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Flow of Liquids Through Vertical Circular Orifices and Triangular Weirs

By

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Professor of Hydraulic Engineering

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Nomenclature

α—Central angle of weirs in degrees (deg.)
λ—Kinematic viscosity in square feet per second (sf/s)
ω—Weight in pounds per cubic foot (p/cf); in pounds per minute (p/m)
φ—Parameter, h/d
ρ—Density in slugs per cubic foot (sl/cf)
σ—Surface tension in pounds per foot (p/f)
a—Cross-sectional area of an orifice in square feet (sf)
C—Coefficient of discharge
C_c—Critical coefficient of discharge
d—Diameter of orifice in inches (in)
g—Gravitational acceleration, assumed equal to 32.2 feet per second per second (f/s/s)
h—Elevation head in inches of liquid (in)
h_c—Critical elevation head in inches of liquid (in)
q—Actual rate of discharge
R—Reynolds number
T—Temperature in degrees Fahrenheit (deg. F)
V—Theoretic velocity of the jet in feet per second (f/s)
W—Weber number

Flow of Liquids Through Vertical Circular Orifices and Triangular Weirs

PART I. ORIFICES AND WEIRS

1. Introduction. The flow of all fluids is governed by one immutable law of nature. This law may be expressed mathematically by the Bernoulli equation, the derivation of which is based on either the theory of momentum change or the principle of the conservation of energy, the latter being employed throughout the following discussion. Variations in the behavior of different fluids under like conditions of head or pressure, type of channel or opening, and roughness of the retaining surfaces are caused chiefly by dissimilarity in the physical properties of the fluids, including viscosity, density, surface tension, adhesion, etc.

The data needed to correlate the variations in the physical properties with rates of flow are all too meager and often contradictory. It was with the hope of adding to the fund of information concerning free discharge of liquids from circular orifices and triangular weirs that this investigation was made, with special reference to any dependency of the discharge coefficient upon both the Reynolds and the Weber numbers.

The experiments were performed in the Hydraulics Laboratory, School of Civil Engineering and Engineering Mechanics, in co-operation with the Engineering Experiment Station.

2. Acknowledgments. In sincere appreciation of the services rendered him, the author acknowledges his indebtedness to the following individuals: Professor W. E. Howland; Major W. I. Freel, on leave of absence; Mr. Ward Miller, one-time instructor; Mr. W. C. Killin, instructor; and former students Mr. R. C. Burns, Mr. R. H. Bettys, Mr. E. H. A. Smitker, Mr. S. H. Stoner, and Mr. C. A. P. Thomas.

3. Outline of Investigation. The experiments were performed with two different sets of equipment; one designated Apparatus A, Figs. 1 and 2, for the accommodation of flow under low heads, and the other termed Apparatus B, Fig. 3, for higher heads and correspondingly greater rates of discharge. The experiments on the orifices were divided into two groups, comprising Series I and II, and performed on Apparatus A and B, respectively. All weirs were tested with Apparatus B and comprise Series III. The experiments in

Series I dealt with the effects of both kinematic viscosity and surface tension upon the coefficient of discharge, while those in Series II and III were concerned almost exclusively with surface tension.

All orifices and weirs were cut from smooth brass plates, 0.25 in. thick, in the University shops. The upstream edge of each aperture was square with the inner face of a plate. Beveling a plate at an angle of 30 deg. to the plane of an orifice or a weir made certain that the escaping stream touched the boundary of an opening along a line represented by the upstream edge. The diameters of the orifices were 0.252, 0.381, 0.502, 0.625, 0.754, 0.875, 1.00, 1.50, and 2.00 in. The central angles of the weirs were 30, 60, and 90 deg. The symmetry of the latter openings was marred slightly by small deformations in the vicinity of the vertexes. Although the discharge coefficients of these slightly imperfect notches are not acceptable as standard values, nevertheless the experiments thereon are significant for comparing the effects of the physical properties of a liquid upon the coefficients of any one weir. The liquids were cylinder oil, furnace oil, a mixture of cylinder and furnace oils, soap solutions using softened water, an admixture of DuPont's alkanol and water, sucrose solutions, and water. The specific weight, absolute viscosity, and static surface tension of the oils, soap solutions, and admixtures were measured with standard instruments. Like physical properties of water were noted in the *International Critical Tables,* numerous previous laboratory tests having indicated the water in the laboratory to be similar to distilled water within the limits of experimentation. The following references were used to obtain the characteristics of the sucrose solutions: *U. S. Bureau of Standards Bulletin,* Volume 14; *Lange's Handbook of Chemistry,* 4th edition; and *Handbook of Chemistry and Physics* by F. F. Young and W. D. Harkins, 26th edition.

