NBS TECHNICAL NOTE 771

Some Experiments on the Stirring of Viscous Liquids

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Some Experiments on The Stirring of Viscous Liquids

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Some Experiments on the Stirring of Viscous Liquids*

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The stirring actions of several designs of small stirrers were observed and photographed in transparent viscous model liquids. The fluidity of the liquids was comparable to that of a molten borosilicate glass at fining temperatures. The most efficient features of one or more of these stirrers were incorporated into larger model stirrers and observed under actual stirring conditions. As a result of these performance tests, a final design of stirrer was selected and fabricated of platinum-rhodium metal and used in an experimental glass tank. The design of one of the pots in the experimental glass tank was modified to obtain the maximum stirring action with the selected stirrer.

Key words: Agitators; borosilicate glass; glass melt; glass tank; liquids; stirrer; viscosity.

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*This study (see ref. 1) was performed under Contract AF (33-038) 49-4393 sponsored by the Air Material Command, United States Air Force under Project 0902-33-4405 (Continuous Process for Melting Optical Glass) at the National Bureau of Standards in 1951.

I. Introduction

One of the major problems encountered in the production of good quality optical glass in small pots (0.25 to 20 liters) is the proper homogenizing of the melt. To accomplish this, stirrers have to be designed which give an effective stirring or mixing action in the melt. The design of the stirrers and their efficient use in glass melts has, therefore, been the object of numerous investigations.[2,3,4]

In considering the type of stirrer that will produce the desired mixing action, various modifications of basic designs of stirrers can be made.[5,6,7] These changes may be in the size and the shape of the blades, the number of blades employed, and the location and pitch of blades on the shaft of the stirrer. The selection of an efficient stirrer also depends on the size and shape of the pot, the density and viscosity of the glass to be stirred, the depth of glass in the pot, the location of the stirrer in the pot, and the speed of rotation of the stirrer in the glass.[8,9]

In order to produce good quality optical glass precautions must be taken not to contaminate the glass during its melting and fining stages. When glass is melted and stirred in ceramic pots there usually occurs some solution of the refractory which not only changes the composition of the glass but also, invariably, lowers the quality of glass. With the use of platinum-lined pots and platinum stirrers this corrosion i eliminated and the homogeneity of the glass is much improved. In addition, the design and configuration of the platinum stirrer are very important because the stirrer requires rugged construction to overcome the loss in strength of the platinum metal at high temperatures (1100° to 1450°C).

During the years 1946 through 1956, an experimental glass tank furnace was developed at the National Bureau of Standards for the continuous production of optical glass. In order to produce glass of optical quality, the melt was stirred in the fining stage with two propeller-shaped platinum stirrers. Early in the development of this tank it became apparent that the stirring was inadequate for producing striae-free glass. An investigation on the design and the performance of stirring rods was therefore conducted. It was expected that the experience gained from these tests would also be applicable to platinum stirrers used in the making of experimental laboratory melts.

II. Experimental Procedure and Results

All the performance tests in this study were carried out at room temperature. This meant that the properties of the molten glass had to be simulated at room temperature with a transparent viscous liquid or oil. The liquid used in these tests was a standard viscous oil (Oronite Polybutene, No. 24)* which had a viscosity at room temperature

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*Dow Corning 200 fluids with viscosities ranging from .01 to 1000 poises (1 poise = 1 g/cm s) can also be used in such tests as performed here.

equivalent to that of borosilicate glass at 1200°C. The viscosity of this oil at 20°C was 350 poises, at 25°C was 220 poises, and at 40°C was 61 poises. The density of this oil at room temperature was approximately 0.88 g/cm^3. This was not the same as that of molten borosilicate glass which has a value of approximately 2.20 g/cm^3. In order to check what effect the density of the liquid played in the circulation paths from different stirrers, some effort was made to make a liquid whose density and viscosity were the same as molten glass at room temperature. This liquid consisted of a mixture of light corn syrup which had been evaporated down to 70-75% of its original volume and a concentrated solution of zinc bromide. The prepared liquid had a density of 2.08 g/cm^3 at room temperature, but by varying the ratio of corn syrup to zinc bromide, within narrow limits, the viscosity could be changed as well as the density. This liquid was only used to test the final design of the stirrer.

An oil soluble red dye was used as a coloring agent to observe the circulation paths by the striae method during the stirring cycle. Carbon black was also used and proved to be more satisfactory for photographing.

All of the preliminary performance tests were carried out with 1/3 scale model reproduction of the stirrers to be used in the experimental glass tank. A circular container, a 3000 ml beaker, was used to run the tests on each of the small stirrers. The diameter and height of the beaker were 14 and 21 cms, respectively. During the tests the liquid depth in the beaker was kept approximately equal to the diameter of the beaker. The diameter of the beaker was a little over twice the diameter of the stirrer.

The small stirrers, Fig. 1, were constructed of brass and copper with an overall diameter of 6 cm and a 1.25 cm diameter shaft. The blades were soldered to the grooved shaft and were 0.16 to 0.32 cm thick, depending on the design of the stirrer. The basic designs of small stirrers[5-11] used in this study were (a) the propeller, (b) radial propeller, (c) a combination of regular and radial propeller, (d) the helix, and (e) the spiral. Other combinations or modifications of the pitch, shape, and location of the blades of the above types of stirrers were tested. Those that gave the best stirring actions, Figs. 2-12, were made into full scale models to be tried out in the larger pots of the experimental tank.

Four of the large stirrers tried in the tank-size pots are shown in Fig. 13. The single two-bladed propeller which was originally used in the tank is not shown in Fig. 13 (see Figs. 15 and 16).

The shapes of the pots used in the experimental glass tank were reproduced with plaster-of-paris models for the room temperature tests. Each pot had glazed portholes on each side for illumination and observation of the stirring action in the middle and bottom of the pots. The usual technique of creating visible circulation paths with the large stirrers was used; that is, a small quantity of carbon black mixed in with the parent oil was placed into the pot before stirring was started. The different shapes of pots used in these performance tests with the large stirrers are shown in Fig. 14. Shapes 'a' and 'b' were the original container shapes used in the experimental tank and in which the stirring of the glass was carried out before delivery from the tank. After a few tests in container 'b' with the stirrers in the larger end of the container, it was apparent that it was too long for efficient mixing and it was shortened to the length of container 'c'. Of course, the shape of containers shown in 'a' and 'd' of Fig. 14 are ideal shapes for maximum stirring actions.

The performance tests for the large stirrers are shown in Figures 15-19. Figure 20 shows a schematic drawing of the stirring action of the final design of the stirrer, No. 2 in Fig. 13, in container 'd' of Fig. 14. No pictures were taken of stirrers 3 and 4 in Fig. 13, even though performance tests were made, because they were not considered in the final design of the stirrer. The large combined radial and regular propeller stirrer gave the same divided mixing in container 'a' and 'b' as it did in the small beaker. The mixing action in the small end of container 'b' was excellent with this stirrer but, again, to only half of the depth. The bottom half was mixed separately and thoroughly also and with its own circulation paths.

The double three-bladed propeller gave very effective stirring action in container 'c' at low speeds. At higher speeds the mixing became turbulent and because of the concentric shafting and opposite rotations of each set of blades, this stirrer could not be considered, as previously stated, for high temperature application. It was also noticed that when the distance between each set of blades was increased from 2.5 cm to 5 and 7.5 cm the mixing was much more efficient.

III. Summary

The results of these tests with small stirrers show that the triple two-bladed propeller, Fig. 1 - No. 2, gave the fastest mixing. This type of stirrer has considerable lifting action and, consequently, it circulates the liquid in a round container very rapidly. As the liquid is being lifted by the propeller, some of it tumbles off the tips of the blades (see Fig. 20) and not only travels through a minor circulation path but enters the main circulation path. The tumbling action gives a separate circulation path around the tips of the blades on other stirrers, especially the helical and spiral types. As some photographs show, there is a region of little mixing here, and showed that this type of stirrer has no throwing-out action and, therefore, could not be considered as effective stirrers. The helical and spiral type of stirrer appear to have more lifting power than the propeller, but the swirling action of these stirrers tends to increase the region of little mixing.

As a direct result of these performance tests, some conclusions can be made for the stirrers and containers that can be used in the mixing of liquids or molten glass. These are as follow:

1. The modified double two-bladed propeller gives the best mixing because of its lifting and throwing out action.

2. A circular container with a near-hemispherical or 'dished' bottom is the ideal shape for a container.

3. The diameter of the stirrer should be approximately half the diameter of the container. When the stirrer was placed a little off center of the container, better mixing resulted because of the destruction of the symmetry of the circulation paths. The distance off the bottom of the container was approximately half the width of the blade.

4. The speed of rotation of the smaller stirrers could be varied between 100 to 200 RPM depending on the viscosity of the liquid. For the larger stirrers a maximum speed of rotation was 75 RPM.

5. The propeller-type stirrer is rugged in construction and can be fabricated of 90% PT-10% Rh for high temperature use.

The writer wishes to recognize the contributions of C. A. Faick (deceased) who was project leader at the time that this work was performed and to Max Kahn as a co-worker on the project.

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Figure 1. Small Stirrers.

1. Single two-bladed propeller - pitch of blades 15°. This design of stirrer was in use in small melts as well as in the experimental tank in the larger size.

2. Triple two-bladed propeller - pitch of blades 15° with each pair of blades 60° apart around the shaft and 3.75 cm along the shaft.

3. Radial propeller - pitch of horizontal blade 15° and vertical vanes at each end 3.75 cm long.

4. Combined radial and regular propeller - top and bottom pair of blades at a 15° pitch but opposite to each other. Vertical blades were still 3.75 cm long. This design of stirrer was also being used in small melts because of its rugged construction.

