HYDRAULIC TESTS OF SMALL DIFFUSERS
BY F. T. MAVIS, ANDREAS LUKSCH, AND HSII-HOU CHANG

I. TESTS OF DIFFUSERS WITHOUT CONICAL INSERT

1. Synopsis. — Tests of two small diffusers, resembling spreading draft tube models of brass and glass, respectively, are reported herein. Part I summarizes tests of the diffusers without solid inserts while Part II summarizes the effects on discharge induced by eight separate conoids inserted coaxially with the diffuser.

The diffuser, 5.67 in. high, 1.77 in. in diameter at the throat, with an included angle of 17 degrees between side walls, was the connecting conduit between headwater and tailwater tanks. The diffuser was trumpet-shaped, and the lowest part was bounded by a plane ring surface 8.85 in. in outside diameter and approximately 1 1/2 in. in width.

A circular impact plate 11 in. in diameter was held in a position parallel to and successively at different distances from the outlet face of the diffuser.

Water entered the diffuser horizontally through a set of guide vanes which directed the water either radially toward the axis of the tube or non-radially with assigned deflection angles measured at the inner tip of guide vane blades. Water also flowed from the diffuser horizontally between the surfaces of the diffuser and the impact plate.

Operated at a constant head of 1.78 ft., the two diffuser models were tested in combination with each set of guide vanes, and the discharge through each model was measured as a function of the
clear distance between diffuser and impact plate. Quantitative data are summarized graphically in the report.

Qualitative observations of flow through the transparent glass tube were made visually and photographically with the model illuminated along a thin vertical section near its axis by means of a screened arc light. Stream paths were made visible first by introducing a suspension of aluminum powder into the headwater tank and later by introducing five streams of minute air bubbles into the throat of the tube by means of a special atomizer. Selected photographs are reproduced and the qualitative observations are correlated with the characteristic curves of discharge through the model for different angles of approach and for different positions of impact plate with reference to diffuser tube outlet.

2. Acknowledgments. — Part I is based on a thesis by Andreas Luksch, begun under the supervision of the late Prof. F. A. Nagler and completed under the supervision of the senior author. Acknowledgment is gratefully made to Edward Soucek, research assistant engineer, Iowa Institute of Hydraulic Research, for assistance in carrying on the tests.

The experiments were conducted in the laboratory of the Institute of Hydraulic Research — an integral part of the College of Engineering, of which Francis M. Dawson is Dean. Prof. F. T. Mavis is head of the Department of Mechanics and Hydraulics, and Prof. E. W. Lane is associate director of the Institute in charge of the laboratory.

The following quotation was instrumental in suggesting the laboratory investigation:

"The tests of the small models [4 in. diameter intake] led the Power Company engineers to believe that model 'M' [a symmetrically flared radial-discharge type] with the cone in the center, while it did not give as high an efficiency as the model without the cone in the center, seemed to offer more stability than the other — that is to say, the models giving the highest efficiency did so only at the critical velocity, the efficiency falling off rapidly at greater or less discharges. These more efficient models were also very sensitive in regard to . . . [the clear distance between draft tube outlet and the tail race floor] — a slight variation in this dimension making a difference in the regainer efficiency. The small model with flat plate was found to be more sensitive in this respect than the one having a conical center.

"The writer has noted with interest, however, the records of tests in the paper of the symmetrically flared type with a model water wheel, with and without cone center, and apparently the author has not found the sensitivity under actual working conditions which was found in the small model. It is probable that further practical experience will show that this sensitivity was due to the small models used and will not be found in actual practice.

"The final alternate model adopted was tested after removing the cone center and it was found that the efficiency of this model under that condition was no less than with the cone center in place.

"It should be understood that these model tests were made under ideal conditions with straight flow lines. . . .

"The company engineers did not have the advantage of determining the effect of the whirling action upon the models or of any other disturbances caused by an actual water wheel runner, and therefore their tests did not prove that the relative results secured would hold true in actual practice."