Stopwatches, weighing scales, and other instruments were calibrated at least twice during the investigation. The head on the various apertures, at all times sufficient to insure free discharge, was measured at room temperatures with a piezometer and a hook gage attached externally to the approach channel, and by a hook gage located within the channel when the temperature of a liquid was above that of the atmosphere. The maximal head on the 0.754-in. and 0.875-in. orifices, used with apparatus A, was limited to less than the desired height by the relatively small capacity of the pump producing circulation. The height of the channel walls in all other instances determined the range in head.

The physical condition of the approach channels, especially as concerns the interior surfaces in the vicinity of the discharge openings, remained unchanged, a fact providing a better comparison of the effects of the physical properties of the several liquids upon the discharge coefficient than is possible when experiments are conducted in different laboratories with different channels of approach. The conclusions reported herein are applicable within the limits of shape and size of discharge opening, the head causing flow, and the physical properties of the fluids used in the investigation. It is undeniable that definite correlations must exist as concerns head, size and shape of aperture, and physical properties of the escaping liquids; but the information now in print fails to disclose the exact nature of such relations. A great deal of research on the subject remains to be done; and it may well be that certain pertinent data will remain unavailable as, for instance, the exact length of the perimeter of the nappe issuing from a weir, a distance necessary for computation of the effect of the true surface tension.

4. Description of Apparatus A. The apparatus, photographs of which appear in Figs. 1 and 2, included the following essential components: approach channel, cathetometer, discharge tank, piezometer, pumping unit, storage basin, wasteway, and weighing scales. The channel of approach, 20 in. long, 15 in. wide, and 15 in. high, was made of galvanized iron with the exception of a removable, brass downstream end or plate. Each plate, in which a given orifice had been cut, was held in place by 16 capscrews, leakage being prevented by an intervening rubber gasket. The inflow to the channel, controlled by a valve in the 1-in. supply line, was released near the channel floor and through a series of small holes on the upstream side of a horizontal header, made from 2-in. pipe, capped at both ends. Three perforated galvanized iron baffles, inserted between the inlet and the opening to the piezometer connection, effectively eliminated the disturbance created by the incoming liquid. Preliminary tests disclosed slight deflections in the wood supports upon which the approach channel rested. A substituted base of concrete blocks proved satisfactory.

Fig. 1 shows from front to rear, left-center, an engineer's level, the cathetometer, and the gage for measuring the relative elevation of the liquid surface within the piezometer. To the right of the center-line appears the approach channel, from which oil is being discharged through a small orifice into the moveable wasteway and thence through a hose into the storage basin. Directly below the wasteway is the discharge tank supported on weighing scales. To the far right is shown the pumping unit, circulating liquid from the storage basin to the approach channel, flow being controlled by a valve in the discharge line from the pump. The instruments for measuring the physical properties of the several liquids under test are arranged on the far left side of the photograph. Fig. 2 presents a close-up view of the main portion of the plant, the wasteway moved to permit flow directly into the discharge tank.

