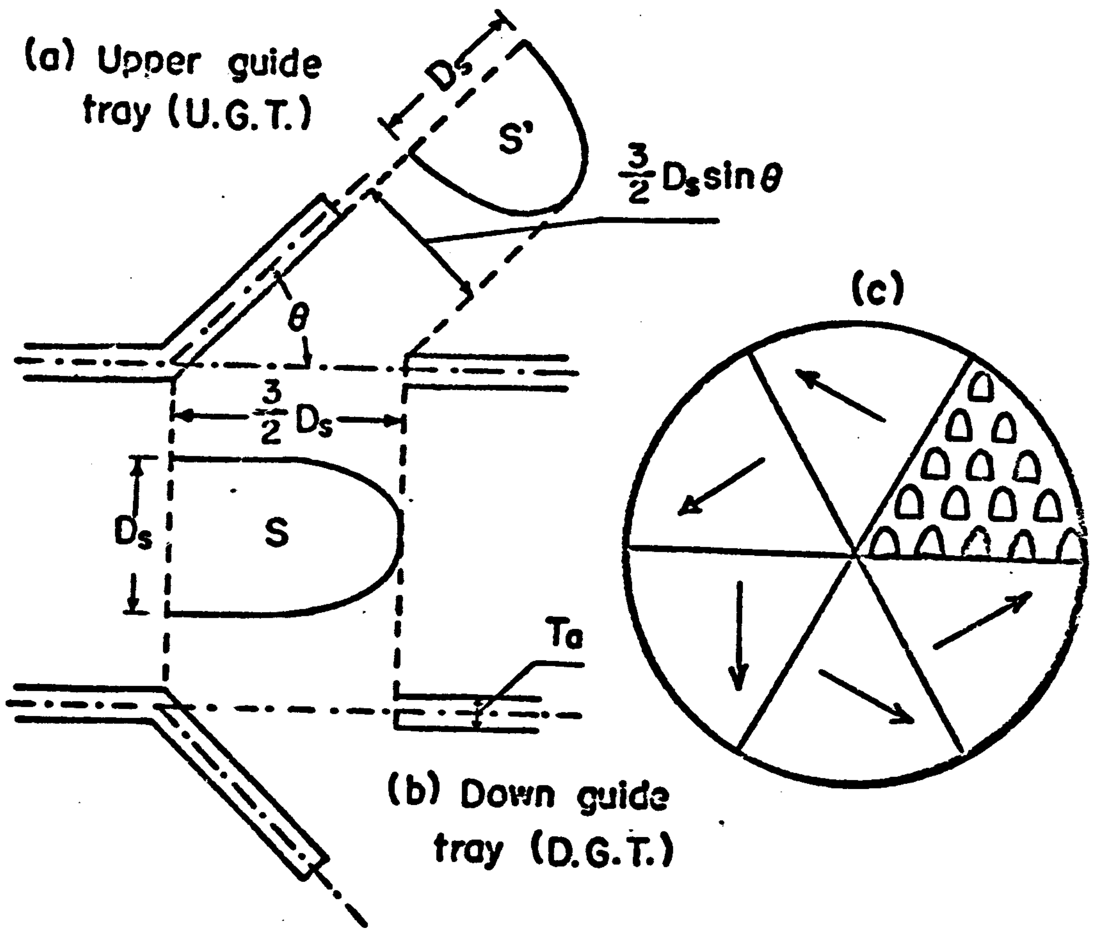


Fig. I Structure of rotational-current tray

	Tray	D_t	D	A_h/A_c	W
⊙	Counter-current type perforated	15	1.52	0.186	1.42
□	Kittel tray	50	0.36:0.86	0.27	1.95
◌	Ripple tray	69	—	—	0.57
ɸ	Ripple tray	69	—	—	1.13
○	Upper guide tray	14.6	0.72	0.172	1.77
○					2.62
△	Down guide tray	14.6	0.72	0.172	1.77
△					2.62

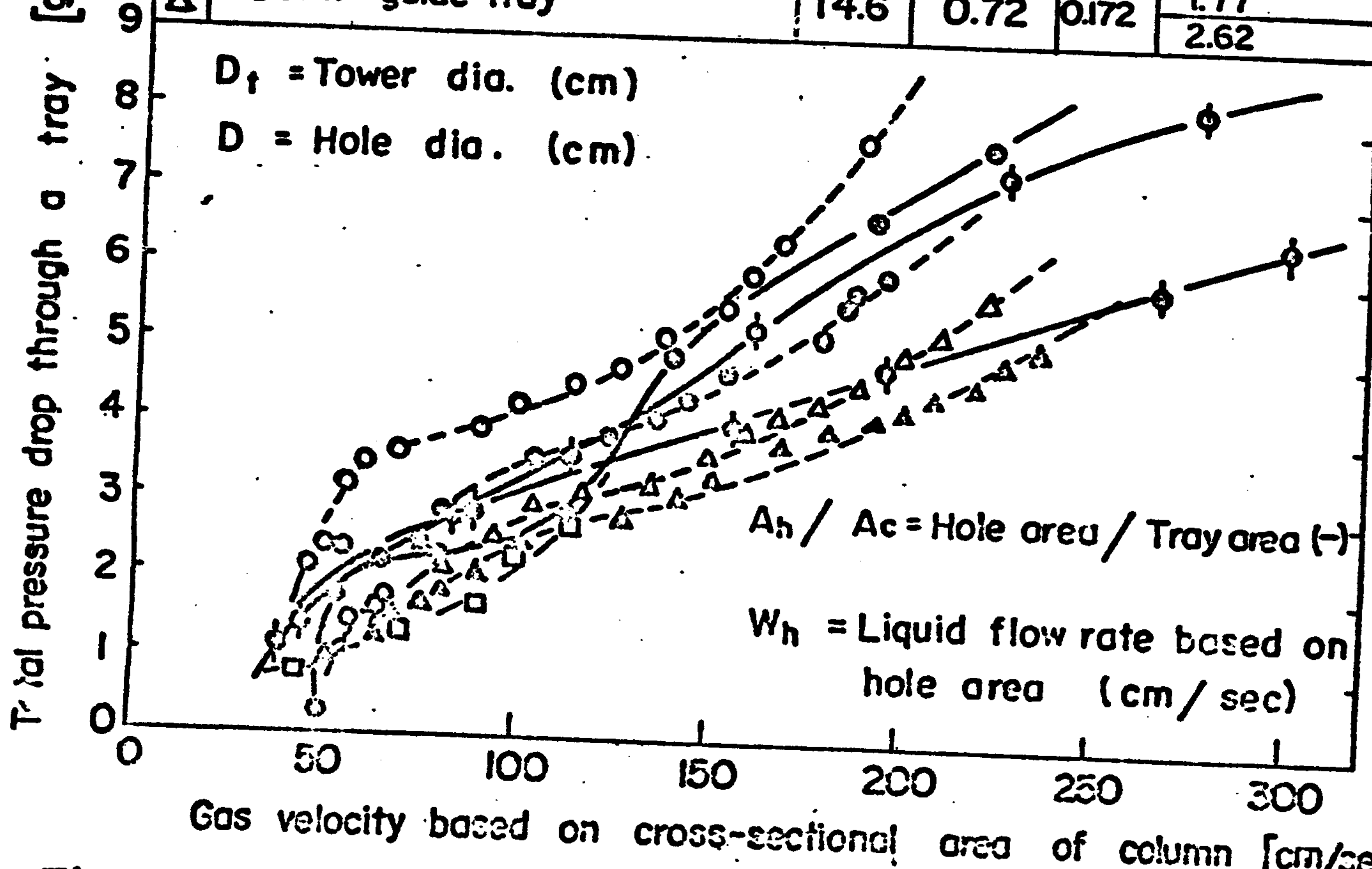


Fig.2 Comparison of total pressure drop through a tray.