The apparatus used in the tests was patterned as closely as practicable after the apparatus used in tests by A. Hofmann at the Technische Hochschule in Munich, and the background afforded by Hofmann’s prior study is gratefully acknowledged.

3. Objectives. — The purpose of this study was:

(1) To determine under conditions of constant head and radial inflow the relationship between discharge through a diffuser (resembling a spreading draft tube) and the distance of its outlet from a level impact plate (simulating a tailrace floor);

(2) To investigate the influence of angular inflow to the diffuser on the above relationship; and

(3) To observe and photograph the flow paths in a transparent model with a view to explaining the phenomena of flow.

4. Apparatus. —

(a) General Description

Fig. 1. Shows the general arrangement of the apparatus. A cylindrical head water tank 20 in. in diameter and 20 in. high was made of galvanized sheet metal. The upper 8 in. of the cylindrical


shell was perforated with \( \frac{3}{4} \) in. holes at 1-in. centers and served as the innermost of three concentric baffles which were intended to direct the water uniformly through the upper periphery of the cylinder to the headwater pool. Attached to the outside of the headwater tank 7 in. below its upper edge and concentric with it was a second sheet-metal cylinder 30 in. in diameter and 12 in. high forming an annular space into which the baffles were fixed. A 3-in. pipe in the University distribution system, connected to the outer cylindrical shell, supplied the water for the tests.

Attached to the headwater tank were the diffuser models and the supports for an adjustable impact plate, simulating the tailrace floor, which are described below.

The tailwater tank, 25 in. wide, 35 in. long, and 24 in. deep, was made of galvanized sheet metal. One side and one end were provided with plate glass windows, and the other end was fitted with adjustable plates used in regulating the tailwater level.

The water leaving the tailwater tank passed through a short conduit into a weir tank with a 90-deg. V-notch which had been calibrated gravimetrically as a unit at the beginning of the investigation.

Elevations of water surfaces in the headwater and tailwater pools,
and heads on the V-notch weir were observed by hook gages reading to 0.001 ft.

A direct-current arc-lamp and reflector, operating at approximately 50 volts and 55 amperes, directed a parallel beam of light into the transparent end of the tailwater tank and facilitated photographing and observing the details of the flow phenomena. The width of the light beam was regulated by two metal shades whose edges formed an adjustable vertical slit.

(b) Diffusers and Impact Plate

Two diffusers, one brass and the other glass, of substantially the same internal dimensions, were used in the tests. Fig. 1 shows the inside dimensions of the models. The throat diameter was 1.77 in. (45 mm.) for the brass model and 1.84 in. for the glass model. The most effective of Hofmann’s models was used as a guide in selecting the other proportions of the models which were made up as follows:

(1) A rounded approach section 0.88 in. long proportioned after the so-called Hinz Standard Mouthpiece. This approach is relatively shorter than those used by Hofmann.

(2) A cylindrical throat section 1.77 in. in diameter and 0.44 in. long.

(3) A conical expanding section 3.06 in. long with an angle of 17 deg. between outside walls. Hofmann’s tests indicated an 8.5-deg. angle between side wall and axis of diffuser to be the optimum.

(4) An expanding transition of 1.50-in. radius tangent to the inside of the cone and to the bottom of a horizontal plate 8.85 in. in diameter.

Fig. 2(a) shows a photograph of the brass model with guide vanes in place ready to be attached to the bottom of the headwater tank. The upper face of the model diffuser was flush with the inside of the headwater tank.

Fig. 2(b) shows the diffuser model and impact plate with the tailwater tank removed. The impact plate was 11 in. in diameter and was attached to three steel angles as shown. The angles, suspended by threaded rods from brackets on the headwater tank, could be raised and lowered by means of knurled adjusting nuts. First the impact plate was adjusted to its initial position 0.177 in., be-


low the bottom of the diffuser with the aid of steel gages. The threaded rods and their nuts subsequently served the dual purpose of adjusting and micrometer-measuring devices with a least count of approximately 0.002 in.