5. Helical stirrer with three turns and a pitch of 2.5 cm.

6. Helical stirrer with two turns and a pitch of 3.75 cm.

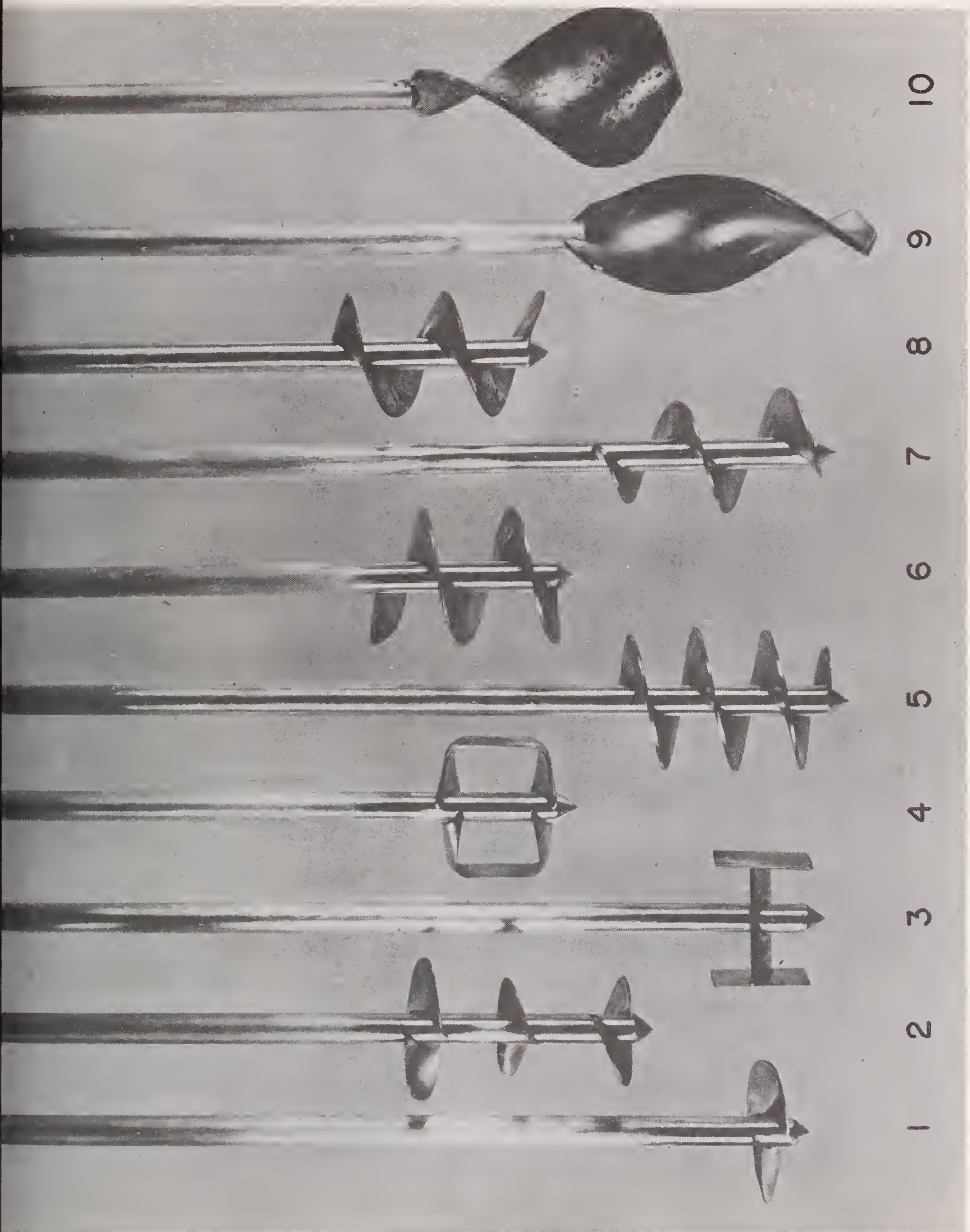
7. Helical stirrer with two turns and a pitch of 3.75 cm and tapered blade from bottom to top.

8. Helical stirrer with two turns and a pitch of 3.75 cm. The blade was tilted downward 15° so that it was cone-shaped.

9. Spiral stirrer with a 180° twist in the blade. The blade was 12 cm long.

10. Spiral stirrer with a 180° twist in the blade. The blade was tapered from bottom to top and 11.5 cm long.

Shaft diameter - 1.25 cm
Diameter of stirrer - 3.75 cm


1
2
3
4
5
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7
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9
10

Figure 2. Two-bladed Propeller.

This group of photographs* shows the conventional stirring action of a propeller for clockwise rotation. At the end of one minute in photograph 'b' the dye is in the main circulation path along the side of the container and has formed an envelope two-thirds of the way down the outside path. After two minutes of stirring as shown in 'c', the dye has reached the bottom of the container, has been lifted through the middle of the stirrer, and is spreading out on the top surface of the oil ready for the second round. This picture clearly shows the lift of the propeller with each revolution because the successive layers of dye may be seen above the blades and also the upward movement of the dye in the cyclonic cone below the blades. The pushing forward or the propelling action of the stirrer was also noticeable in this photograph because the cone below the blades waved back and forth as the stirrer rotated. At the end of six minutes photograph 'd' shows the successive revolutions of the propeller as streaks of dye throughout the container of oil and with each journey through the circulation path the dye gradually disperses. After twenty-six minutes of stirring, the dye is completely dispersed as shown in photograph 'e'. Photograph 'e' shows the stirrer rotated 90° more than shown in photographs a - d.

Speed of rotation - 120 RPM
Container - beaker 14 cm diameter, 21 cm high
Depth of oil - approximately 15 cm

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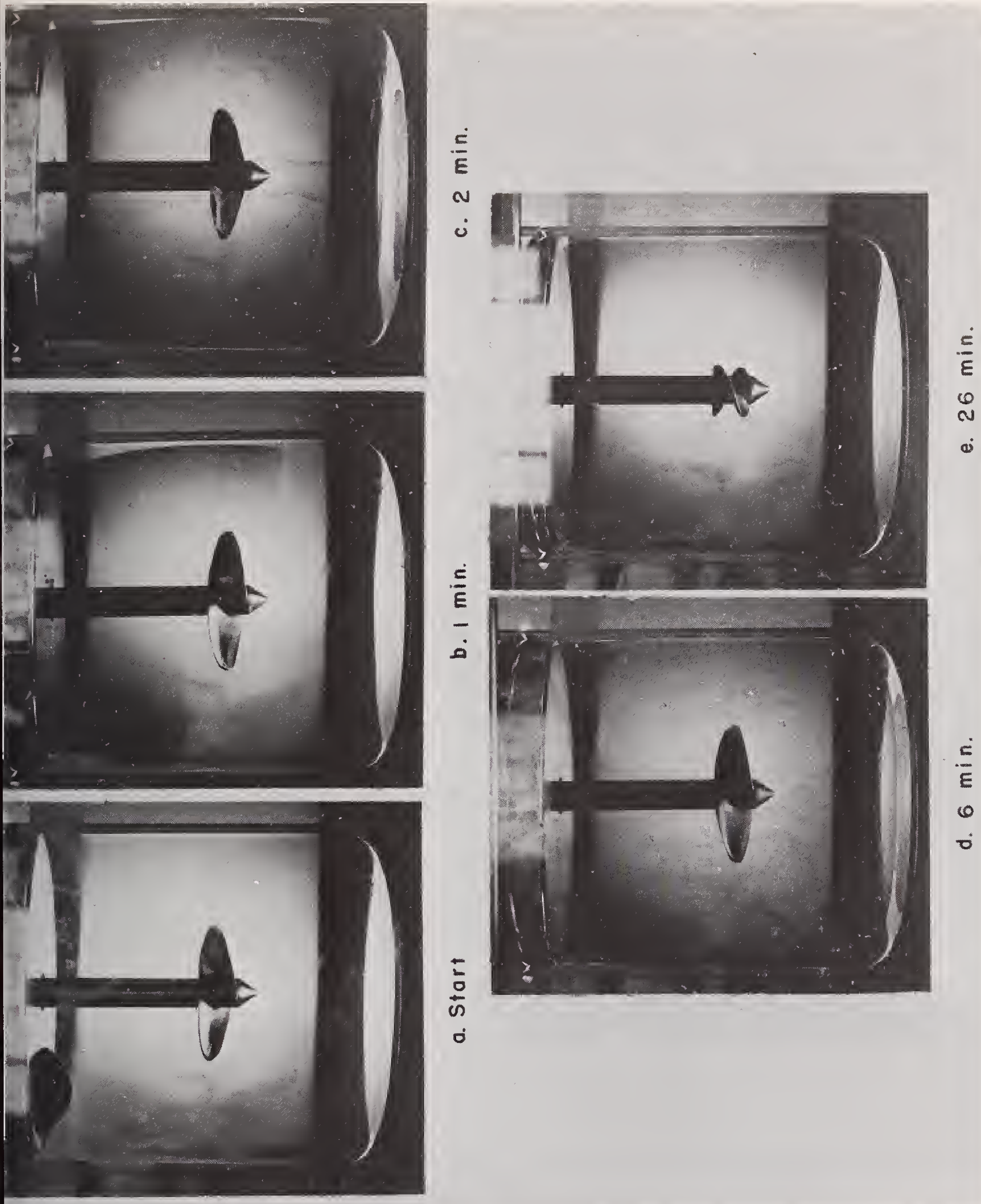
*All photographs in this figure as well as those that follow were taken with the stirrer stopped. The viscosity of the oil was high enough to prevent the circulation patterns from dispersing in the time required for the pictures to be taken.



a. Start

b. I min.

c. 2 min.

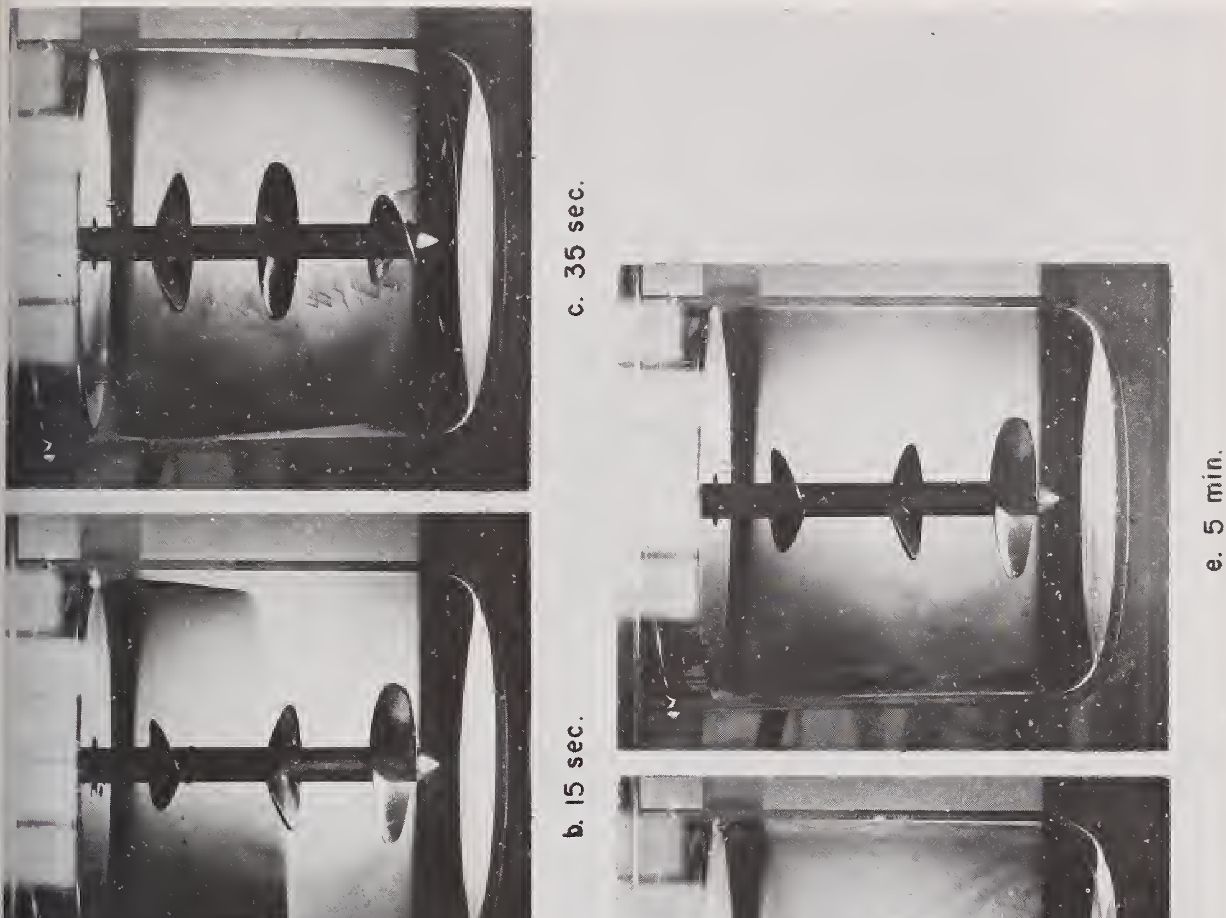
d. 6 min.

e. 26 min.