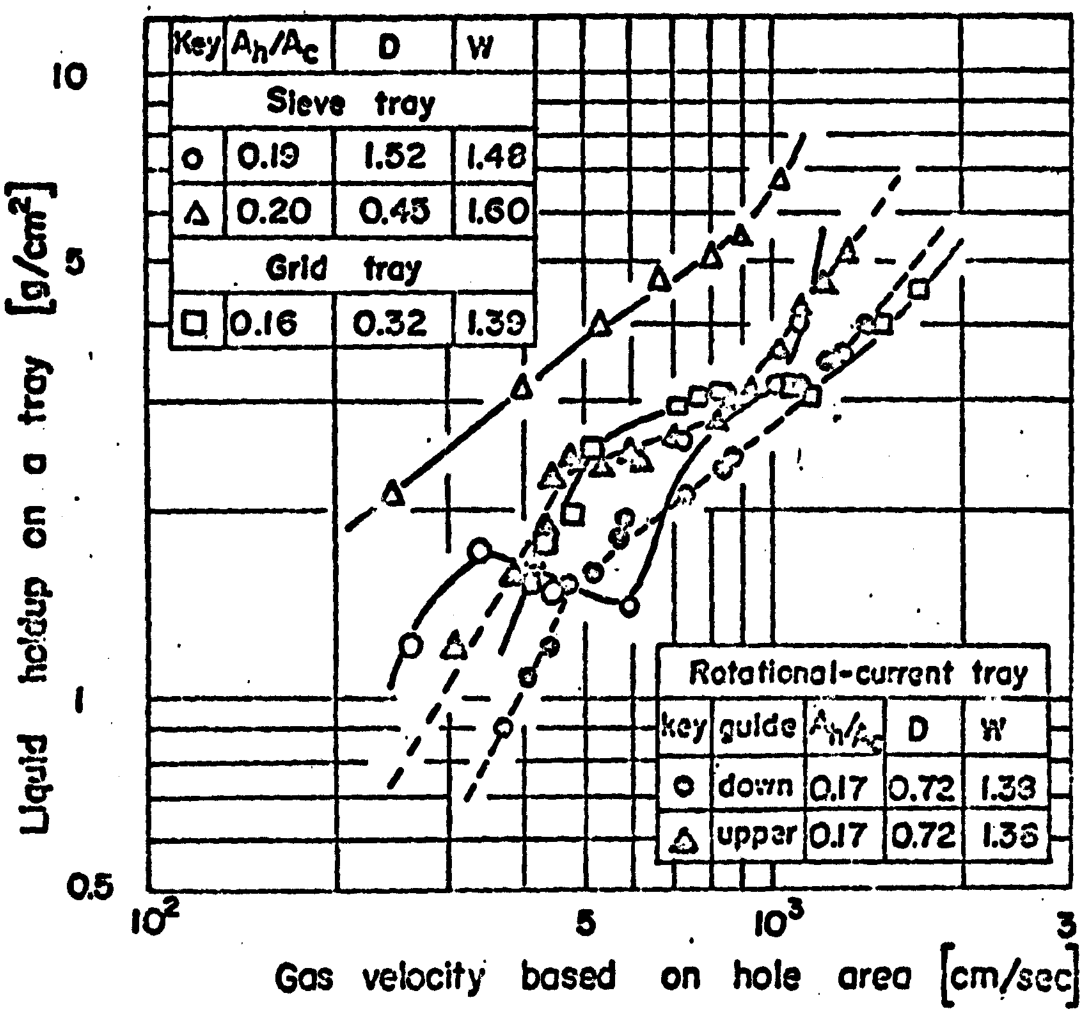


Fig. 3 Comparison of liquid holdup on various counter-current trays.

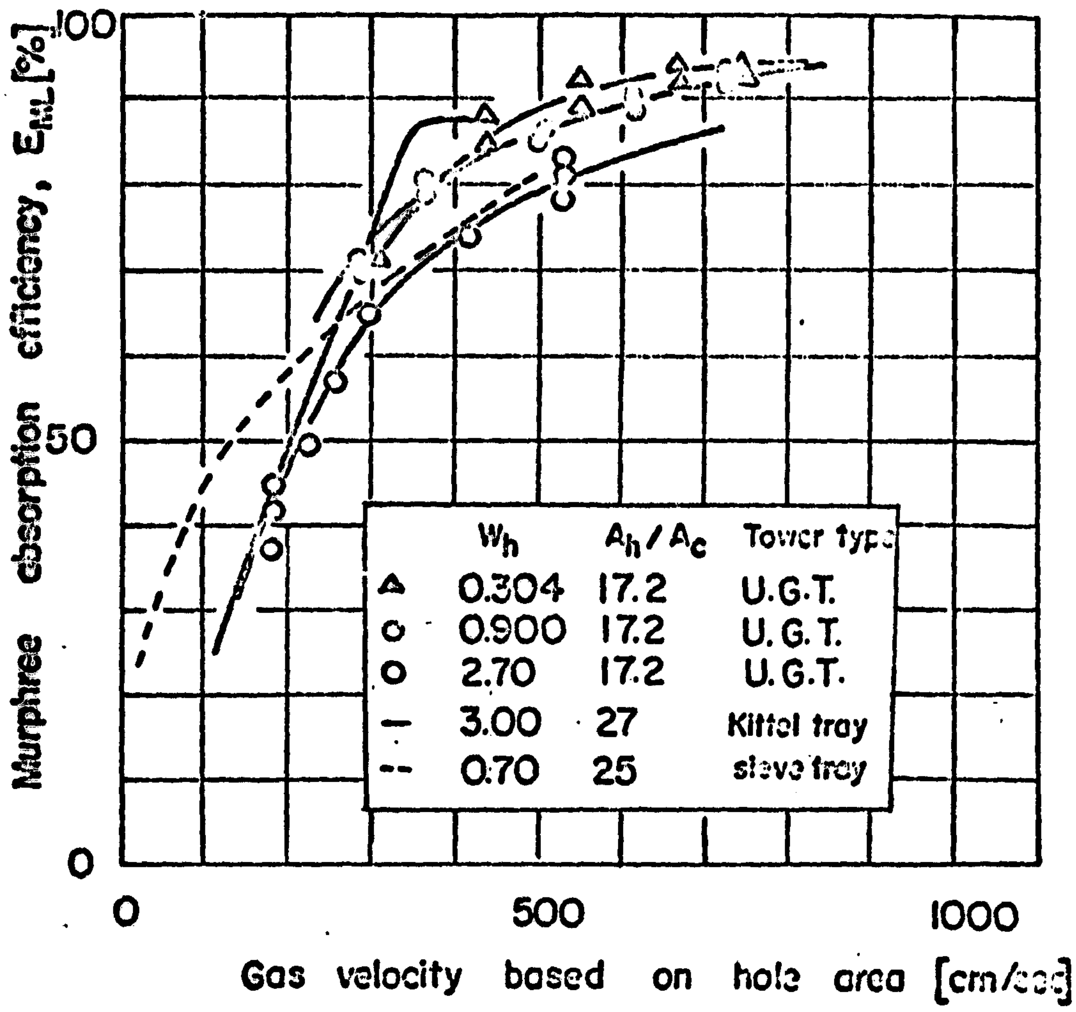


Fig. 4 Comparison of absorption efficiency based on liquid phase.