(c) Guide Vanes

The direction of flow entering the diffuser model in each series of tests was maintained by means of a set of guide vanes clamped against the upper face of the model as shown in Fig. 2. Each set consisted of a disc turned out of 3/4-in. wood stock, twelve guide vanes of 1/32-in. sheet brass, and a wooden plug. After they were shaped, the discs and plugs were soaked in linseed oil, dried, and shellacked. Table 1, referring to the sketch of guide vanes in Fig. 1, shows diameters of disc \( d_1 \) diameters of plug \( d_2 \), blade angles \( \theta \), and blade lengths.

<table>
<thead>
<tr>
<th>Angle ( \theta )</th>
<th>( d_1 )</th>
<th>( d_2 )</th>
<th>Blade Length</th>
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<td>90</td>
<td>5.00</td>
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</table>
5. **Procedure.** — After the diffuser tube and guide vane assembly had been placed the impact plate was brought to a position parallel to and a known distance below the outlet face of the tube. The rate of flow through the model was regulated manually until the head, as indicated by the headwater and tailwater hook gages, was 1.78 ft. The head was maintained as nearly 1.78 ft. as practicable, deviating less than 0.02 ft. from this amount in half the 557 tests performed. All observations of discharge were converted to an equivalent discharge at 1.78 ft. head on the assumption that the rate of flow varied as the square root of the head.

The tailwater level in all except one series of tests was maintained from 0.33 to 0.36 ft. above the bottom of the tube.

For each position of the impact plate three to five observations of head and discharge were made. The rates of flow shown in the figures are means of the individual readings.

The procedure in the tests to determine the discharge under constant head as a function of the distance of the diffuser outlet from the impact plate under conditions of (a) radial inflow, and (b) angular inflow may be listed as follows:

1. Adjust the impact plate to a known position parallel to the bottom face of the diffuser tube.
2. Adjust flow through model to maintain (a) tailwater level approximately 0.35 ft. above bottom of tube, and (b) total head of 1.78 ft. on the model.
3. Observe and record hook gage readings (a) for headwater pool, (b) for tailwater pool, and (c) for head on weir.

In one series of tests using the glass model qualitative observations of flow phenomena and photographs were made at operating heads less than one foot. The general characteristics of flow at the low heads did not appear to be different from those at the head of 1.78 ft. used in the quantitative tests previously described. With the facilities available for illuminating and photographing it was impossible to obtain clear pictures at a head of 1.78 ft. used in the quantitative tests. Representative photographs are shown in Figs. 4 and 5, and they are further discussed in Articles 6 and 7.

The arc-light, screened by the metal shades over the end window in the tailwater tank, cast a narrow beam of light in a vertical plane parallel to the front window and illuminated a cross-section of the tube brilliantly. A camera was set up in front of the side window.

In the earlier tests an aqueous suspension of aluminum powder
FIG. 3. TESTS OF BRASS DIFFUSER WITHOUT CONICAL INSERT.

FIG. 4. TESTS OF GLASS DIFFUSER WITHOUT CONICAL INSERT.
was poured into the headwater tank and the photographic exposure was made as the flakes of powder passed through the tube and reflected the light from the arc. Later it was found that a stream of minute air bubbles was more effective than aluminum powder in reflecting the light. The air streams were introduced through the guide-vane disc by means of a manifold with five capillary-tube outlets. The flow of air to the manifold was controlled by a screw-clamp on the rubber tube which passed through the water in the headwater tank.