Figure 3. Triple Two-bladed Propeller.

This group of photographs shows the stirring action of the triple two-bladed propeller to be the same as that of the single two-bladed propeller but completely disperses the dye in one-fifth the time. This stirrer was placed about 2.5 cm off the bottom of the container, and it is believed that this position gave a more vigorous stirring action.

Speed of rotation - 120 RPM
Container - beaker 14 cm diameter, 21 cm high
Depth of oil - approximately 15 cm

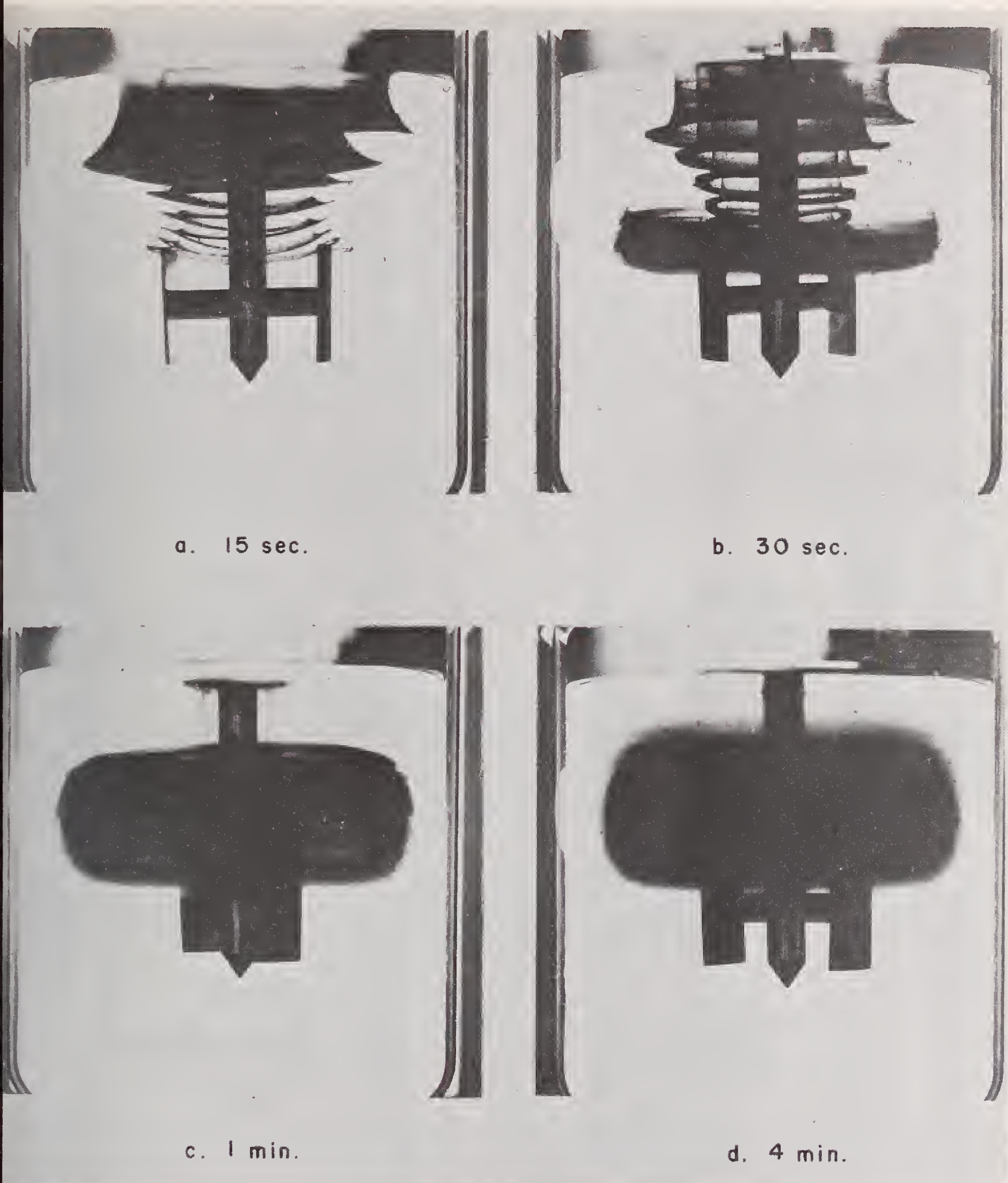


a. Start
b. 15 sec.
c. 35 sec.
d. 55 sec.
e. 5 min.

Figure 4. Radial Propeller.

This set of photographs shows the top circulation path of a radial propeller. The carbon black used here photographs much better than the dye. Adding the vanes to a modified propeller blade resulted into two circulation paths for this stirrer. The liquid which is lifted by the horizontal blade from the bottom of the container is caught in the circulation path set up by the side vanes and thrown out to the sides of the container and returns to the bottom. As the liquid is thrown out to the sides of the container, the liquid to replace it is not only drawn from the bottom of the container but also drawn down from the top along the shaft. In photographs 'b' and 'c' after 30 seconds and one minute, respectively, of stirring this action is clearly shown. After four minutes of stirring, photograph 'd', the maximum mixing with this type of stirrer has been reached. Longer periods of stirring and different positions of the stirrer in the liquid were tried, but no radical changes occurred in the mixing.

Speed of rotation - 120 RPM
Container - beaker 14 cm diameter, 21 cm high
Depth of oil - approximately 15 cm



a. 15 sec.

b. 30 sec.

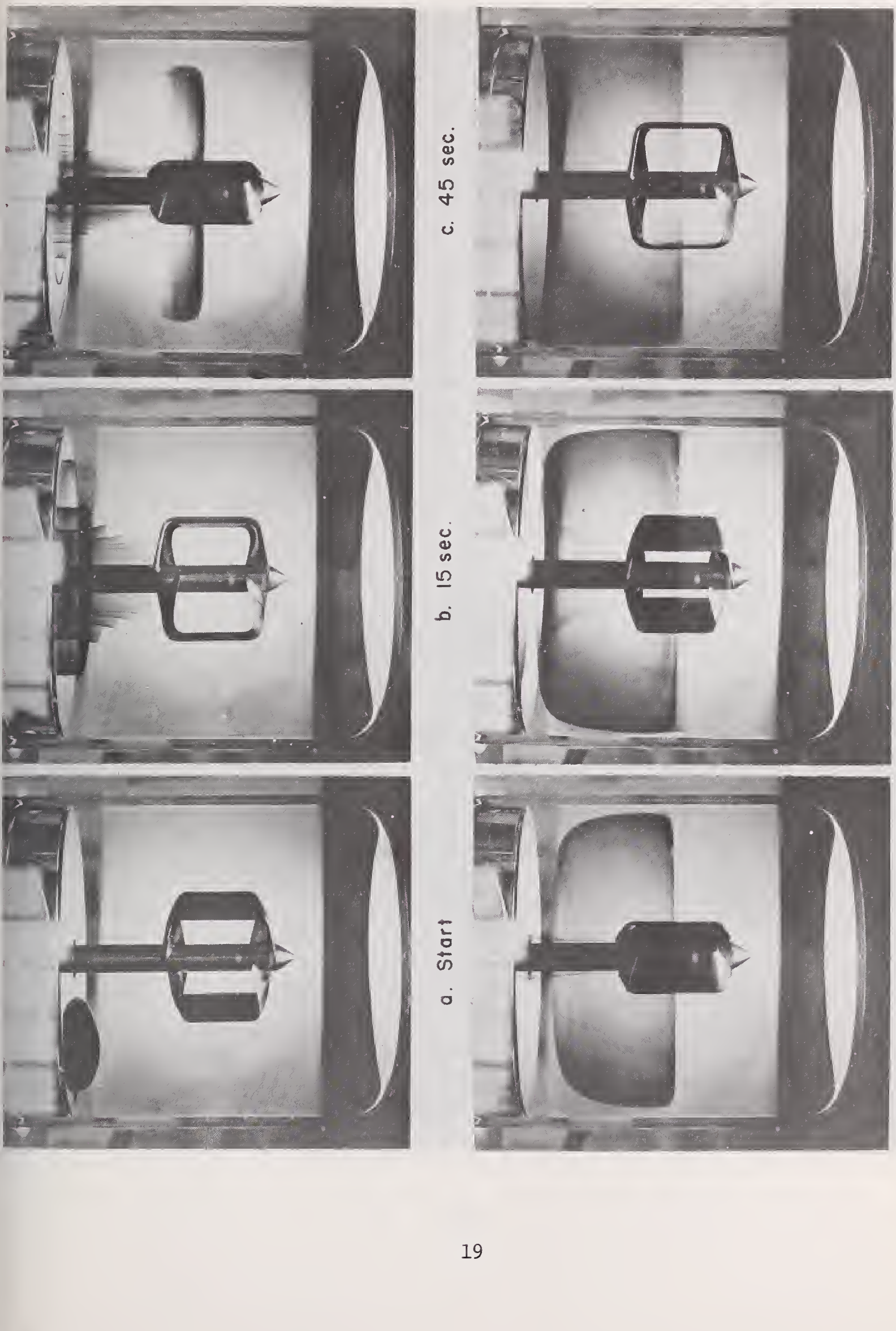
c. 1 min.

d. 4 min.

Figure 5. Combined Radial and Regular Propeller.

This stirrer gives the two main circulation paths as discussed under Fig. 4 but to a more marked degree. It gives a perfect divided field of mixing after 28 minutes. Photograph 'f' clearly shows the top half with the dye dispersed and the lower half without any dye. The bottom half gave the identical result except that the circulation path was opposite to that of the top. This was tested when a quantity of dye was allowed to sink to the bottom and the stirring started. When the stirrer was either raised or lowered, the line between the two fields of mixing followed the change in position of the stirrer.