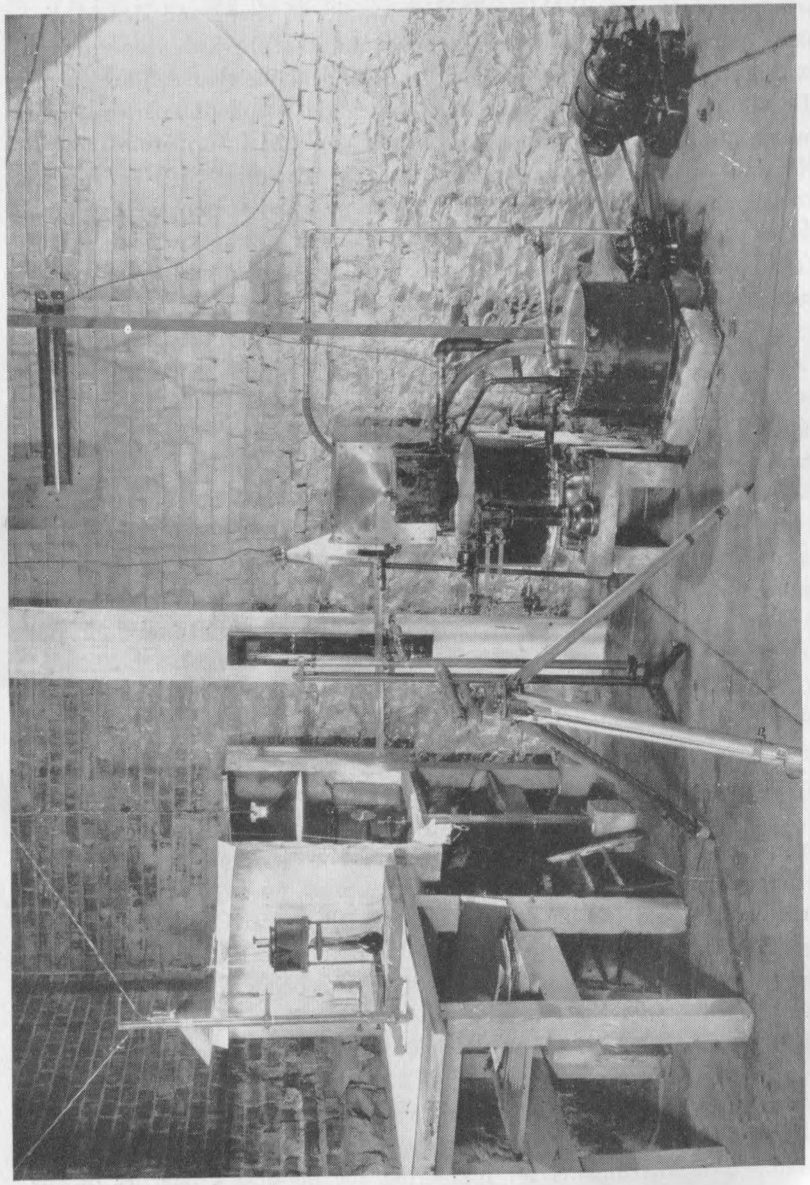

FIG. 1. APPARATUS A.

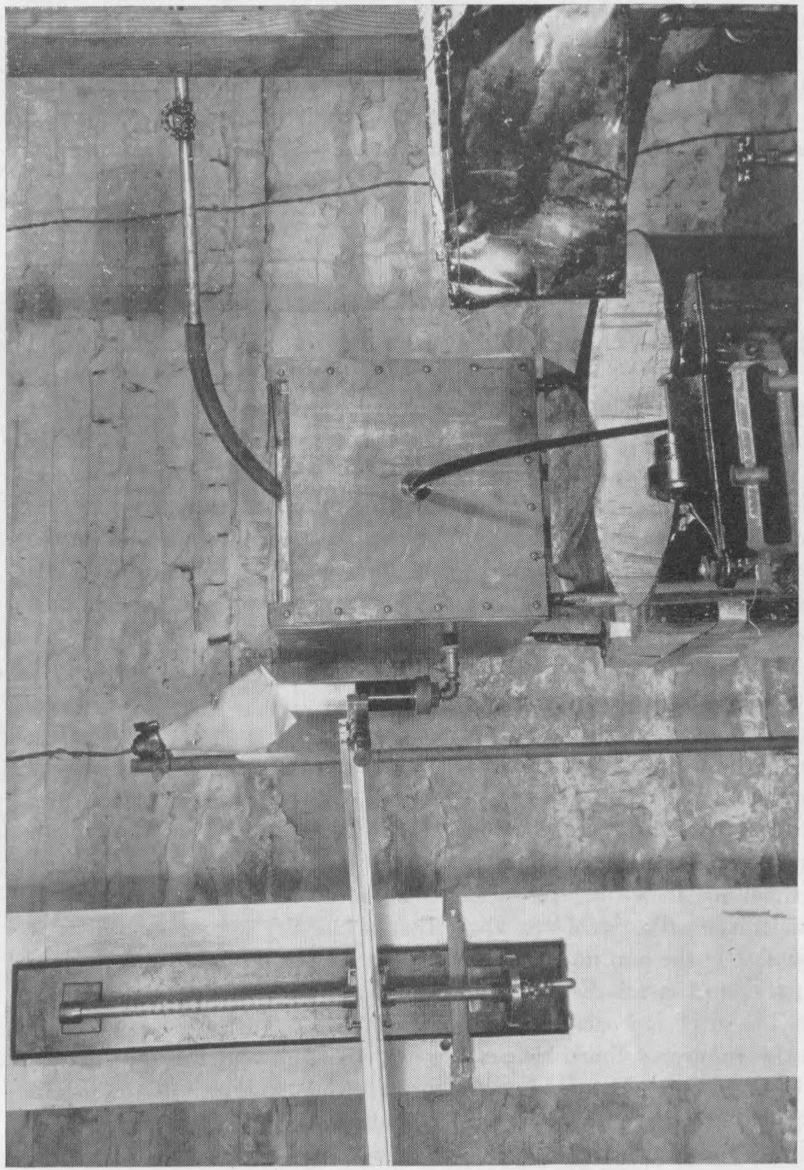

FIG. 2. CLOSE-UP VIEW OF PART OF APPARATUS A.