6. **Discharge for Radial Inflow.** — Figs. 3 and 4 show summaries of the tests of the brass and glass diffuser tubes, respectively. Measured discharge through the model in sec.-ft. at a head of 1.78 ft. is plotted as ordinates, and the clear distance between the tube and the impact plate (relative to throat diameter) as abscissas. The abscissas represent ratios \( z/d_0 \) in which

\[
\begin{align*}
  z &= \text{clear distance between tube and impact plate in in.} \\
  d_0 &= \text{diameter of diffuser throat, in in.}
\end{align*}
\]

The uppermost curves in Figs. 3 and 4 represent respectively the data obtained in tests of the brass and glass models for radial inflow using 0 deg. guide vanes (Table 1.) In the first tests in this series the clear distance between tube and impact plate was 1/10 the throat diameter. As this distance was increased in subsequent tests, keeping the total head constant and equal to 1.78 ft., the discharge through the model increased reaching a maximum value when this clear distance was approximately 1/4 the throat diameter. As the impact plate was further lowered, increasing the clear distance between it and the tube, the discharge decreased, and for clear distances greater than the throat diameter appeared to become asymptotic to approximately 75 per cent of its maximum value.

For radial inflow and for \( z/d_0 \) greater than 1/4, the discharge through the glass model was 16 to 21 per cent less than the corresponding discharge through the brass model at the same operating head. Since the glass model was slightly larger than the brass model, these differences in capacities must be attributed to causes more important than differences in size. Whatever these causes may be, any theory respecting them must be consistent with the observation that for radial inflow the glass model discharged more water than the brass model, and for angular inflow the glass model...
discharged as much or more than the brass model. The theory pertinent to the latter observation is discussed more fully in Art. 7.

The brass model was turned on a lathe, and its inner surface was smooth and true. The glass model was not cast in a mold, and although it was skillfully made in a craftsmanlike manner, it was not so true as the brass model. The throat of the glass tube was slightly

**FIG. 5. PHOTOGRAPHS SHOWING FLOW THROUGH GLASS DIFFUSER.** In each view the angles, $\theta$, and the ratios $z/d_o$ were, respectively: (a) $0^\circ$-0.1; (b) $0^\circ$-0.27; (c) $0^\circ$-1.0; (d) $30^\circ$-0.1; (e) $30^\circ$-0.27; (f) $30^\circ$-1.0.
larger than that of the brass tube and it was not a perfect circle. Side walls of the glass tube were perceptibly wavy. Observations of radial flow through the glass tube indicated that the jet was not wholly stable and that it would adhere to one wall, depart from the other, and form an eddy. Under conditions of radial inflow, the stream paths were not wholly stable, and the jet itself yawned back and forth. In the case of radial inflow, this instability of the main jet may have had a more pronounced effect upon energy conversion in the slightly irregular glass model than in the more symmetrical brass model.

Figs. 5a, b, and c show photographs of flow through the glass model with radial approach and with $z/d_0$ ratios respectively .10, .27, and 1.0. These figures provide qualitatively a basis for explaining the variation of discharge at constant heads with the ratio $z/d_0$ as indicated by the uppermost curves in Figs. 3 and 4.

In Fig. 5a the impact plate is .10 of the throat diameter below the tube. The flow is throttled between the tube and the impact plate, and eddies form in the lower part of the tube near its side walls. These eddies are not conducive to efficient energy conversion.

In Fig. 5b the impact plate is .27 of the throat diameter below the tube. With the impact plate in this position the stream paths follow along the side walls of the tube and the eddies within the expanding section are inappreciable. Virtually the entire cross section of the expanding conduit is effective in carrying the water downward and outward, and for this position of the impact plate there is the most efficient conversion of kinetic to potential energy.

In Fig. 5c the impact plate is one diameter of throat below the bottom of the tube. Below mid-height the stream paths do not follow the diverging walls of the tube, and for a distance of two diameters they define a jet which is roughly cylindrical. This vertical jet is deflected horizontally by the impact plate, and efficient energy conversions seem unlikely because of the ill-defined "effective boundary" of the jet and attendant eddying in the lower part of the tube.

Close observation of the flow through the expanding sections under conditions of radial entry suggested qualitative inferences consistent with the quantitative observations of discharge and clear distance between diffuser and impact plate as shown in the uppermost curve of Figs. 3 and 4.