Speed of rotation - 120 RPM
Container - beaker 14 cm diameter, 21 cm high
Depth of oil - approximately 15 cm



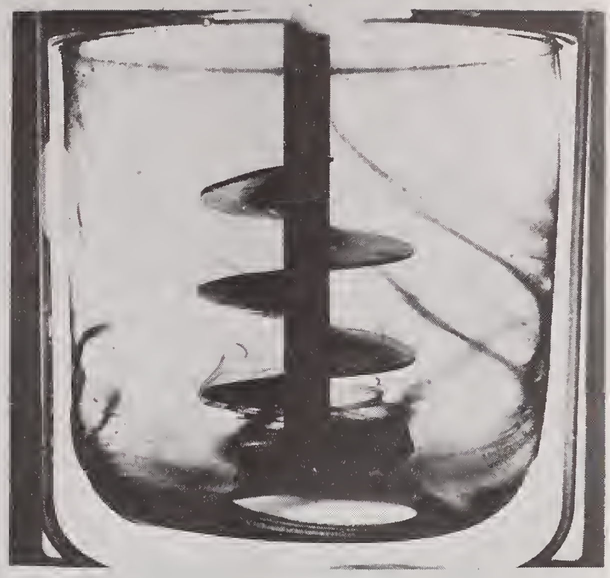
a. Start
b. 15 sec.
c. 45 sec.
d. 1 min. 30 sec.
e. 2 min. 45 sec.
f. 28 min.

Figure 6. Helical Stirrer - Three Turns.

These three photographs show the typical circulation path of the helical stirrer in the first minute. As shown, the carbon black follows the movement of the liquid in the outside path and up through the middle of the stirrer.

Speed of rotation - 120 RPM
Container - beaker 14 cm diameter, 21 cm high
Depth of oil - approximately 15 cm

a. 15 sec.



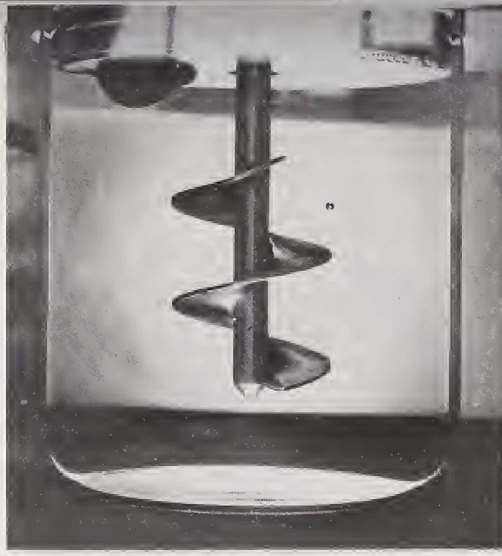
b. 30 sec.

c. 1 min.

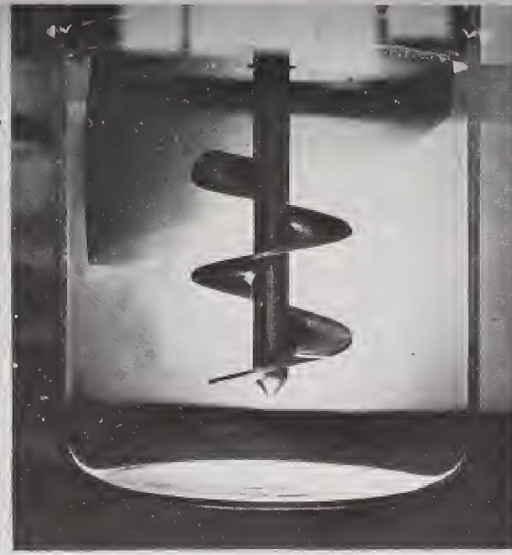
Figure 7. Helical Stirrer - Two Turns.

The straight helical stirrer with two complete turns gave essentially the same results as the helical stirrer with three turns, except that it took a little longer to give the same amount of stirring.

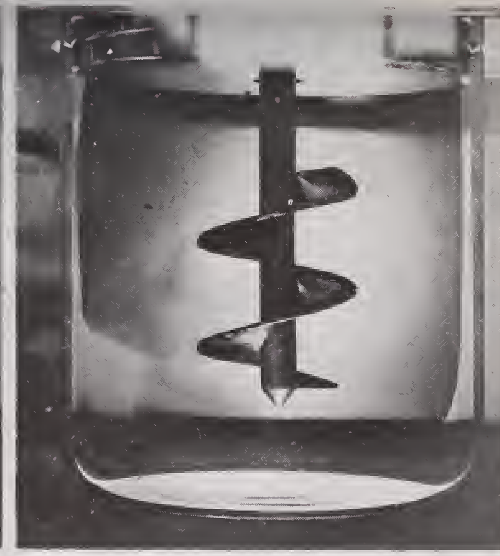
Speed of rotation - 120 RPM
Container - beaker 14 cm diameter, 21 cm high
Depth of oil - approximately 15 cm



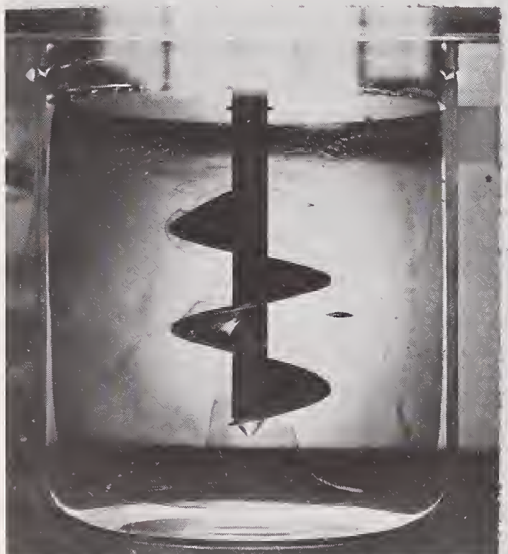
a. Start



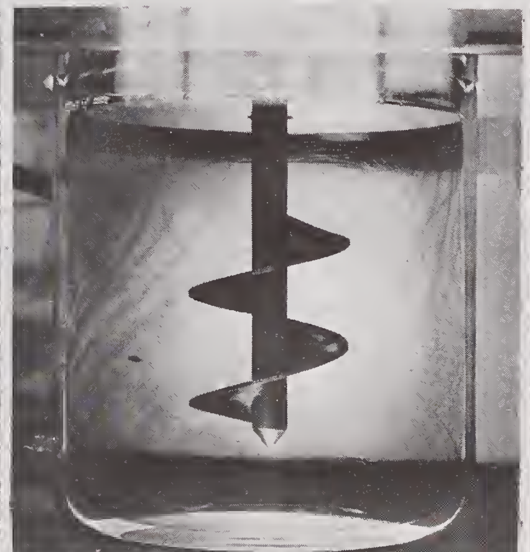
b. 20 sec.



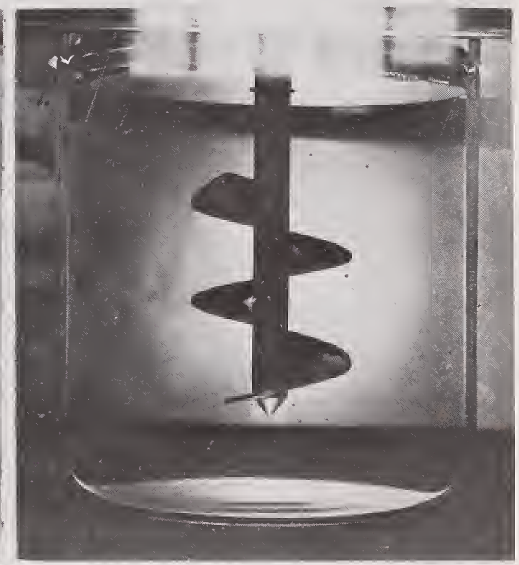
c. 40 sec.



d. 1 min. 15 sec.



e. 2 min. 15 sec.



f. 13 min. 25 sec.

Figure 8. Tapered Helical Stirrer - Two Turns.

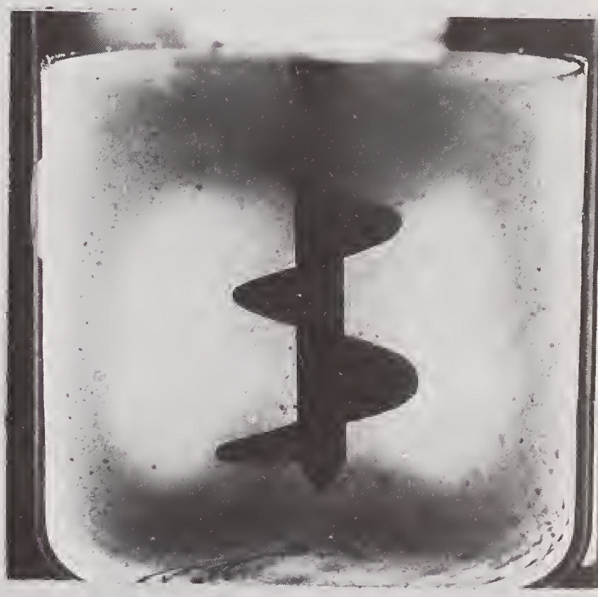
To increase the tumbling action of this type of stirrer, a tapered blade (i.e. width of blade narrows from bottom to top) was used. The tumbling action is clearly evident in photograph 'c' in which the carbon black seems to fall off in successive revolutions of the stirrer. The last photograph in this set clearly shows a region of light or no mixing around the stirrer. This concentric 'doughnut' or region of no mixing was characteristic of this type of stirrer.

Speed of rotation - 120 RPM
Container - beaker 14 cm diameter, 21 cm high
Depth of oil - approximately 15 cm

a. 15 sec.

b. 30 sec.

c. 1 min.



d. 4 min.

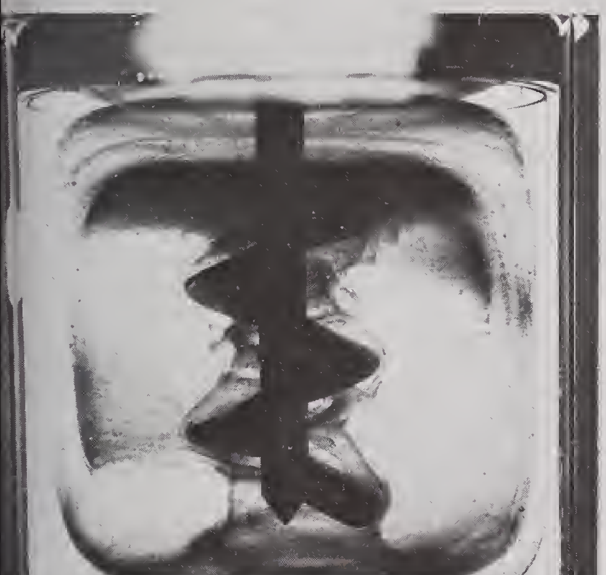
Figure 9. Cone-shaped Helical Stirrer - Two Turns.