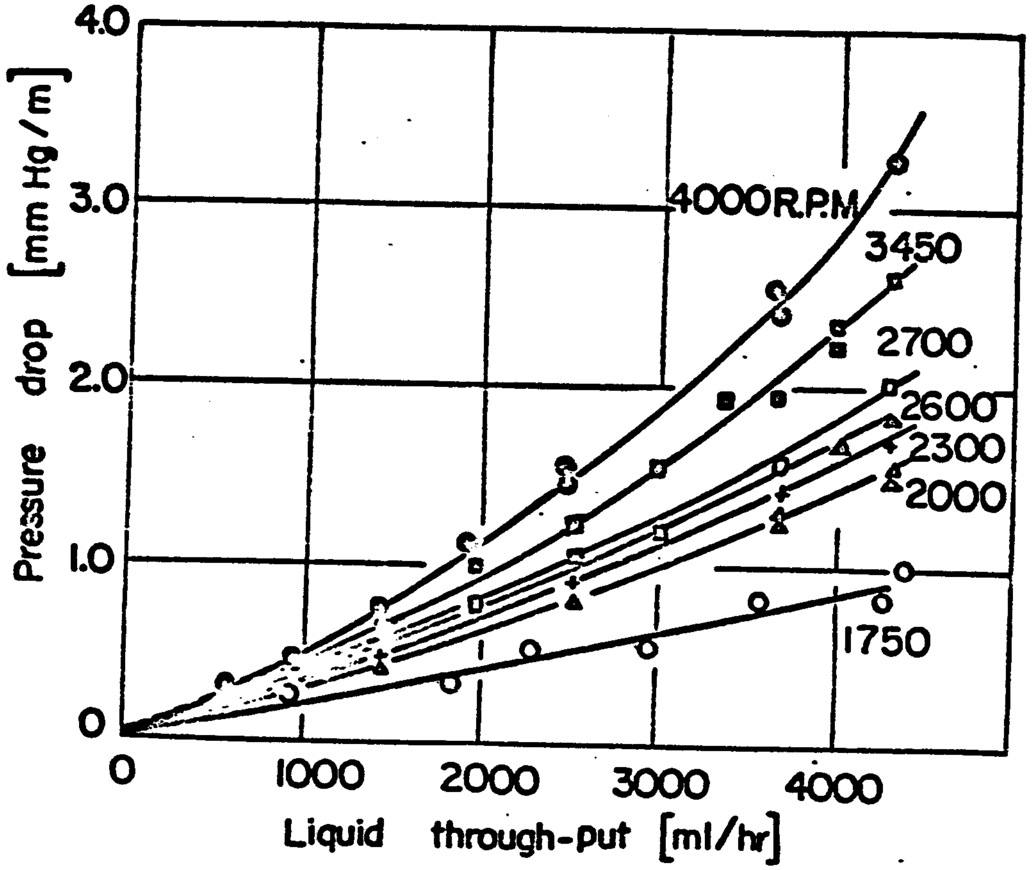


Fig. 5 Pressure drop

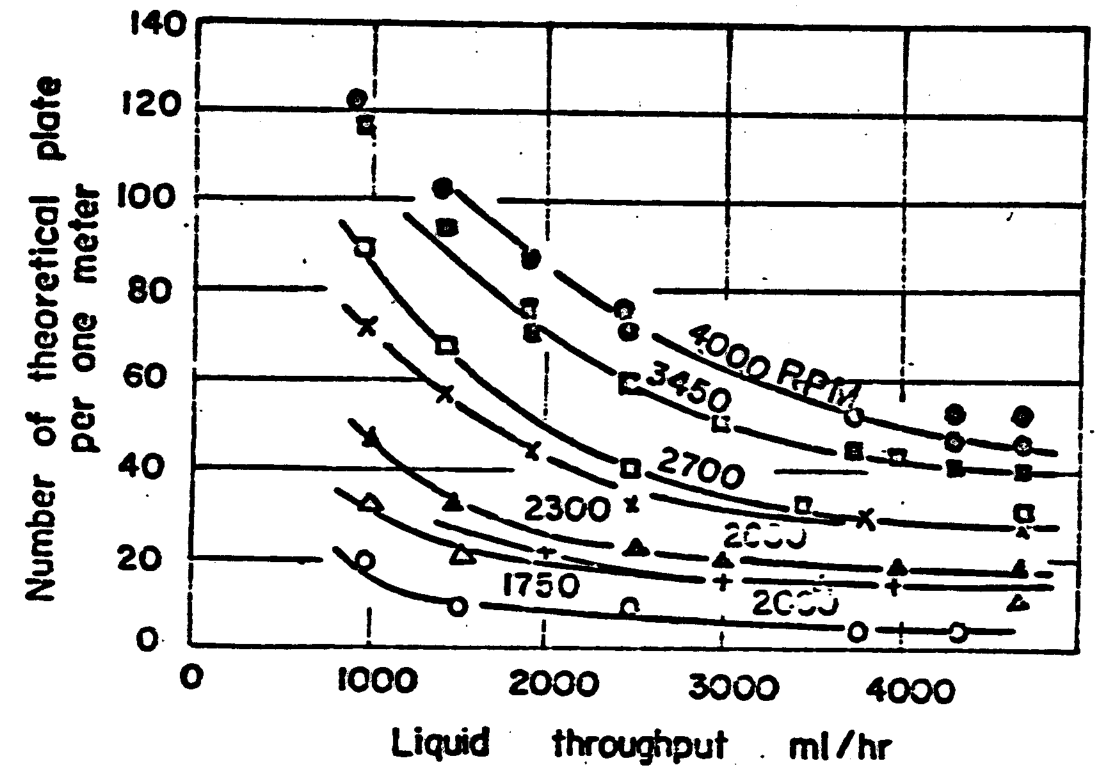


Fig. 6 Number of theoretical plate