The weighing scales were of the conventional platform type, with the smallest increment of load equal to 0.50 oz. The cathetometer, used to ascertain the reading on the piezometer corresponding in elevation to the bottom of an orifice, was composed of three units: a telescope extracted from an engineer's level; a vertical, threaded shaft supported on bearings, on which the telescope was mounted; and a stand to support both shaft and telescope. Vertical motion of the telescope was produced by rotation of the shaft. One set of screws was provided to level the telescope and another set was used to adjust the shaft to a true vertical position.

The pump, a rotary unit donated by the G. D. Roper Corporation, was belt driven by a small motor. The piezometer consisted primarily of a vertical 1.625-in. glass tube with a 0.25-in. connection, opening into the approach channel at a distance of 4 in. above the bottom and 15 in. upstream from the discharge end of the channel. Elevation of the liquid surface in the glass tube was determined with the aid of a telescope mounted on a carriage, which in turn was actuated vertically by a screw operated by a crank wheel. A vernier attached to the wheel allowed elevations to be noted to 0.001 in. The wasteway, or diversion tank, was arranged so that it could be swung horizontally to divert the flow from the approach channel to the storage basin between tests. The discharge tank also emptied into the same basin, which in turn formed the sump for the pump.

5. Description of Apparatus B. The second apparatus, B, illustrated diagrammatically minus certain auxiliary elements in Fig. 3, was similar in general plan to apparatus A, the two setups differing mainly in size. The telescopic attachment to the piezometer was omitted. One hook gage was arranged with an exterior, glass-sided stillbox to measure the head on the weirs with flow at atmospheric temperature. A second such gage was placed within the approach channel for measuring the head on both orifices and weirs when the temperature of a liquid was above that of the air, and steam coils were installed in the two interconnected storage tanks of 1,500-gal. combined capacity to control the temperature of the liquids.

The steel approach channel (Fig. 3) was 5 ft. long, 3.5 ft. wide, and 4 ft. deep. Suitable openings were provided in the downstream side to accommodate the various brass orifice and weir plates. The liquids flowed by gravity from the storage tanks to a centrifugal pump, which discharged through a 2-in. pipe into an overhead, vertical, cylindrical, constant-head tank of approximately 200 gal. capacity. The function of this reservoir was to maintain constant heads in the channel of approach. This operation was accomplished by diverting excess flow through a relatively large wasteway near the top of the tank. The flow from this tank to the approach channel was by gravity feed through a 2-in. pipe into a perforated, horizontal header, opening upstream, and located near both the bottom and the upstream side of the channel. Any disturbance then remaining in the incoming current was dissipated by a baffle, constructed of wire mesh and concrete fragments. Flow from the orifices and the weirs was directed through small flumes into the diversion trough, from which channel the discharge was guided by ducts into either the weighing tank resting upon the platform scales or into the storage basins. The piezometer, graduated to 0.001 ft., was used to measure the head on all orifices when the liquids were at room temperature.