To increase the tumbling action still further, a cone-shaped helical blade stirrer was used. After four minutes of stirring, the carbon black was well dispersed in the oil with the exception of the light region which still remained. This stirrer gave the same results in less time than the other types of helical stirrers and gave evidence that the downward slope of the blade increased the tumbling action which in turn increased the mixing.

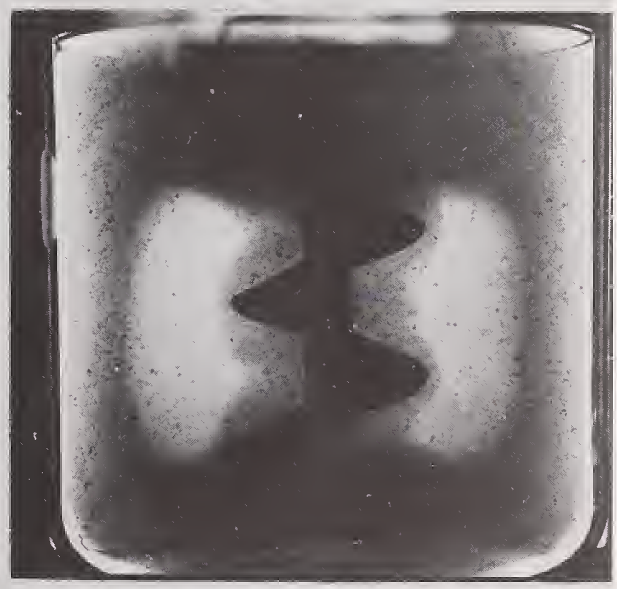
Speed of rotation - 120 RPM
Container - beaker 14 cm diameter, 21 cm high
Depth of oil - approximately 15 cm

a. 15 sec.

b. 30 sec.



c. 1 min.

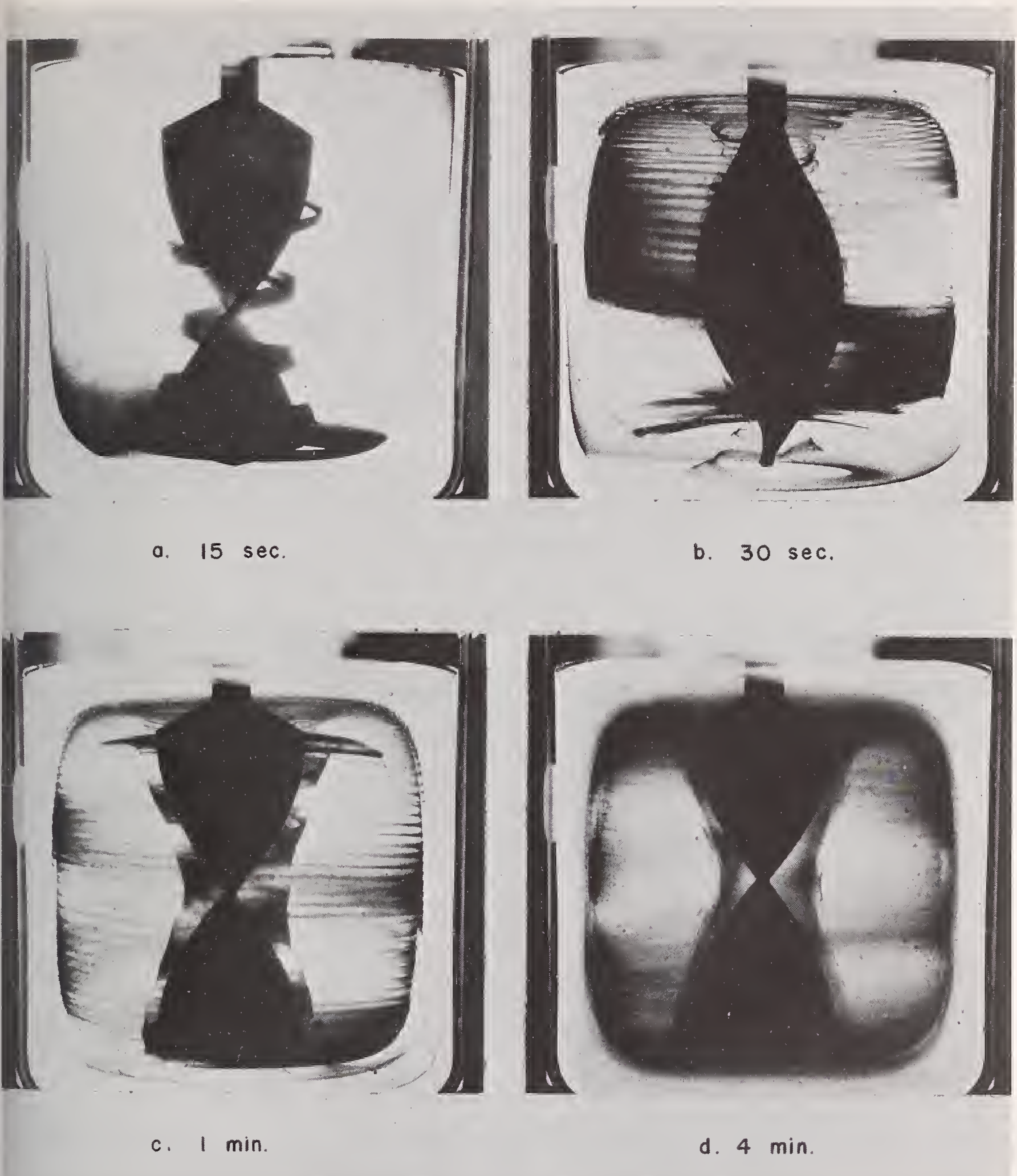


d. 4 min.

Figure 10. Spiral Stirrer - 180° Twist.

A particular pattern of mixing is set up by this stirrer, as shown in photograph 'c' after one minute of stirring. Photograph 'd' shows the maximum mixing that this type of stirrer can accomplish. After fifteen minutes of stirring, there was no change in the mixing pattern. The carbon black never reaches the top, the outer edges, or the bottom of the main body of oil. The light region of little mixing, the concentric 'doughnut', around the edge of the blade is very pronounced with this type of stirrer.

Speed of rotation - 120 RPM
Container - beaker 14 cm diameter, 21 cm high
Depth of oil - approximately 15 cm



a. 15 sec.

b. 30 sec.

c. 1 min.

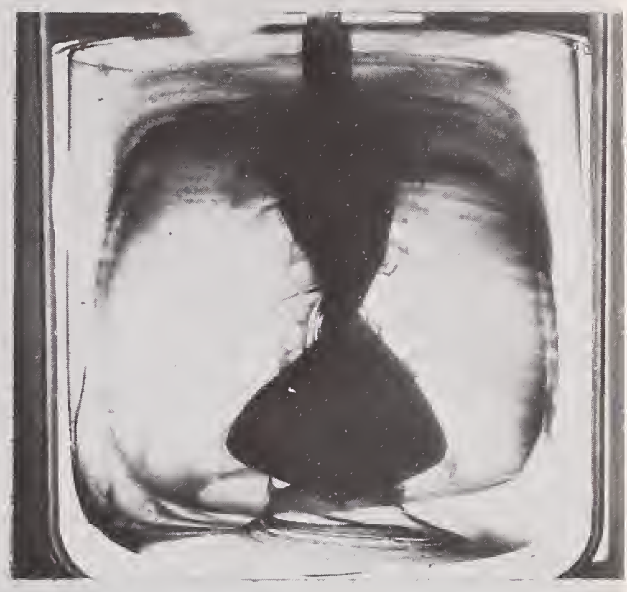
d. 4 min.

Figure 11. Tapered Spiral Stirrer - 180° Twist.

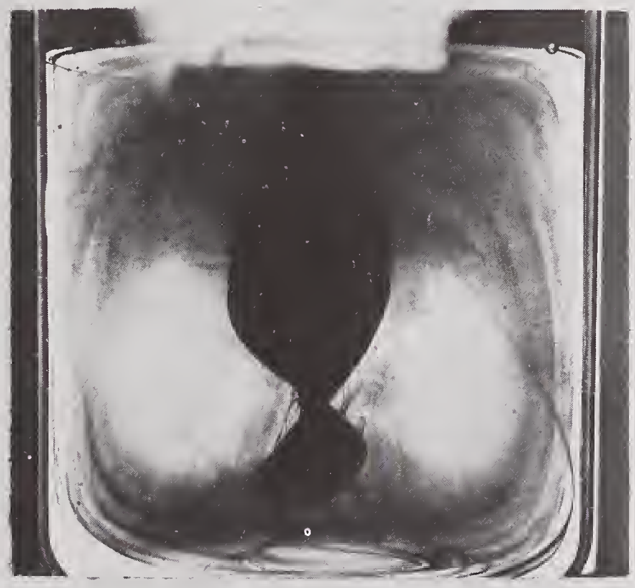
This stirrer has a blade which is wide at the bottom and decreases in width towards the top. As the photographs show, this stirrer does much better than the previous stirrer, Figure 10, in that it disperses the carbon black to the walls of the container and also to the top and bottom surfaces. After fifteen minutes of stirring, this stirrer also gave the light region or region of little mixing at the edge of the blade, but lower down, at the widest section of the blade. This was evidently caused by the increase in tumbling action along the upper portion of the stirrer.

Speed of rotation - 120 RPM
Container - beaker 14 cm diameter, 21 cm high
Depth of oil - approximately 15 cm

a. 15 sec.



b. 30 sec.