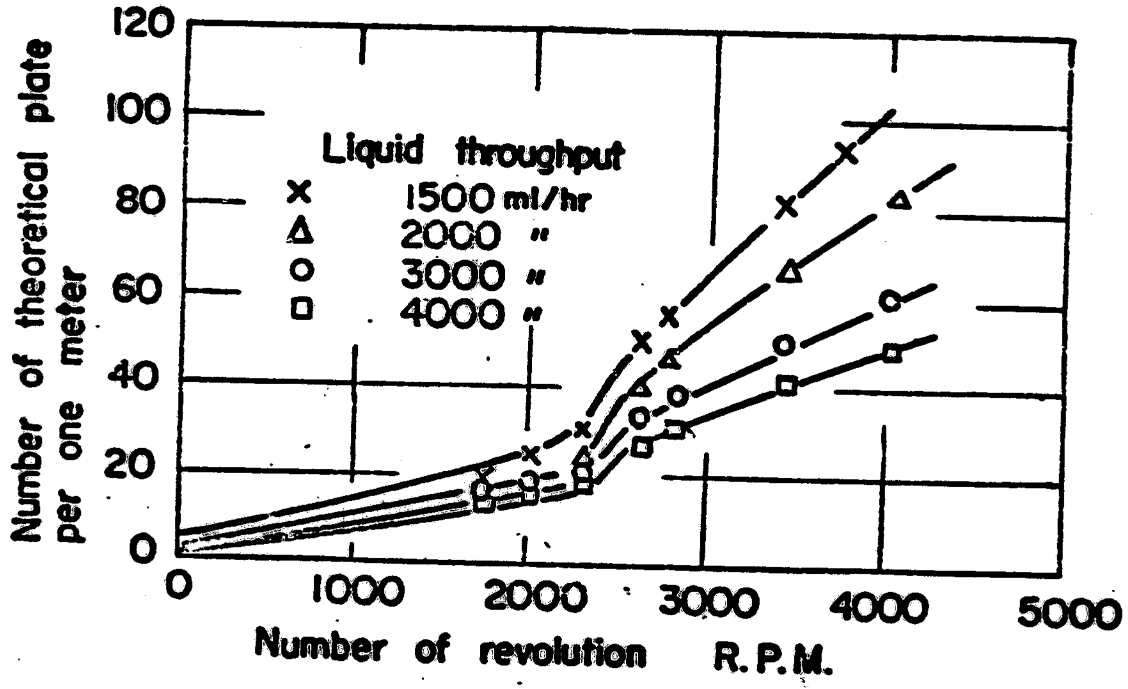


Fig. 7 Number of theoretical plate

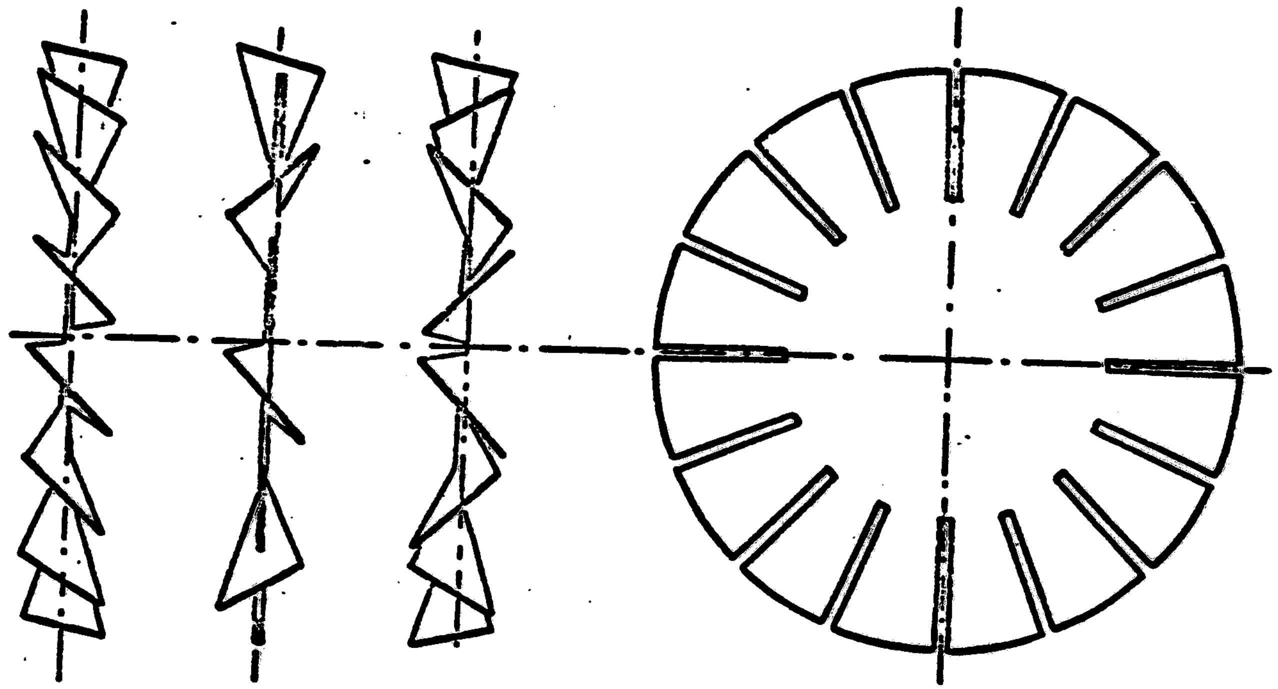
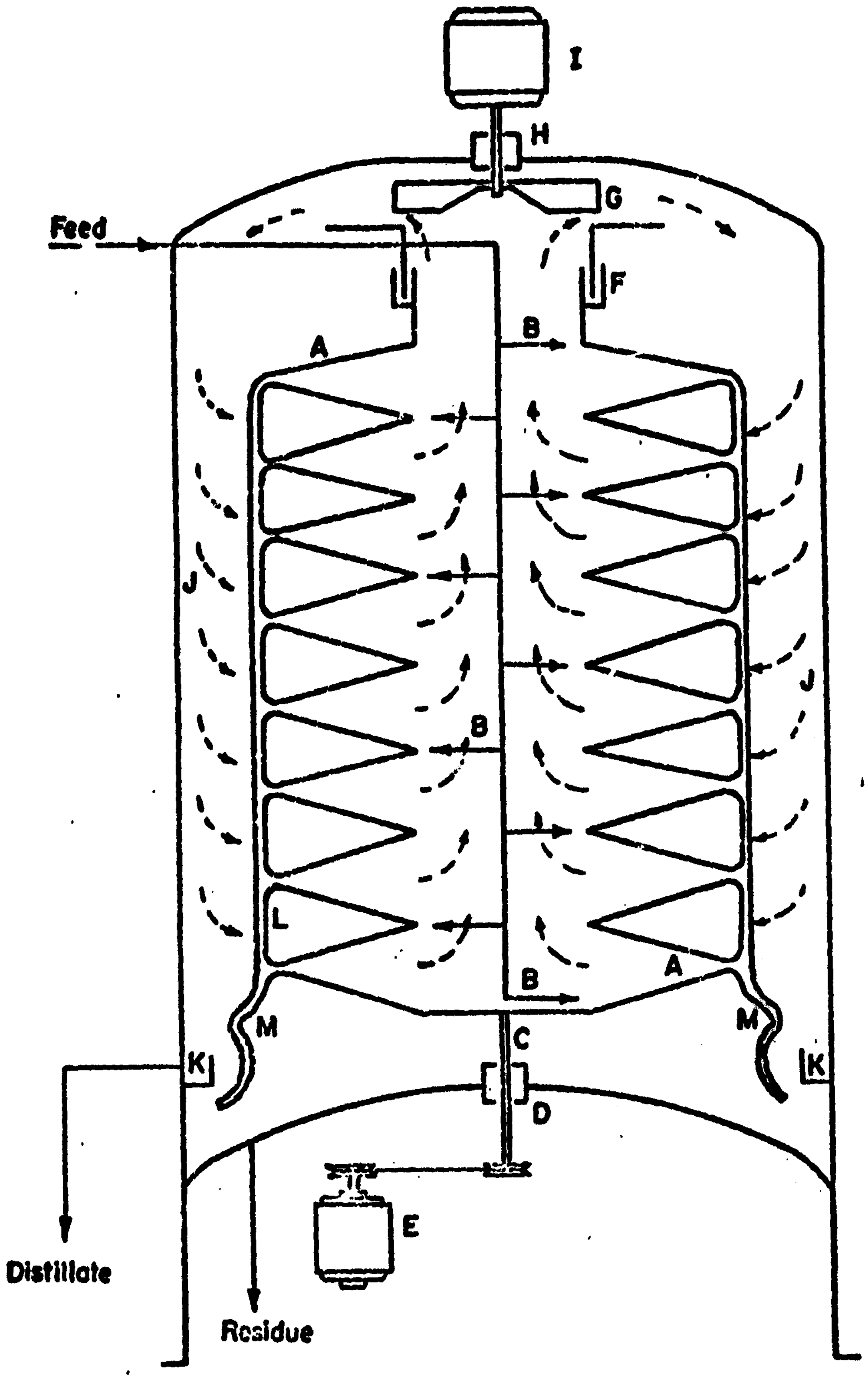