7. Discharge for Angular Inflow. — Rotational components were
induced into the flow in the tube by guide vanes which have been described in Art. 4 (Fig. 1 and Table 1.). The depth of the approach channel was .79 in. For guide vanes with deflection angles of 0, 30, 45, 60, and 90 deg., the inner tip of each blade was 1.28 in. from the vertical axis of the tube, and the outer tip was 2.50 in. from the axis. The minimum cross sectional area of water passages ranged from 6.35 to 1.65 sq. in. For guide vanes with deflection angles of 0, 40, and 54 deg., the minimum effective flow area at the inner tip of the blades was constant and equal to 6.35 sq. in. The inner tips of the blades were respectively 1.28, 1.42, and 1.59 in. from the axis of the tube.

Figs. 3 and 4 show as ordinates the observed discharge in sec. ft. as a function of the clear distance between the tube and the impact plate for both models, the angle of guide vane being indicated for each curve. An inspection of the curves representing non-radial entry suggests first that for similar operating conditions the glass model discharges as much or more water than does the brass model, second that the discharge is a maximum when the impact plate is approximately 1/4 the throat diameter below the tube, and third that the discharge for ratios of \( z/d_0 \) greater than 1/4 is reduced less than 10 per cent below this maximum value within the limits of the tests. Qualitative observation of the flow within the transparent conduit suggests an explanation of these flow characteristics.

Figs. 5d, e, and f show representative photographs of the flow through the glass model for \( z/d_0 \) ratios of .10, .27, and 1.0 respectively. For each of these photographs the 30 deg. guide vanes directed the flow into the model. It is apparent that only the section of the tube near the walls is effective in carrying water through the model and that there is a conical vortex zone near the axis.

The general appearance of the flow patterns in Figs. 5d, e, and f are similar. Evidently the position of the impact plate with reference to the bottom of the tube has little effect upon the general form of stream paths through the expanding section. In Fig. 5d there is only a faint suggestion of throttling, as evidenced by the irregular eddy core near the top of the tube. For radial entry, however, the impact plate played an important role in making the tube as a whole serve as a fully effective expanding conduit.

Assuming the flow in the eddy core (Figs. 5d, e, and f) behaves as a free vortex, the rotational or tangential component of the velocity of a particle is inversely proportional to its distance from the
axis and therefore is greatest near the axis of the tube. The swirling water is confined by the walls of the tube, along which it flows downward with a spiral motion into the tailwater tank. The eddy core itself is roughly conical in shape and there is a component of flow vertically upward in the region near its axis. The impact plate, lowered to a position beyond which it does not throttle the flow, serves chiefly as a surface defining the base of the eddy core and little affects the discharge for a given head and angularity of approach.

Direct observations indicated that the peripheral velocity was greatest near the axis of the tube. The phenomena of flow through a diffuser under conditions of radial entry are evidently much less stable than those under conditions of angular entry. It is reasonable that flow phenomena inherently unstable should be more affected by surface irregularities and waviness of side walls of conduit, while phenomena which are inherently stable should be relatively less affected by surface conditions. Evidently, therefore, for conditions of radial inflow the glass model with its surface irregularities induced unstable flow conditions to a greater degree than did the somewhat smaller but more regular brass model. Under conditions of non-radial inflow, however, the flow phenomena were equally more stable in both conduits, and the greater size of the glass model was reflected in greater capacity for the same head and angularity of approach.

Fig. 6 shows the effect of angular approach on the flow through the brass diffuser under constant head of 1.78 ft. Ordinates show the discharge through the tube in second-feet, and abscissas show the angles between the radial line and the guide vanes at their inner tips. Data are selected from Figs. 3 and 4 for clear distances between tube and impact plate, representing $z/d_0$ ratios of .10, .27, .50, and 1.0.

This analysis does not suggest any definite conclusions excepting that for angular approach and free get-away the relationship between discharge and angularity of approach appears to be well defined.

Angularity of approach, as used herein, is arbitrary. Further study of this problem may lead to generalizations valid beyond the limits of the particular studies presented here.