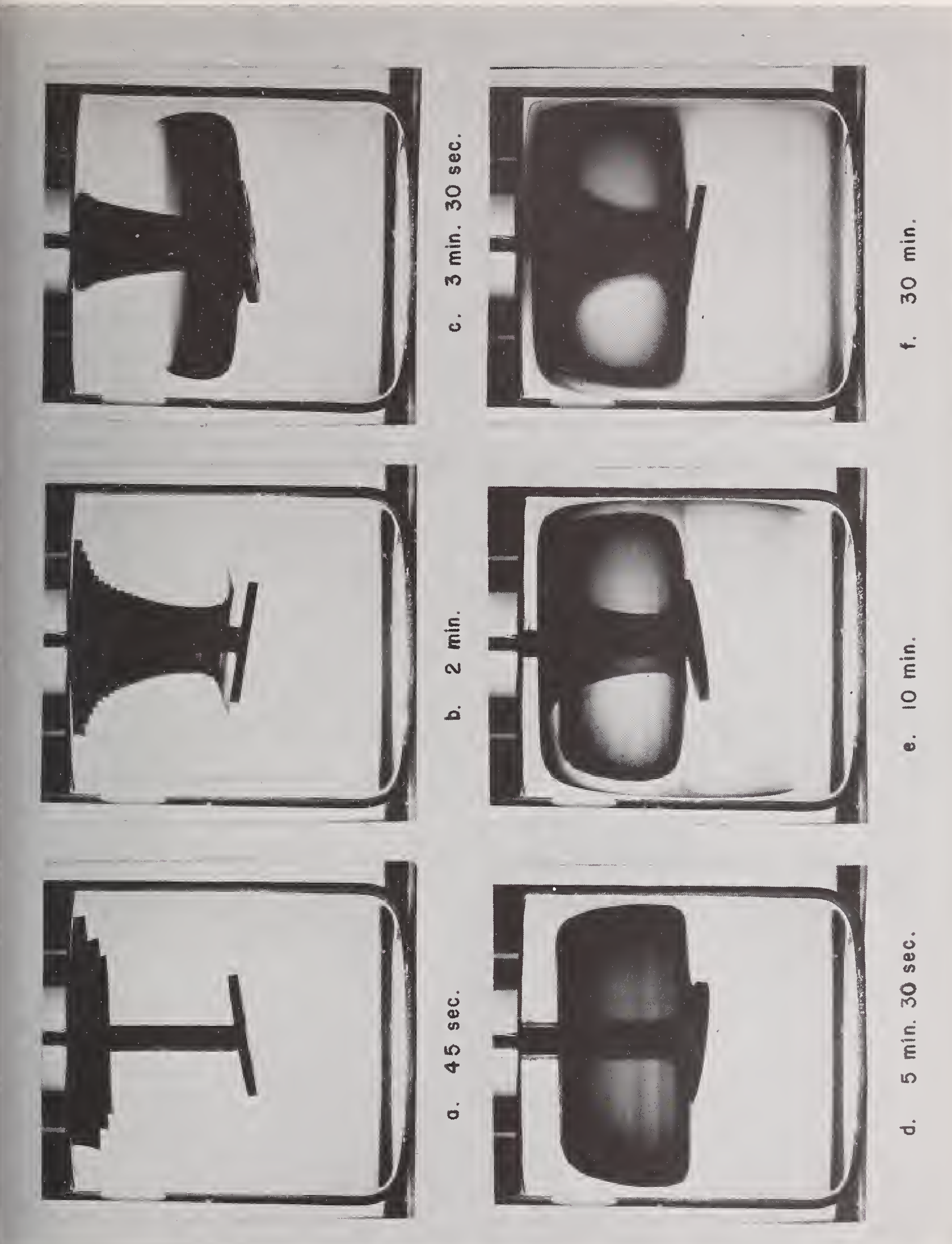


c. 1 min.

Figure 12. Perforated Disc Stirrer.

A stirrer not shown in Fig. 1 consisting of a perforated disc mounted on the end of a rod at a tilt of 15° is shown in this group of photographs. The circulation paths are the same as those obtained with the combined radial and regular propeller, Fig. 5, and similar to those obtained by the radial propeller, Fig. 4. Even though a divided mixing also occurs with this stirrer, a comparison with the others shows that it is much slower in its mixing and that the carbon black actually never reaches the container walls as shown in the last photograph. Closer examination of the last picture reveals that some of the carbon black has reached the bottom half of the beaker and is being dispersed in the circulation paths opposite to those in the top half. Once again, raising or lowering the stirrer had no radical effect on the resulting circulation paths.

Speed of rotation - 120 RPM
Container - beaker 14 cm diameter, 21 cm high
Depth of oil - approximately 15 cm



a. 45 sec. b. 2 min. c. 3 min. 30 sec.

d. 5 min. 30 sec. e. 10 min. f. 30 min.

Figure 13. Large Stirrers.

1. Tapered helical stirrer.
    a. Blade 5 cm pitch - width of blade 5 cm at the bottom tapering to 2.5 cm at top.
    b. Three turns of blade.
    c. Shaft diameter - 3.18 cm O.D.

2. Modified double two-bladed propeller.
    a. Bottom blades - 15° pitch, 7.5 cm wide.
    b. Top blades - 45° angle downward with axis of shaft, 19 cm from the tip of shaft; blades are about 9 cm long and 7.5 cm wide, and 90° around the shaft from the bottom blades.
    c. Shaft diameter - 3.18 cm O.D.

3. Combined radial and regular propeller.
    a. Top and bottom propeller blades - 15° pitch and opposite to each other and 12.5 cm apart. Each blade 5 cm long and about 3 cm wide.
    b. Side vanes about 3 cm wide.
    c. Counter-clockwise rotation.
    d. Shaft diameter - 3.18 cm O.D.

4. Double three-bladed marine propeller.
    a. Blades - 15° pitch and 120° apart. Each set of blades of opposite pitch; therefore, opposite rotation - bottom clockwise, top counter-clockwise. Width of blade - 5 cm.
    b. Shafts - concentric - outer shaft 3.18 cm O.D. - inner shaft 2.54 cm O.D.
    c. Distance between each set of blades - variable up to about 20 cm.

Overall diameter of stirrer - 15.2 cm.

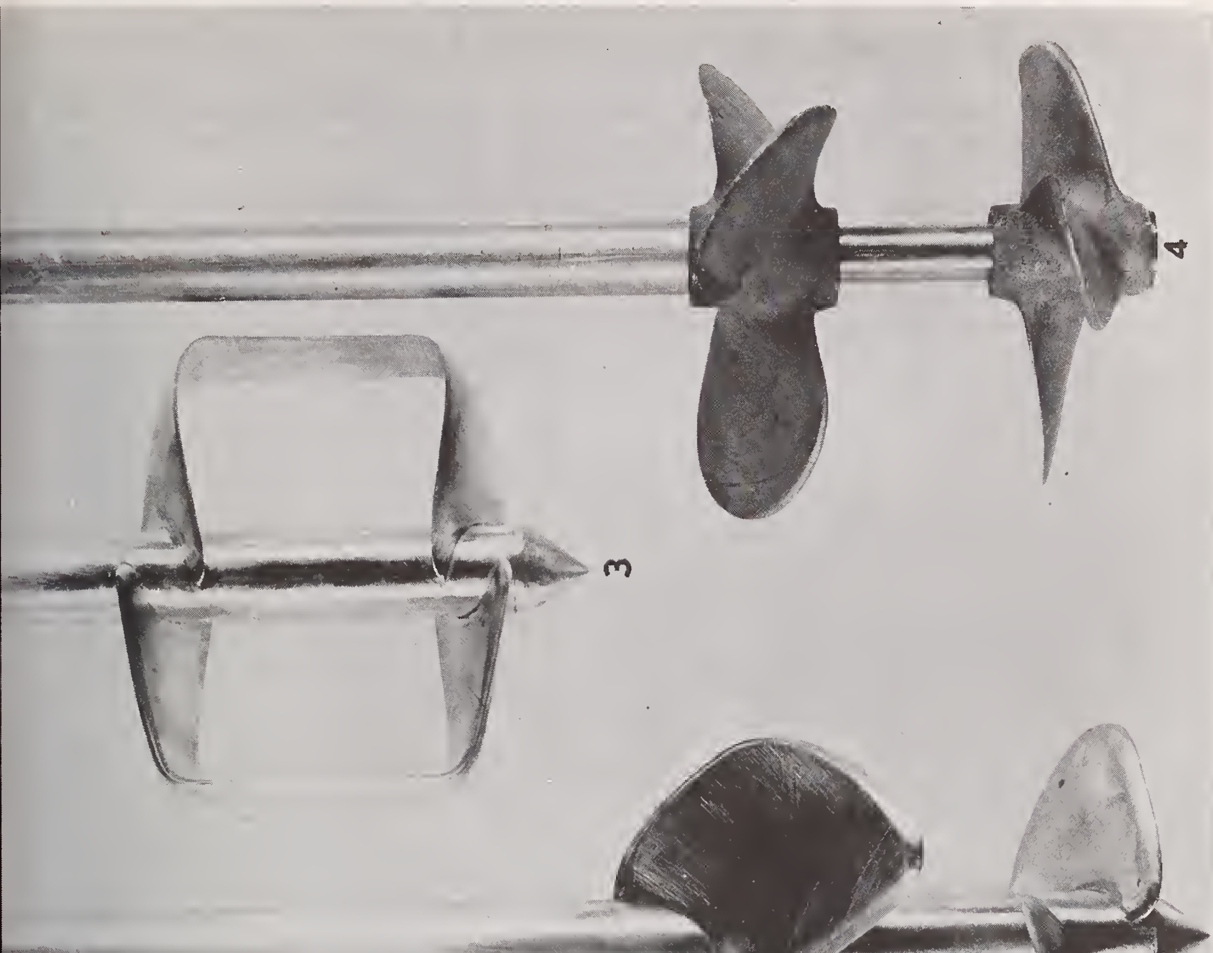

1
2
3
4

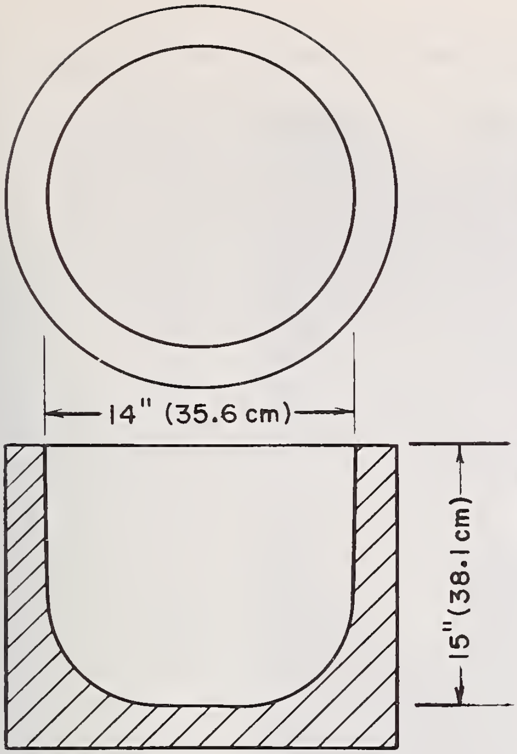
Figure 14. Container Shapes Used with Large Stirrers.

a. Cylindrical with a dished bottom.

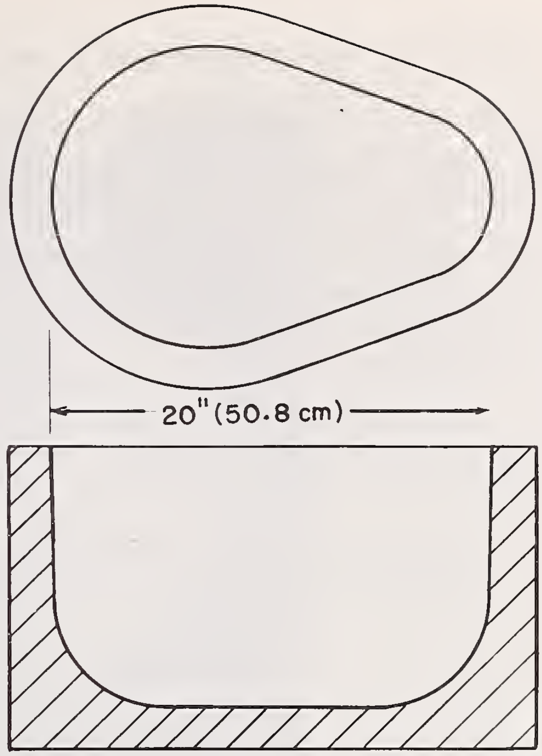
b. Semi-cylindrical with one end or side elongated and half the radius of the other end or side - also with a dished bottom.

c. Modified version of 'b' with a dished bottom.