Fig. 8 Structure of impeller



A. Rotors
B. Feed Nozzles
C. Rotor Drive Shaft
D. Rotor Shaft Seal
E. Rotor Drive Motor
F. Rotating Seal
G. Blower
H. Blower Shaft Seal
I. Blower Drive Motor
J. Outer Shell
K. Distillate Trough
L. Downspout
M. Trap

Fig. 9 Diagramatic sketch of Rotary-surface vapor-compression still.

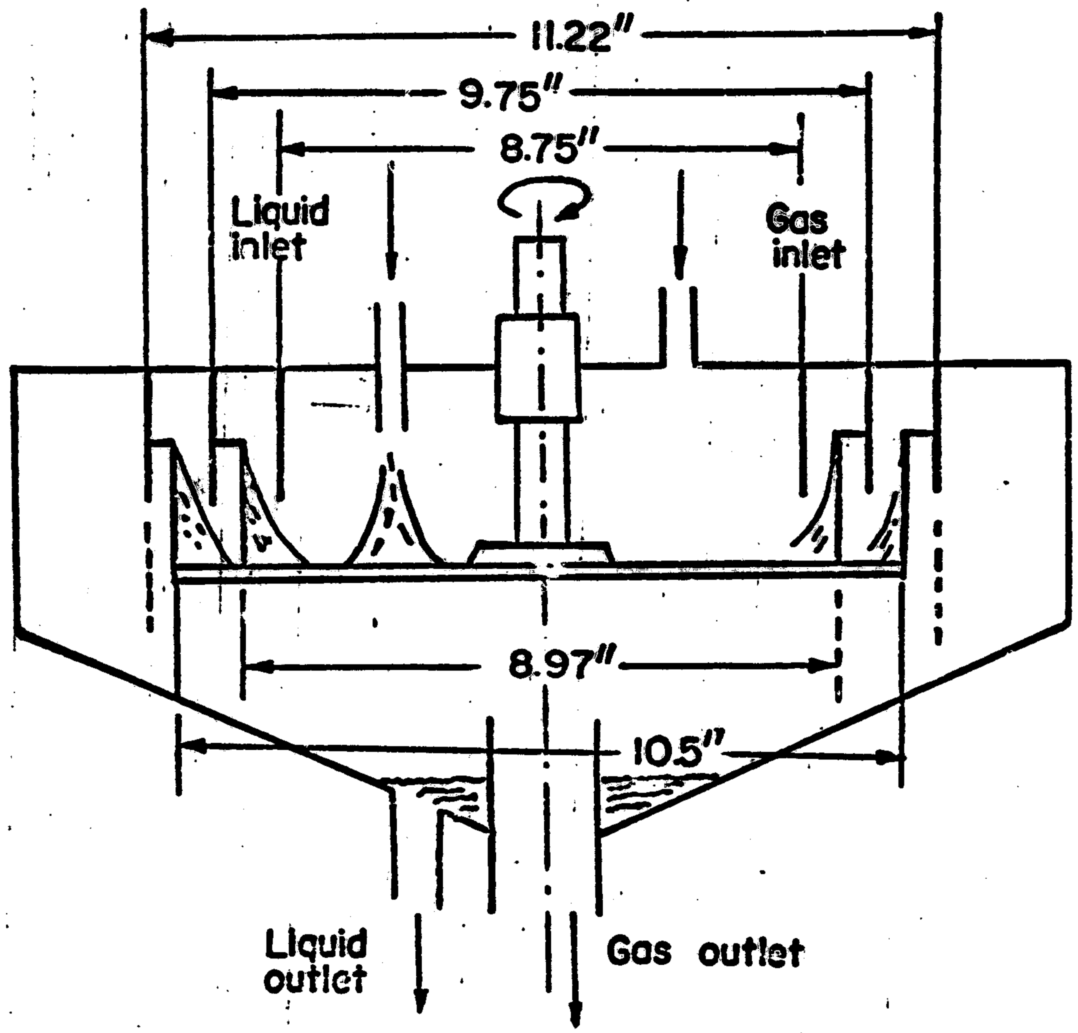


Fig. 10 Diagramatic sketch of Piazza absorber.