8. Conclusions. — (1) For radial inflow the discharge under constant head is a maximum if the clear distance between diffuser
outlet and impact plate is about 1/4 the throat diameter. For greater distances the discharge decreases rapidly, reaching about 70 per cent of its maximum value when the clear distance between tube and impact plate exceeds 1.0 diameter.

(2) For angular inflow and for clear distances between tube and impact plate equal to or greater than 1/4 the throat diameter, the discharge at constant head is virtually independent of the position of the impact plate.

(3) For angular inflow an eddy core forms about the axis of the tube, and only a ring-shaped section bounded by the walls of the tube is effective in discharging water. The position of the impact plate has little effect on the eddy core or on the discharge through the tube under conditions of non-radial entry and constant head.

II. TESTS OF DIFFUSERS WITH CONICAL INSERTS

9. Synopsis. — The glass diffuser described in Art. 4 was tested with eight conoids of different shapes attached to the impact plate coaxially with the tube. The tests included both radial and angular inflow at a constant head of 1.78 ft. Rates of flow were measured
for each installation as a function of the clear distance between base of tube and impact plate.

10. Acknowledgments. — Part II is based on a thesis\(^8\) by Hsi-Hou Chang prepared under the supervision of the senior author. Acknowledgment is gratefully made to Andreas Luksch and to Edward Soucek, research assistant engineer at the Iowa Institute of Hydraulic Research, who gave valuable assistance throughout the tests.

11. Statement of the Problem. — Previous tests of the flow of water through the glass diffuser at a constant operating head of 1.78 feet showed (1) that for radial inflow the rate of discharge through the model reached a maximum value when the impact plate was approximately 1/4 the throat diameter (0.44 in.) below the bottom of the tube; (2) that as the impact plate was lowered to a level approximately 2 in. below the tube, the rate of discharge through the model became substantially constant and equal to 70 per cent of its maximum value; (3) that for angular inflow introduced by guide vanes, the rate of discharge was substantially constant when the clear distance between diffuser and impact plate exceeded 1/4 the throat diameter; (4) that for angular inflow the principal flow through the tube took place with a kind of whirling motion, and was concentrated near the walls of the tube. Water near the axis of the tube appeared to circulate within a roughly conical space moving upward along the axis of the tube, downward along the outer surface of this hydraulic cone, and in toward the axis of the tube along the impact plate.

For angular inflow this hydraulic cone was rather well defined and relatively stable. For radial inflow, however, the flow near the axis of the tube was quite unstable as the impact plate was lowered below its position of maximum efficiency and the filaments of flow near the axis of the tube became erratic and unstable.

The foregoing observations lent support to the theory that the over-all efficiency of the diffuser might be increased by inserting a solid of revolution axially within the tube and thus replacing the unstable hydraulic cone by a solid of revolution supported on the impact plate. These solids of revolution are somewhat loosely called

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\(^8\) "Tests of a model flaring draft tube with conical inserts," by Hsi-Hou Chang. Thesis submitted in partial fulfillment of the requirements for the degree Master of Science in Hydraulics, State University of Iowa, June 1937.
Fig. 7. Details of Conoids Used in Tests.

Fig. 8. Tests of Glass Diffuser Without Conical Insert.
12. *Apparatus and Method.* — The apparatus used in these tests was in general the same as that described in Art. 4, supplemented as hereinafter described. The procedure differed in no essential details from that described in Art. 5. Only the glass model and guide vanes with angles 0, 30, 45, 60, and 90 deg. were used in these tests.

Fig. 7 shows the details of the conoidal inserts which were attached to the impact plate co-axially with the diffuser. These inserts were turned of wood, waterproofed by soaking them in linseed oil for 24 hrs. and painting them with several coats of pyralin diluted with dipping solution. Plasticine was used to extend the surfaces of Cone Nos. 2, 3, 4, 5, and 6 to the impact plate with smooth fillets.