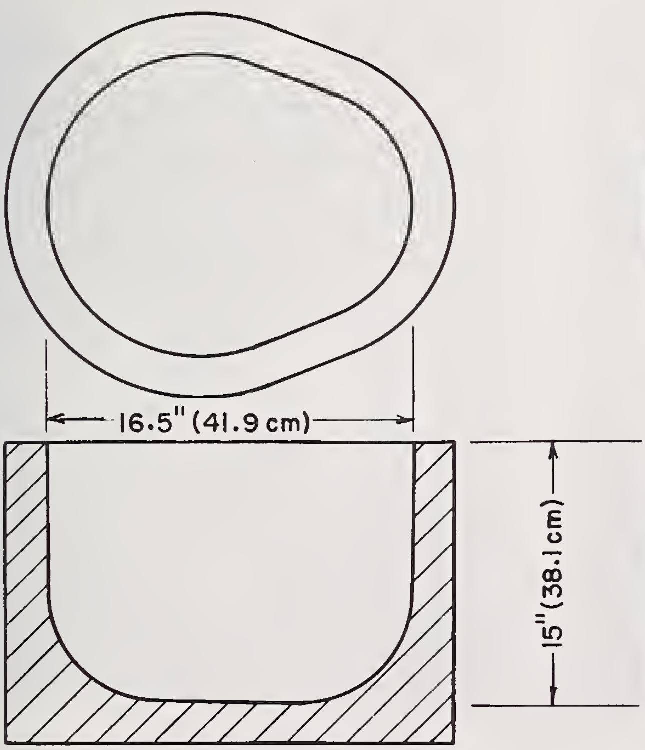
d. Cylindrical glass container with a flat bottom.



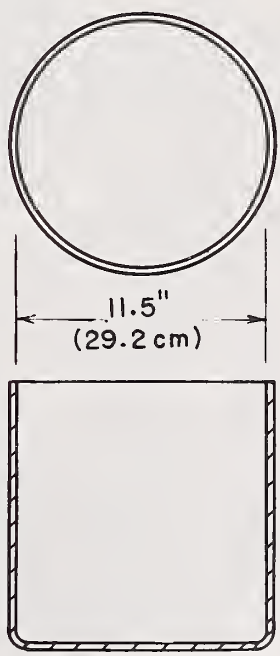
a.



b.



c.



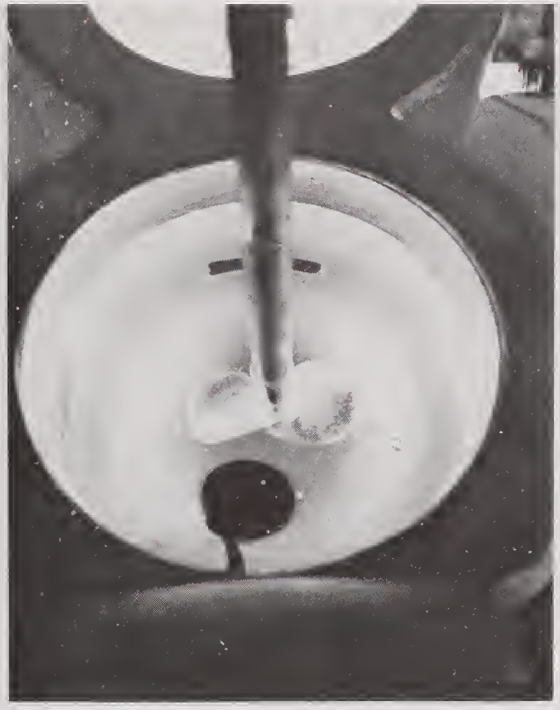
d.

Figure 15. Stirring Action of Two-bladed Propeller in Container 'a', Fig. 14.

The carbon black was allowed to sink to the bottom of the container before the start of stirring. In photograph 'b' after 1.5 minutes of stirring, the carbon black has been mostly dispersed but the main circulation path is till evident as the liquid is being lifted up from the bottom of the container. In the last photograph the color has been completely dispersed but has not reached the sides or the top.

This set of photographs, as well as those that follow, are taken looking down into the top of the container.

Speed of rotation - 75 RPM
Depth of oil - 25.5 cm



(a) START

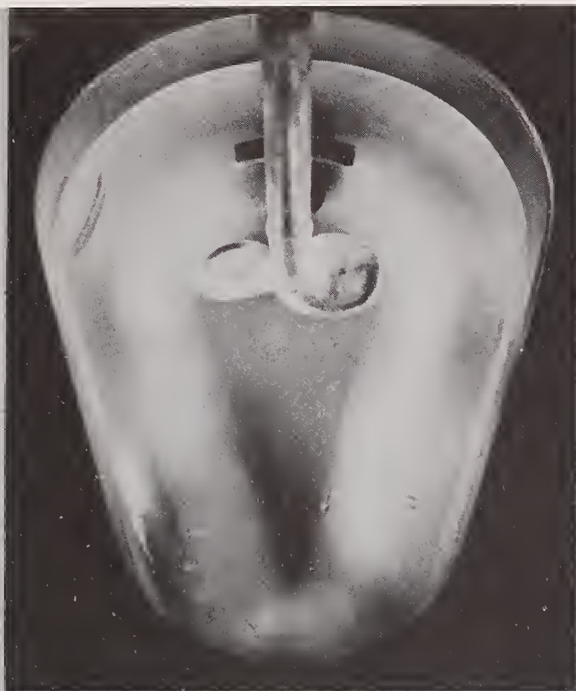
(b) 1 min 30 sec

(c) 3 min

Figure 16. Stirring Action of Two-bladed Propeller in Container 'b', Fig. 14.

The stirring action with the single two-bladed propeller was incomplete in the small end of this container as shown in photograph 'c'. No definite circulation paths could be observed. When the carbon black was put into the small end of container 'c' and stirring started, it curved downward parallel to the wall and in the direction of rotation of the stirrer. As the carbon black came to the top again, it was not pushed out completely to the small end of the container but pulled down about ten centimeters from the wall.

Speed of rotation - 75 RPM
Depth of oil - 25.5 cm



a. Start

b. 20 sec.

c. 2 min. 5 sec.

Figure 17. Stirring Action of the Tapered Helical Stirrer, Fig. 13 - 1, in Container 'a', Fig. 14.

The tapered helical stirrer gave a faster stirring action in the round container than the single two-bladed propeller. At the end of nine minutes, this stirrer had accomplished the same results as the two-bladed propeller in twenty minutes.

Speed of rotation - 75 RPM
Depth of oil - 25.5 cm

(a) START

(b) 40 sec

(c) 1 min 30 sec

(d) 3 min

Figure 18. Stirring Action of the Tapered Helical Stirrer in Container 'b', Fig. 14.

The performance of the helical stirrer in container 'b' was not as efficient as the two-bladed propeller in that it gave a very slow action in the small end of the container. Here there was a definite line between the mixed and unmixed portions of the liquid which gave considerable evidence that no stirring action occurred in the small end of the container. When the carbon black was added to the top surface of the liquid in the small end of the container as in the case of two-bladed propeller, it followed the same circulation path except for the appearance of a reverse flow or counter-current in the bottom and middle of the container. In this test, when the stirrer was placed off center, that is, about 5 cm towards the small end, the stirring action was similar to that of the propeller and gave better stirring.

Speed of rotation - 75 RPM
Depth of oil - 25.5 cm

(a) START (b) 20 sec

(c) 40 sec (d) 3 min (e) 8 min

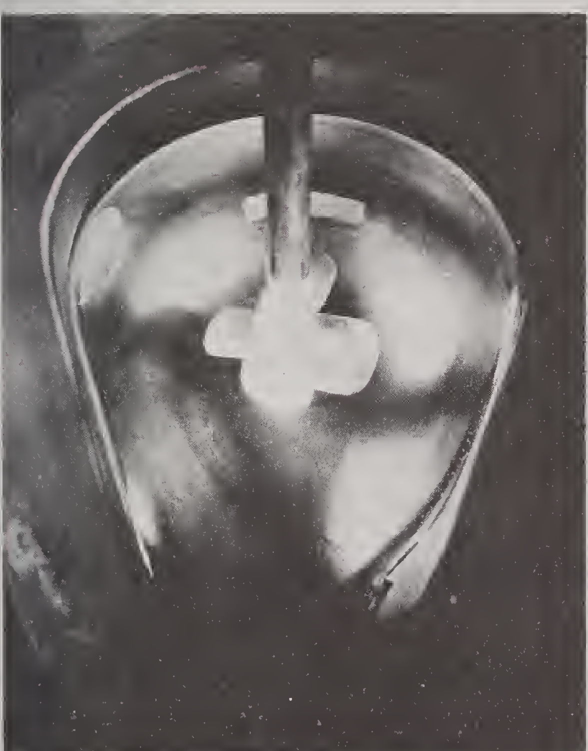
Figure 19. Stirring Action of the Modified Double Two-bladed Propeller, Fig. 13-2, in Container 'c'.

The double two-bladed propeller gave the best stirring action in container 'b'. The continued presence of an eddy or counter-current flow in the small end of the container was the same as that with the single two-bladed propeller and the helical stirrer. This indicated that the container was too long and, with this in mind, container 'c' was designed to correct this condition in the small end of the container. This set of photographs shows the modified two-bladed propeller in container 'c'. The stirring action was adequate throughout the container including the eventual disappearance of the eddy current flow in the small end of the container. The same degree of mixing was accomplished in half the time in this container as in container 'b' with this stirring rod.

Speed of rotation - 75 RPM
Depth of oil - 25.5 cm

a. 20 sec.

b. 40 sec.



c. 1 min. 30 sec.

d. 3 min.

Figure 20. Circulation Paths in Container 'd', Fig. 14, with the Modified Double Two-bladed Propeller.

The double two-bladed propeller was tested in container 'd' with a liquid of proper density and viscosity (corn syrup and zinc bromide). Rather than mix carbon black in the body of liquid, solid objects (pieces of glass) were used to study the mixing action of the stirrer. The stirring action was adequate, as shown in the schematic drawing, and showed much improvement in this liquid of higher density. This removed the doubt that the higher density of the liquid would be a detriment to good mixing with this stirrer. Several speeds were tried with this stirrer in this liquid, and it was found that at the lower speeds, the mixing was considerably slowed down.