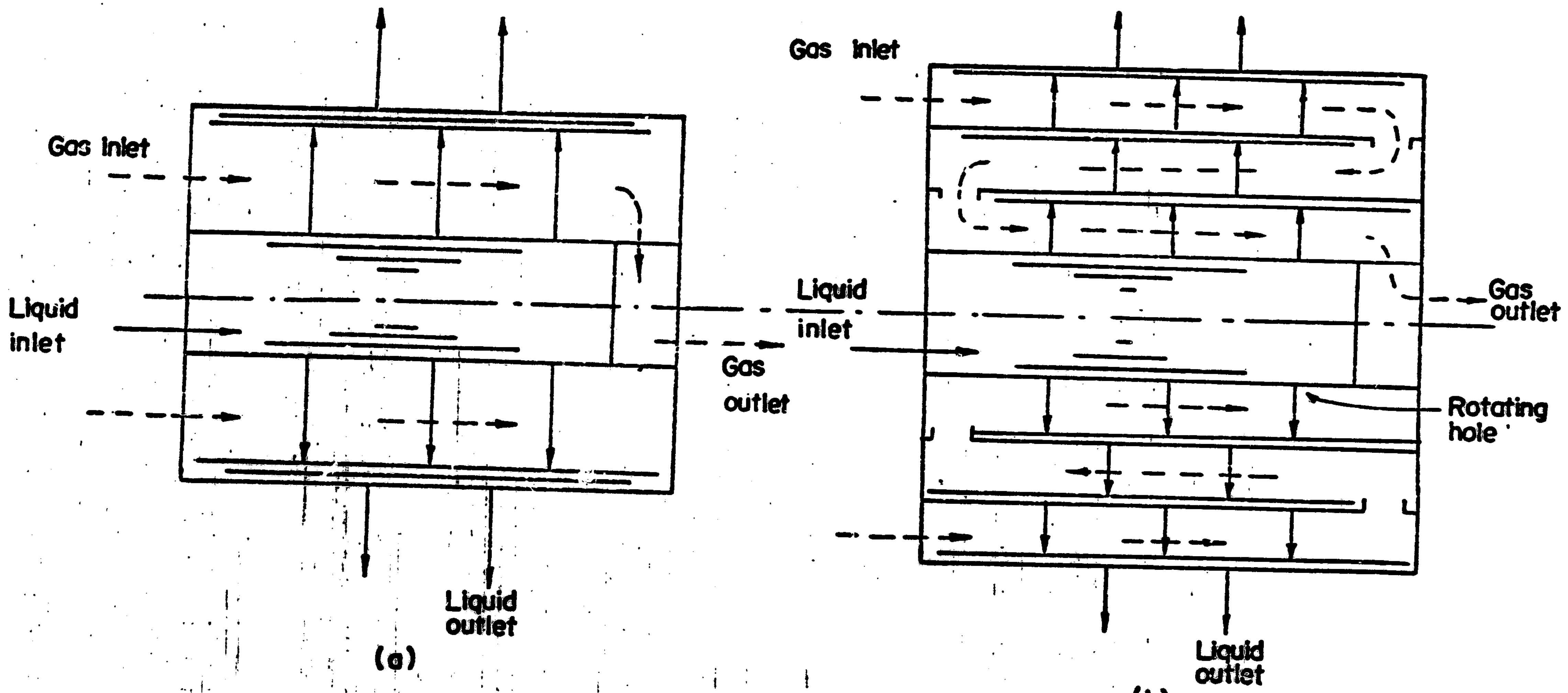


Fig. 11 Diagramatic sketch of centrifugal gas-liquid contactor.

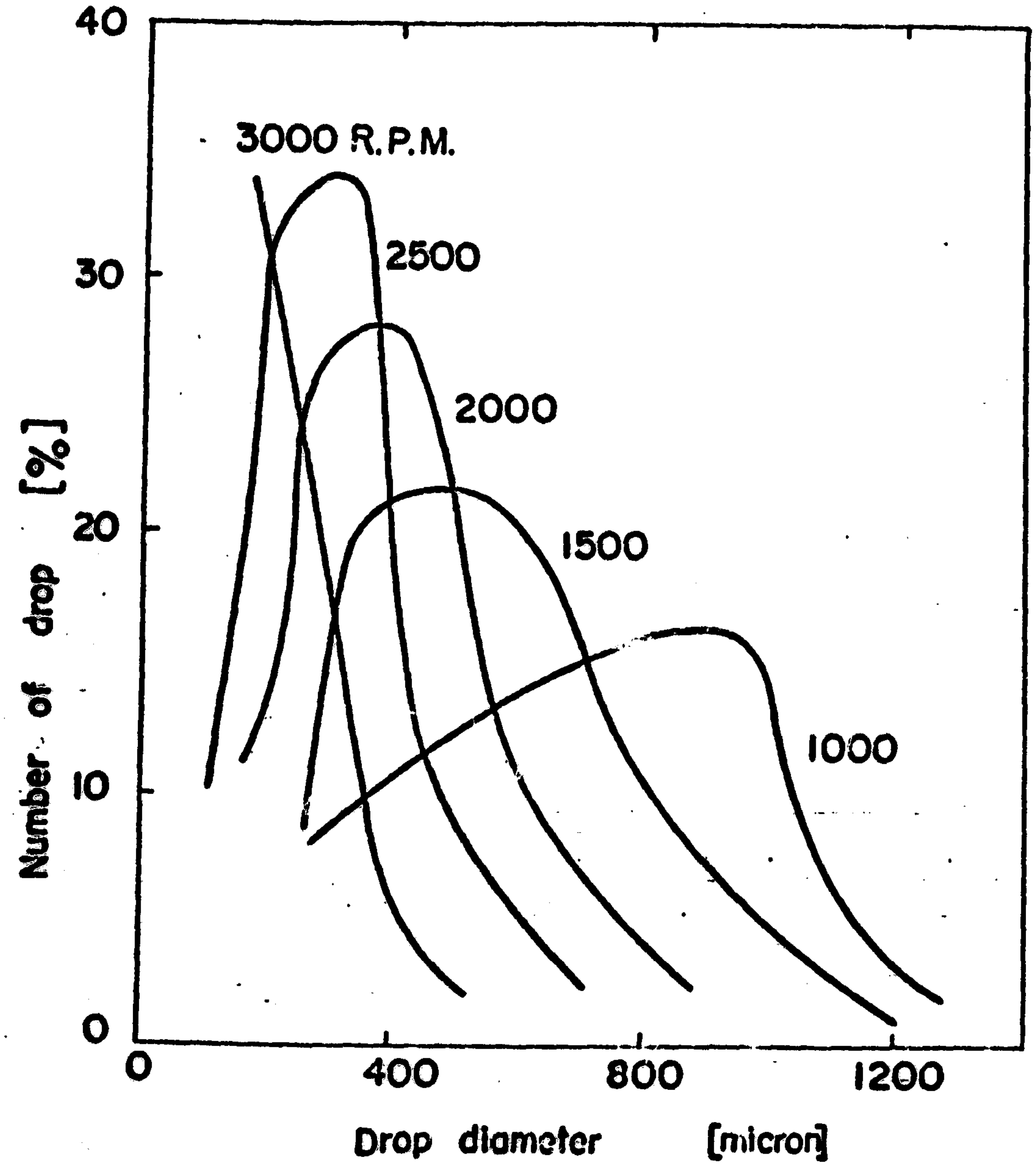


Fig. 12 Distribution of drop diameter.