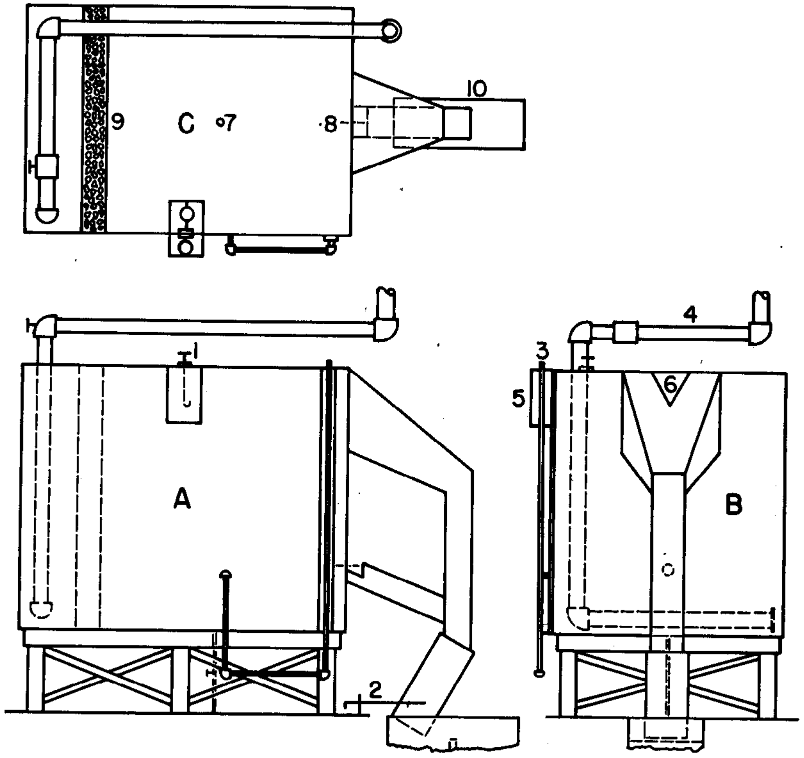

Fig. 3. Diagram of Apparatus B.

A. B. C.—Side, end, and top views, respectively. 1. Hook gages. 2. Lever. 3. Piezometer. 4. Supply pipe from constant-head tank. 5. Stillbox. 6. Triangular weir. 7. Drain. 8. Centerline of orifices. 9. Baffle. 10. Diversion trough discharging into weighing tank or into storage basins.

6. Method of Testing. The initial step in the procedure with apparatus A, used to calibrate orifices from 0.252 in. to 0.875 in. in diameter, was to check the vertical alinement of the orifice plate with

the use of a transit and a spirit level. The diameter of an orifice was assumed equal to the average of four measurements, two horizontal and two vertical, made with inside micrometer calipers accurate to 0.001 in. Corresponding measurements, used for checking purposes, were made on an enlarged photograph of the orifice, the correct scale ratio between image and prototype being interpreted from a separate photograph of a lineal steel scale placed on a horizontal line projected from the center of the orifice. The next step was the determination of the reading on the piezometer corresponding to zero head after the approach channel had been partially filled with liquid. The cross-hair in the piezometer telescope was adjusted to a horizontal position by making it coincident with the upper line formed by the meniscus. The line of collimation through the piezometer telescope was in turn made horizontal by adjustment of a screw arranged for that purpose. An accurate check on the leveling of this latter telescope was made possible by setting up an engineer's level at a convenient distance and sighting first on the line through the point of intersection of the cross-hair attachment and then on the center of the eyepiece. The telescope, maintained at this same level and rotated about its vertical axis, was sighted on the cross-hair attachment of the piezometer telescope and the reading on the piezometer was noted to 0.001 in. A similar procedure was used to obtain a reading at the bottom of the orifice. The average of two sets of readings was used in the computations.

The minimal head at which the jet from an aperture will spring clear will be affected to at least a slight degree by the manner in which the head is changed; that is, whether the head is being raised on a dry surface or being lowered on a wet surface. This variation is caused by differences in adhesion on the surfaces. In order to maintain like conditions throughout the investigation, all tests were made by first using maximal head, the flow being later decreased in successive stages. The efflux was directed into the discharge tank during a test and into the wasteway between tests. Readings of the head were noted at equal time intervals, thus giving like consideration to each reading. The head was in all instances sufficient to create free discharge, the mean value of several readings of the head during a test being used in the calculations. The temperature of the jet was measured before and after each test to the nearest 0.50 deg. F. Samples of the discharged liquids were extracted at frequent intervals for analysis of their physical properties. The various elements of the apparatus were cleansed thoroughly after use with each particular liquid, mixture, or solution.

Orifices with diameters of 0.502, 1.00, 1.50, and 2.00 in. and the three weirs were calibrated with apparatus B. The procedure was similar in most respects to that employed with apparatus A. It was deemed unnecessary, however, to pursue the same high degree of refinement in measurements of the head and discharge because the experiments were concerned with larger apertures and hence relatively greater values of the parameter φ, ratio of head to diameter, than was possible with apparatus A.

A cathetometer was again employed to determine the zero head on both the orifices and the weirs. Checking the elevation of the bottom of an orifice and the vertex of a notch was considered accomplished when (a) the lighted surface of a liquid within the approach channel was free from curvature as observed from beyond an aperture, and (b) the base of the image of the discharge opening, cast upon the liquid surface, coincided with that of the aperture. As mentioned previously, the head on the orifices was observed on a piezometer and that on the weirs was noted with a hook gage and glass-sided stillbox, both instruments located on the exterior surface of the approach channel, when the flowing liquid was at room temperature.