Speed of rotation - 75 RPM
Depth of oil - 25.5 cm

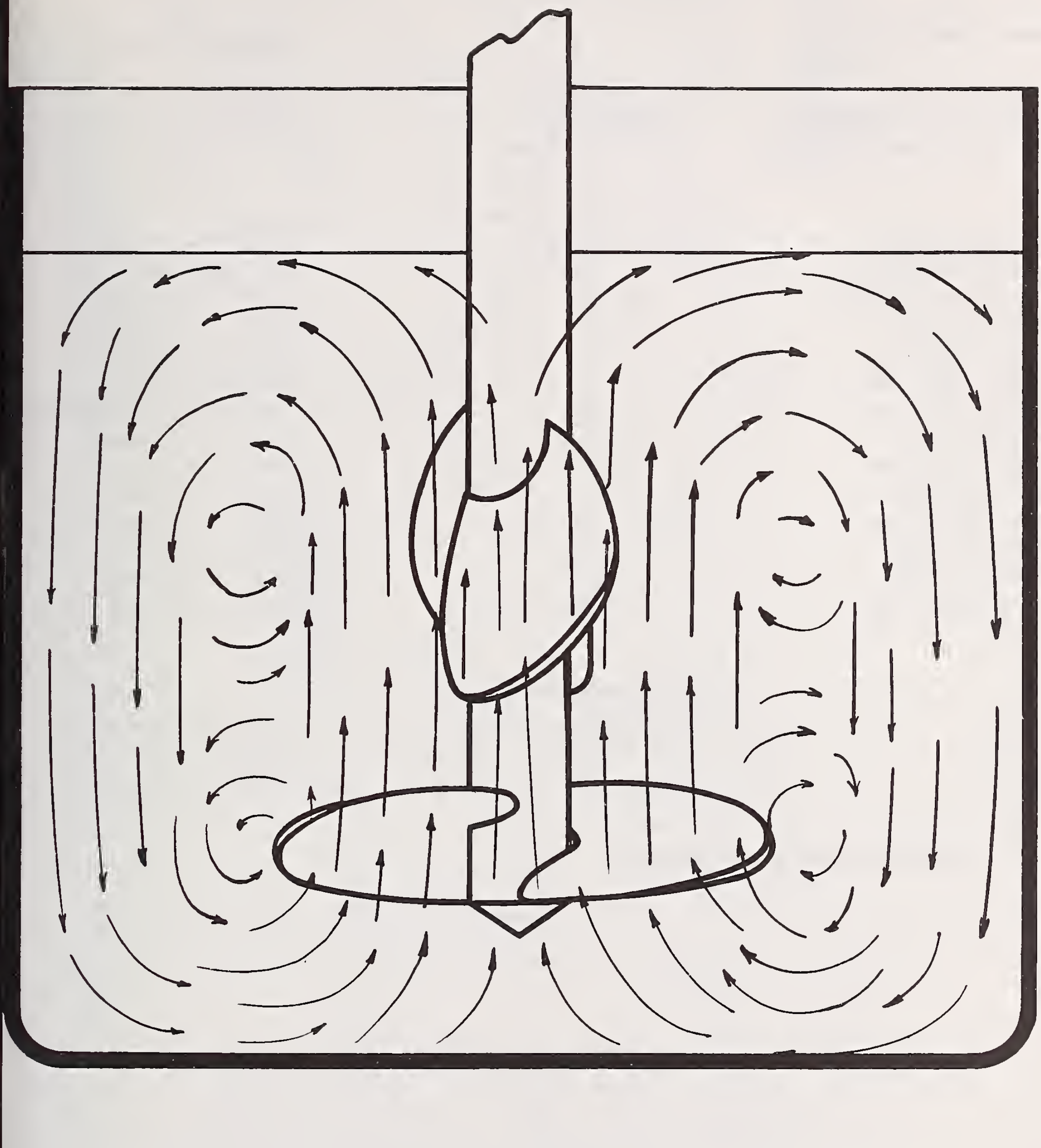
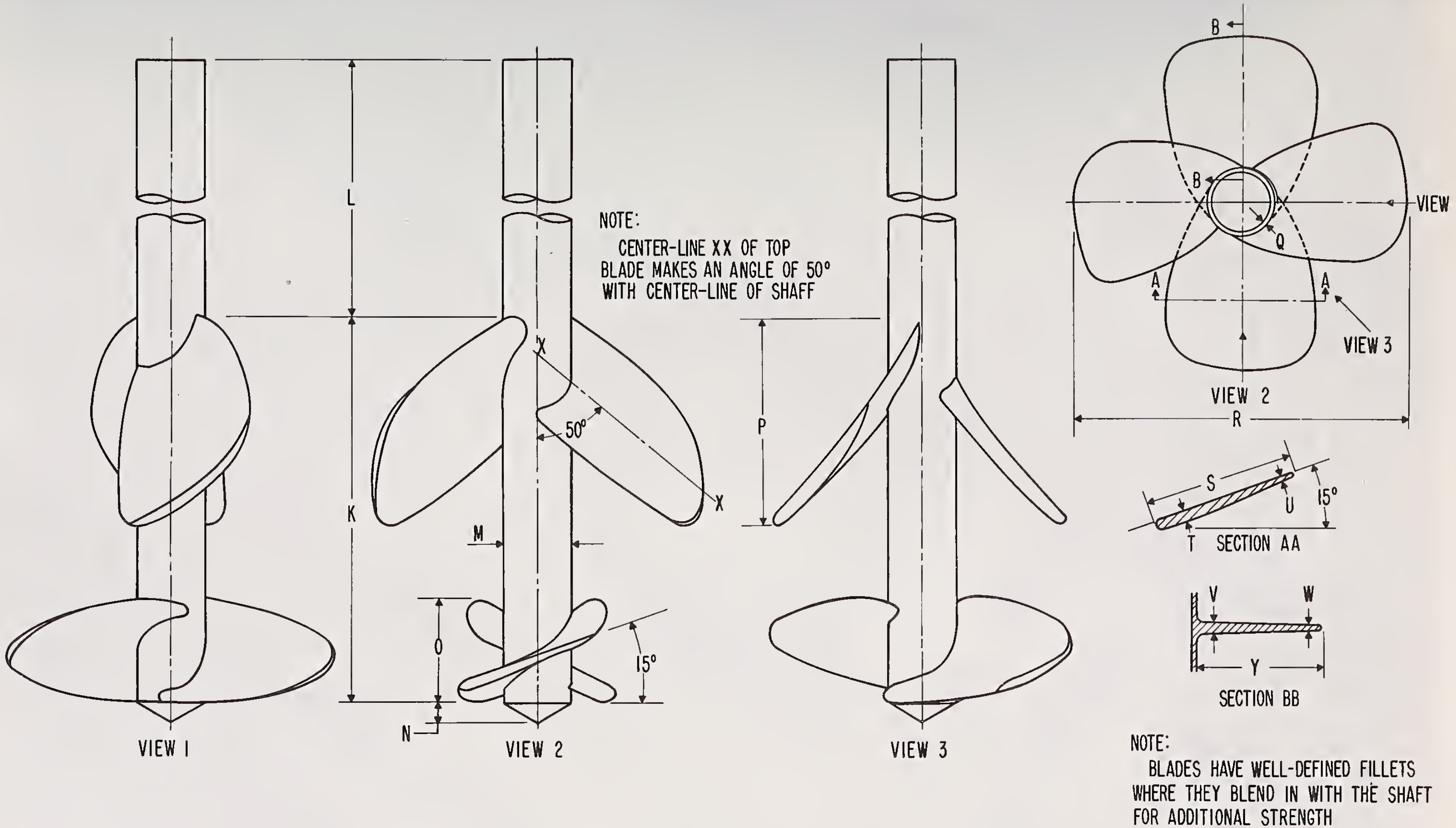


Figure 21. Drawing of Modified Double Two-bladed Propeller.

Stirrer 90% Pt 10% Rh

For Large Crucible		For Laboratory Crucible
15" (38.1 cm)	Depth	3-1/2" (8.9 cm)
12-14" (30.5-35.6 cm)	Diameter	2-1/2" (6.4 cm)
12" (30.5 cm)	Depth of Glass	3" (7.5 cm)
	Stirrer Dimensions	
7-1/2" (19 cm)	K	1-3/4" (4.5 cm)
27-1/2" (70 cm)	L*	14" (35.6 cm)
1-1/4" (3.2 cm)	M	3/16" (0.48 cm)
1/2" (1.3 cm)	N	3/16" (0.48 cm)
2" (5.1 cm)	O	1/2" (1.3 cm)
3-1/2" (8.9 cm)	P	7/8" (2.22 cm)
1/16" (0.15 cm)	Q	Does not apply-solid shaft
6" (15.2 cm)	R	1-1/2" (3.8 cm)
3-1/4" (8.3 cm)	S	5/8" (1.6 cm)
1/4" (0.6 cm)	T	3/32" (0.24 cm)
1/10" (0.25 cm)	U	1/16" (0.15 cm)
1/4" (0.6 cm)	V	3/32" (0.24 cm)
1/6" (0.4 cm)	W	1/16" (0.15 cm)
2-3/8" (6.0 cm)	Y	21/32 (1.67 cm)
	Approximate Weight of Stirrer	
4200 g		150 g

* L - depends on furnace design.



L
K
M
O
N
15°
50°
X
X
P
NOTE:
CENTER-LINE XX OF TOP BLADE MAKES AN ANGLE OF 50° WITH CENTER-LINE OF SHAFT
VIEW 1
VIEW 2
VIEW 3
B
B
A
A
Q
R
S
T
U
15°
SECTION AA
V
W
Y
SECTION BB
NOTE:
BLADES HAVE WELL-DEFINED FILLETS WHERE THEY BLEND IN WITH THE SHAFT FOR ADDITIONAL STRENGTH

Figure 22. Platinum-lined Tank and Stirring Rods.

This photograph shows the original Pt-lined tank with the three compartments. The pots are interconnected and continuous: the first, at the top, being the melting area; the second, the refiner; and the third being the conditioning area where the glass is ready for discharge. The stirring is conducted in pots two and three. The third pot has been shortened as a direct result of these stirring experiments as previously stated. The final design of the stirring rod, 90% Pt, 10% Rh, is shown in the photograph.


3
2
1

Figure 23. Platinum Liner for Larger Crucible and Stirring Rods.

This size of liner was not only used for a pot in the experimental glass tank but, also, for a pot used in unit type melting. Here about 20 liters of glass was usually melted, stirred, and cast into slab form. This method of glass making has been used extensively to make special types of glass. Again, stirring of the melt is very important and requires a special stirrer. The stirrer design resulting from this study satisfied these conditions and homogenous glass could be produced.

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16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

The stirring actions of several designs of small stirrers were observed and photographed in transparent viscous model liquids. The fluidity of the liquids was comparable to that of a molten borosilicate glass at fining temperatures. The most efficient features of one or more of these stirrers were incorporated into larger model stirrers and observed under actual stirring conditions. As a result of these performance tests, a final design of stirrer was selected and fabricated of platinum-rhodium metal and used in an experimental glass tank. The design of one of the pots in the experimental glass tank was modified to obtain the maximum stirring action with the selected stirrer.

17. KEY WORDS (Alphabetical order, separated by semicolons)
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