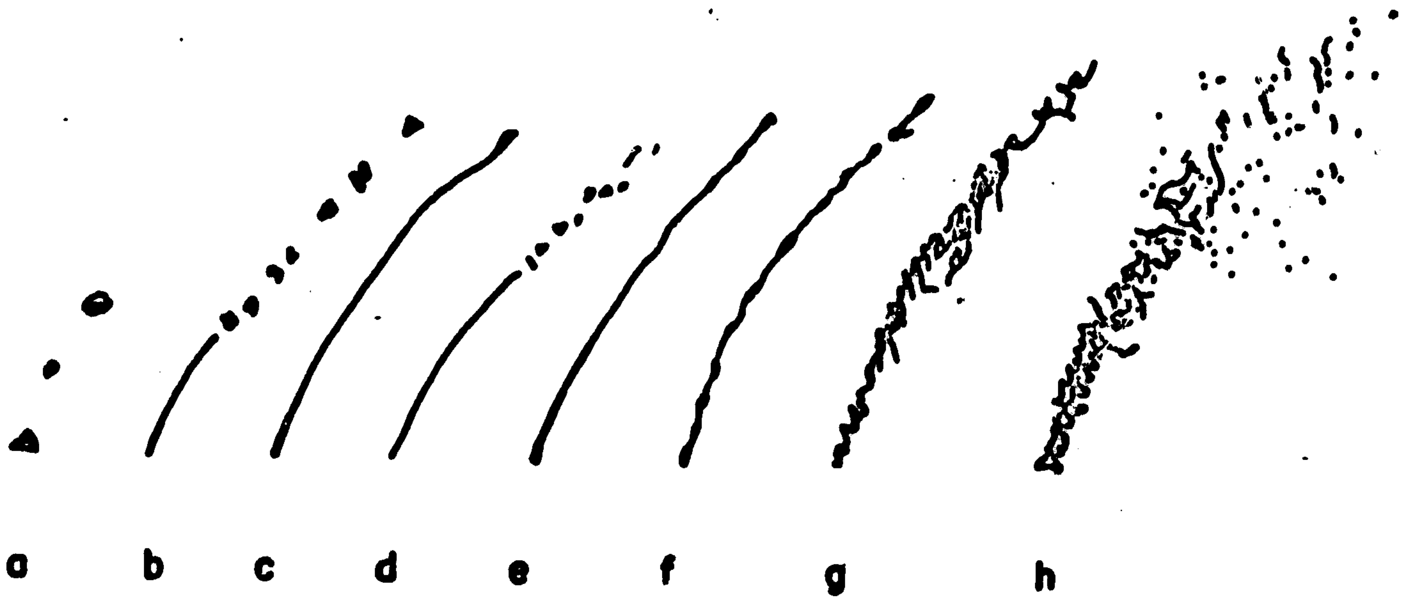


Fig. 13 Flow pattern of rotating liquid jet.

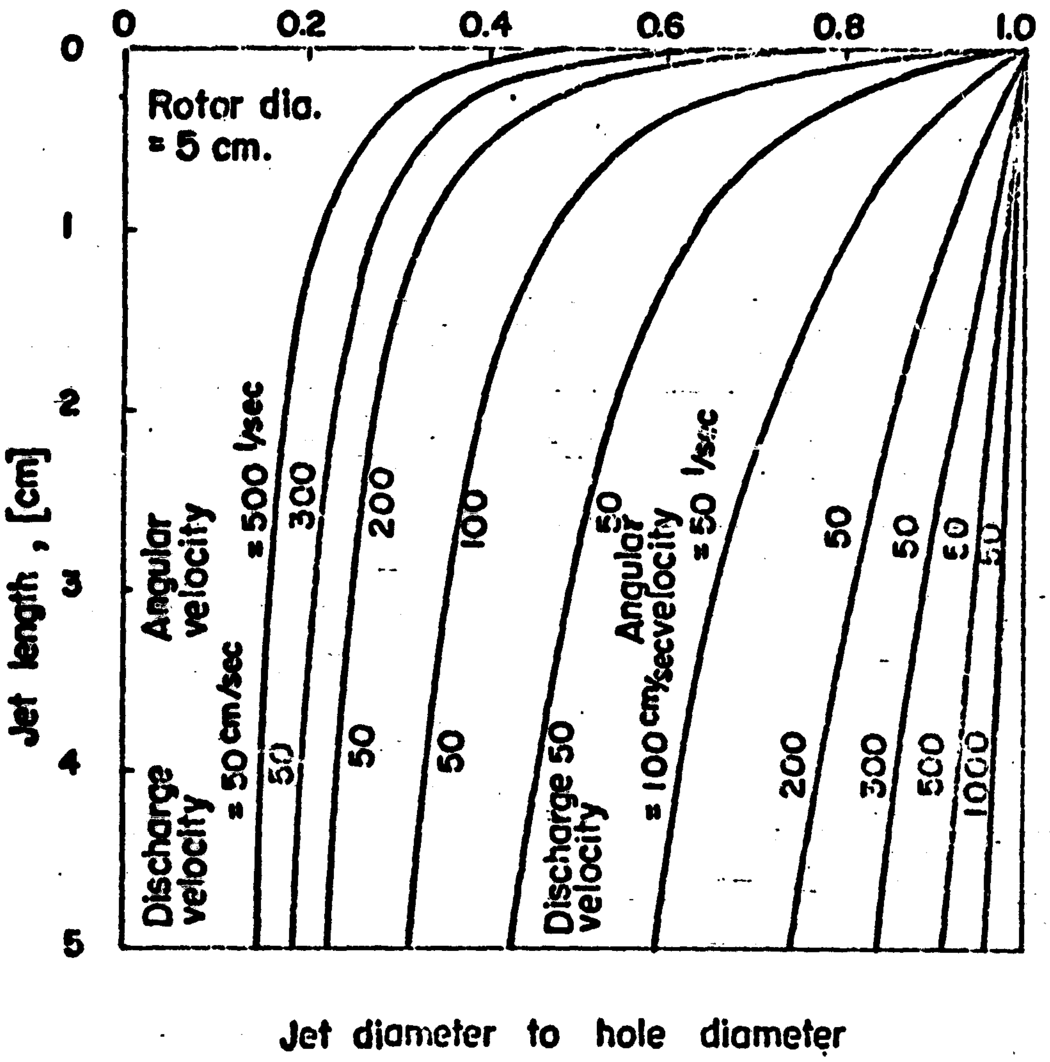


Fig. 14 Relation between jet length and diameter ratio.