In all of the tests with conoidal inserts, the tail water level was maintained 6 in. above the bottom of the tube. The tail water level was therefore about 2 in. higher in these tests than in those reported in Part I of this bulletin.

13. *Summary and Analysis of Data.* — Figs. 8 to 16 show a summary of the data obtained in these tests. Rates of discharge through the glass model without conical inserts as observed by Chang were consistently higher than those observed by Luksch for conditions reportedly identical. These differences were usually from 7 to 12

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*Fig. 9. Tests of Glass Diffuser with Cone No. 1.*
per cent with a maximum value of 16 per cent. Repeated tests and a careful check of all observations and sources of error after the discrepancy was noted failed to show any appreciable error in the data summarized in Fig. 8.

(a) Model with Cone No. 1

Fig. 9 shows rates of discharge as a function of the angle of approach and the position of impact plate with Cone No. 1 attached to the plate. Excepting the curve 1-30 for 30 deg. entry, the curves of Fig. 9 differ markedly from those of Fig. 8. For radial approach to the model with Cone No. 1 the rate of discharge does not reach a maximum as it does in the corresponding model without cone. For 45, 60, and 90 deg. guide vanes and Cone No. 1, however, the rates of discharge reach a well-defined maximum roughly 20 per cent greater than the corresponding limiting discharge without cone when the \( z/d_o \) ratio is one-fourth.

For angular inflow introduced by 30 deg. guide vanes the flow through the model was essentially the same as that for the model without cone.

(b) Model with Cone No. 2

Fig. 10 shows data for tests of the tube with Cone No. 2, which was similar to cone No. 1 except that the lower part was rounded with a two-inch fillet as shown. For radial entry to the diffuser
with cone No. 2 and for \( z/d_o \) ratios less than about 1/3, the discharge was less than that for cone No. 1 for the same clear distances between tube and impact plate. For \( z/d_o \) ratios greater than 1/3 the discharge through both models was the same for a given position of the impact plate.

For angular inflow induced by the 45 and 60 deg. guide vanes the discharge through the model with cone No. 2 equalled or exceeded by as much as 12 per cent the discharge through the model with cone No. 1 for \( z/d_o \) ratios greater than 0.25 and 0.20 respectively.

The discharge through both models was substantially the same for 90 degree guide vanes; the discharge through the model with cone No. 2 was greater by about 3 per cent for \( z/d_o \) ratios between .2 and .5.

(c) Model with Cone No. 3

Strictly this insert was not a cone but a surface of revolution defined by the equation \( r^2y = 1.125 \) cu. in. The curve was rounded off at the top to make a conoid 5.57 in. high.

A comparison of the test data shown in Figs. 10 and 11 indicates only minor differences in discharge for \( z/d_o \) ratios greater than .35. For smaller \( z/d_o \) ratios the discharge observed through the model with cone No. 3 was less than that with cone No. 2.

The rate of discharge indicated by the curves 3-0, 3-30, and 3-45 in Fig. 11 reached a well-defined maximum for \( z/d_o \) equal to about
.35 and a minimum for \( z/d_0 \) equal to about 1.0. This succession of maximum and minimum discharge as a function of the clear distance between diffuser and impact plate is unmistakable in Figs. 10, 11, 12, 13, and 14.
(d) Model with Cone No. 4

This conoid was defined by the equation \( r^2 y = 0.45 \) cu. in. The test data are summarized in Fig. 12.

For radial inflow, this conoid had relatively little effect on the discharge through the model for a given position of the impact plate. Comparisons of curves for axial entry shown on Figs. 8 and 12 indicate that for the same \( z/d_o \) ratio in excess of 0.25 the discharge through the diffuser was reduced less than 10 per cent by the cone.

For non-radial entry comparisons of the curves of Figs. 8 and 12 show that in all but two observations the discharge through the model with cone No. 4 was greater than that through the model without cone insert. For 45 degree entry and \( z/d_o = 0.3 \), the model with cone No. 4 discharged 20 per cent more water at the same head than did the diffuser without conical inserts.