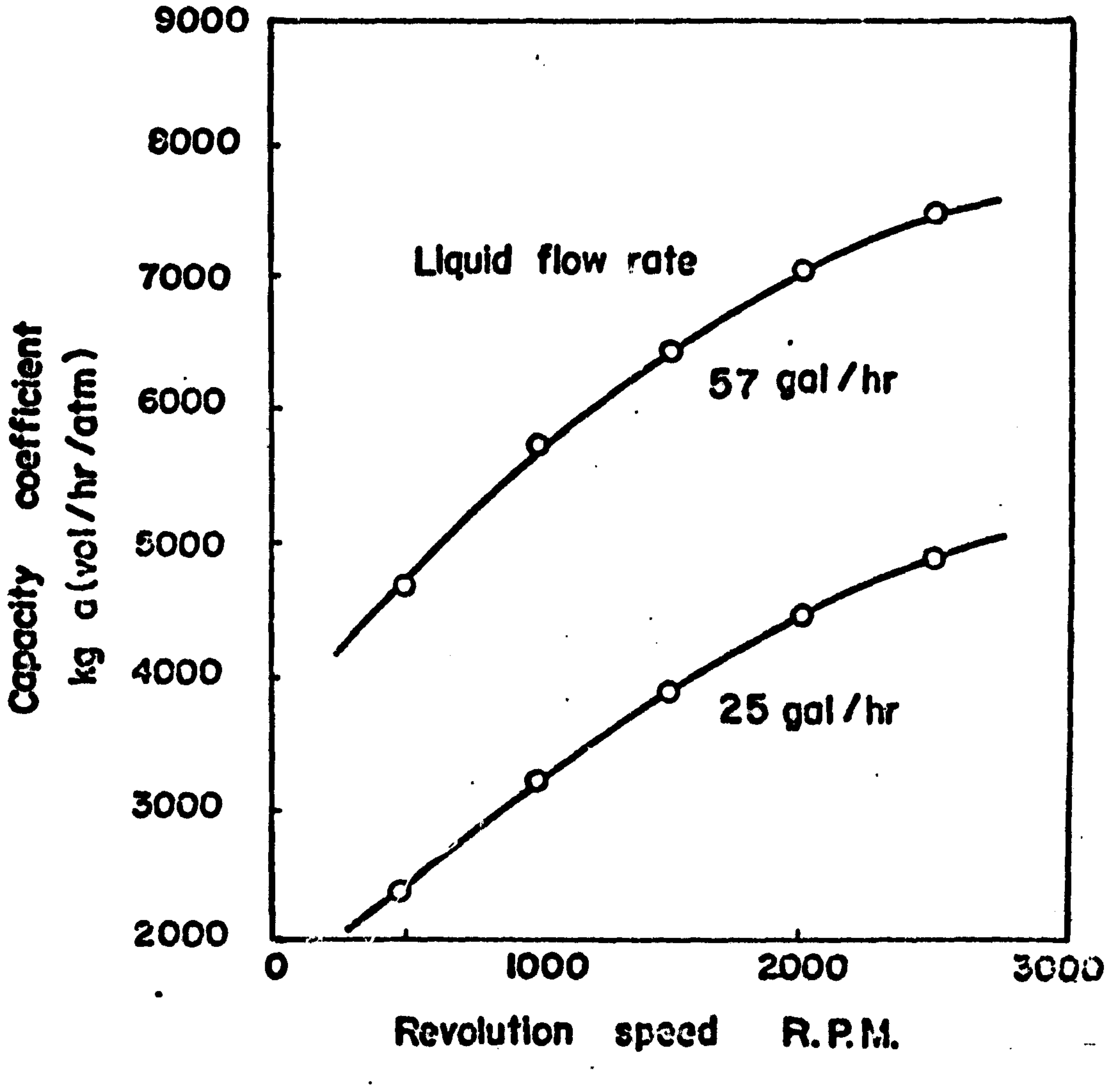


Fig. 15 Effect of revolution speed on mass transfer.

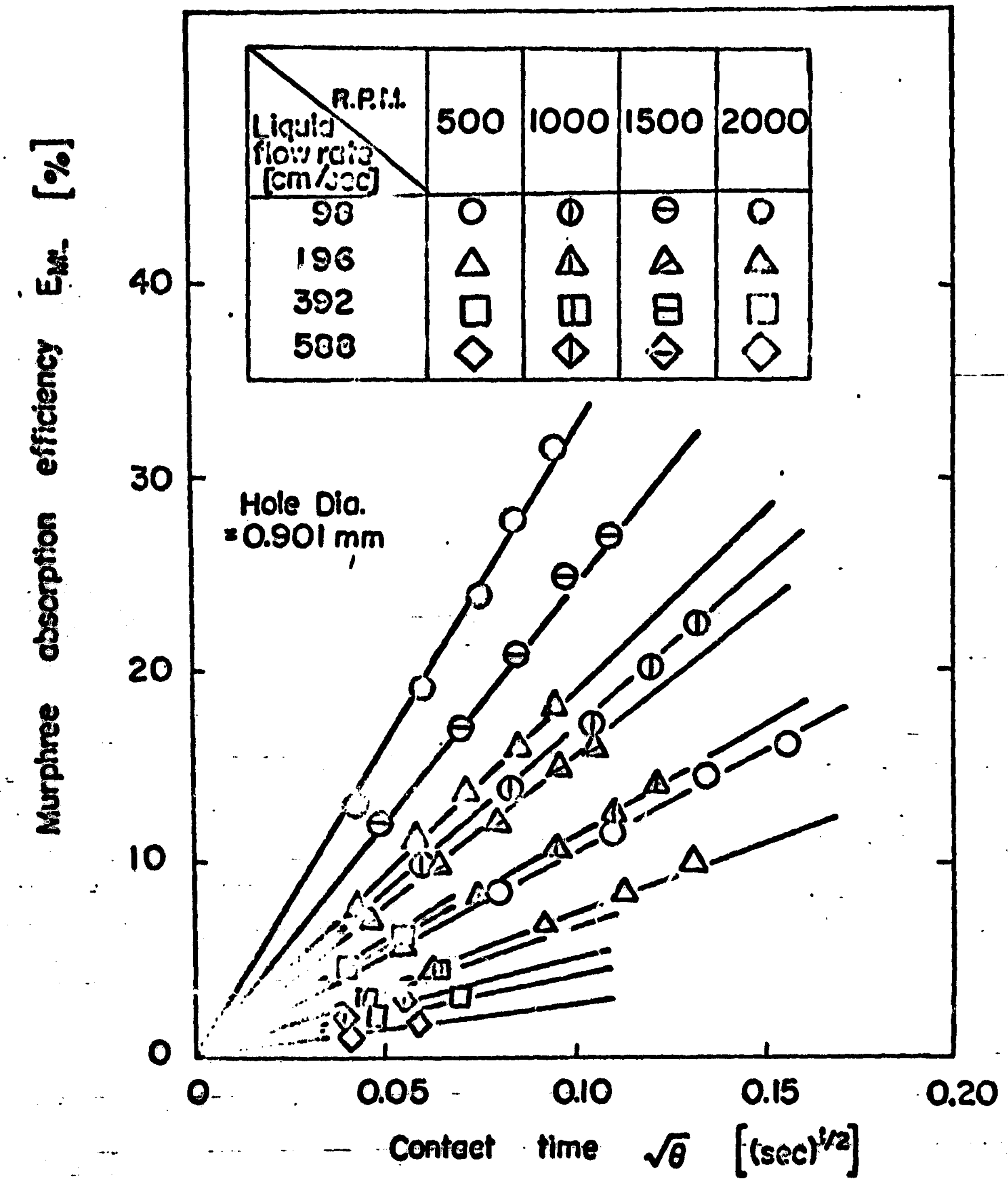


Fig. 16 Relation between contact time $\sqrt{\theta}$ and efficiency of mass transfer E_{ML}.

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13. ABSTRACT

Various types of contactors utilizing centrifugal force (centrifugal contactors) have been used commercially especially in the chemical industry for production of petro chemicals, organics, and pharmaceuticals, for refining petroleum, and for other purposes. The centrifugal contactors have been known to have characteristics of high efficiency, large gas and liquid through-put, small liquid holdup, and short contact time. This research is an evaluation of several types of centrifugal contactors.

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