(e) Model with Cone No. 5

Insert No. 5 was the slenderest conoid, and was defined by the equation \( r^2 y = 0.1 \) cu. in. For radial entry indicated by curve 5-0 in Fig. 13, discharge through the model was less than that through the model without cone inserts, but the difference was generally less than 5 per cent. For non-radial inflow the effect of cone No. 5 was to increase slightly the observed discharge for \( z/d_o \) ratios near 0.25

![Fig. 14. Tests of Glass Diffuser With Cone No. 6.](http://ir.uiowa.edu/uisie/13)
and to decrease the discharge by roughly the same proportion for $z/d_o = 1.0$. The net effect of this cone was to accentuate slightly the sequence of maxima and minima in discharge for 30 deg. and 45 deg. entries.

(f) Model with Cone No. 6

Fig. 14 shows a summary of the data obtained from tests of the diffuser with insert No. 6, which is a conoid defined by the equation $r^2y = 0.70$ cu. in. In size and shape it lay between No. 3 and No. 4. A comparison of the curves in Figs. 14 and 12 indicates that the discharge was substantially the same through the model with cones No. 6 and No. 4. For radial entry the capacity with cone No. 6 was slightly less, and for non-radial entry is some instances slightly more than corresponding capacities with cone No. 4.

Restricting the comparisons of discharges with cone No. 6 (Fig. 14) and cone No. 3 (Fig. 11) to $z/d_o$ ratios greater than .35, corresponding capacities of the model with cone No. 6 were slightly greater for radial entry and 10 to 12 per cent less for 60 deg. and 90 deg. entry than corresponding discharges for the model with cone No. 3. Within this range of comparison there was little systematic difference in the curves for angular entry of 30 and 45 deg.

![Fig. 15. Tests of Glass Diffuser with Cone No. 7.](http://ir.uiowa.edu/uisie/13)
(g) Model with Cone No. 7

Fig. 15 shows the data obtained from tests of the diffuser with cone No. 7, a right circular cone 4 in. high and 2 in. in diameter at the base.

The discharge through the model was little affected by the presence of cone No. 7, and the following comparisons of Figs. 8 and 15 are interesting only as respecting qualitative effects. For radial and 30 deg. entry the presence of cone No. 7 slightly reduced the discharge through the model for $z/d_0$ ratios less than about .3. For 45 and 60 deg. entry, observed discharge through the model with cone No. 7 was consistently somewhat higher (less than 10 per cent) than the discharge through the diffuser without inserts. For 90 deg. entry the presence of cone No. 7 accounted for 15 per cent and 10 per cent additional discharge for $z/d_0$ equal to 0.1 and 0.15 respectively.

(h) Model with Cone No. 8

Fig. 16 shows a summary of test data for flow through the diffuser with cone No. 8. This insert was a right circular cone similar to cone No. 1, supplemented by a 2-inch fillet at its base. The characteristic curves for cone No. 8 and cone No. 4 (Fig. 12) are substantially identical.

![Graph of discharge vs. ratio z/d₀ for Cone No. 8](http://ir.uiowa.edu/uisie/13)

**Fig. 16. Tests of Glass Diffuser With Cone No. 8.**
14. Conclusions. — (1) The conclusions set forth in Part I, Art. 8 were confirmed by the tests reported in Part II.

(2) For radial inflow none of the conoids tested increased appreciably the efficiency of energy conversion in the diffuser — as measured by rate of discharge through diffuser at constant head.

(3) For non-radial inflow the greatest efficiency of energy conversion — as measured by rate of discharge through diffuser at constant head — was generally increased by all inserts excepting the shortest cone and the slenderest conoid.

(4) Through the diffuser with 0, 30, and 45 deg. entry and with inserts defined by the surface \( r^2 y = \text{constant} \), the discharge consistently reached a maximum for \( z/d_o \) near 0.3 and a minimum for \( z/d_o \) near 1.0. An inspection of the curves showing mean velocities throughout the tube has suggested no satisfactory explanation.
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