The physical properties of a liquid in a stillbox or in a piezometer will differ from those of the same fluid in the approach channel to which the devices are attached whenever a differential temperature exists in the system. Therefore the hook gage was suspended within the channel to measure the head on both orifices and weirs when tests were conducted at temperatures of liquids higher than that of the atmosphere, the piezometer being discarded meanwhile. In its exterior position, the hook gage was set to indicate zero head when the point of the hook coincided with its reflection in the liquid surface as viewed from below. Manipulation of the gage followed standard practice when the instrument was placed within the channel, the hook being first lowered below the liquid surface, then raised until the point formed a bulge in the surface, and finally lowered until the protuberance first disappeared. Steam rising from water surfaces at high temperatures caused difficulty at times in obtaining precise readings with the gage The above-room temperatures of the liquids were controlled by heating coils located near the bottoms of the two storage tanks and connected to the laboratory high-pressure steam line. Repeated tests proved the loss of weight per test by evaporation from the discharge tank to be a negligible factor, not exceeding 0.25 p/m at the highest temperature used.

The weir plates were reinforced along the top edge with flat steel bars in order to preserve alinement. Central angles of the notches were measured directly with protractors and checked geometrically from tracings of the openings.

It was impossible to experiment with the oils and the sucrose solutions using apparatus B because of the difficulties involved in cleaning the entire system after the use of each liquid and because of the relatively high financial outlay required in the purchase of the several types of fluids.

PART II. ORIFICES

7. RESULTS. The original data pertaining to the head, *h*, on the center of an orifice and the actual rate of discharge, *q*, for both Series I and II, were first plotted to a very large scale. On the resulting graphs, one for each liquid flowing at constant or near-constant temperature through an orifice, the actual rate of discharge was scaled for stated increments of head. The theoretic velocity of the jet at corresponding heads was computed, using the Bernoulli equation. The actual rate of discharge divided by the product of the area of the orifice and the theoretic velocity of the jet gave us as a quotient the coefficient of discharge, or

$$C = \frac{q}{a\,V} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

Exponential equations, derived from the original data to correlate head and actual discharge rate, were used to check values of the coefficient.

The discharge coefficient, Reynolds number, and the Weber number for various increments of head on the several orifices are enumerated in Tables 1-62, inclusive, pages 28-62. The variation in the discharge coefficient with change in head is illustrated graphically in Figs. 4-13.

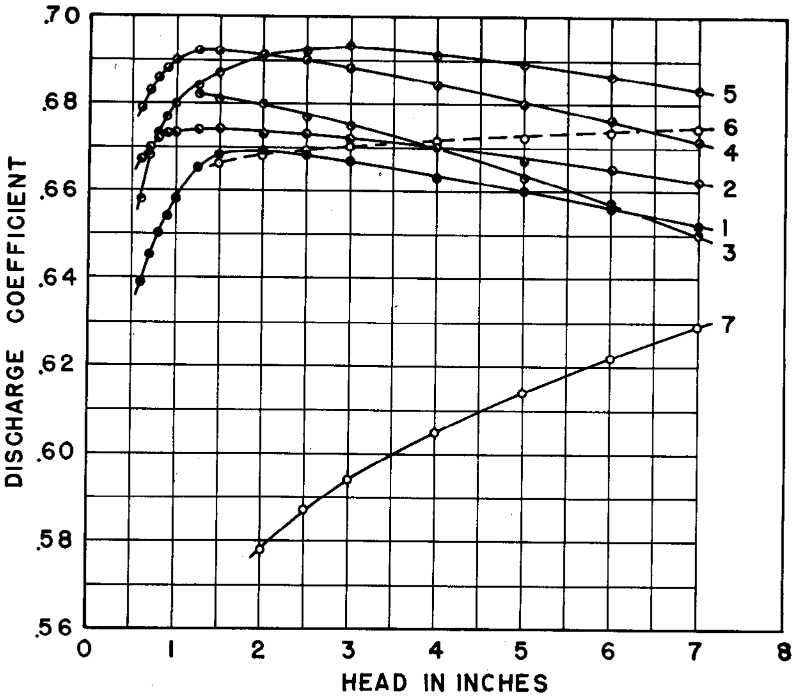

FIG. 4. RELATION OF DISCHARGE COEFFICIENT TO HEAD, 0.252-IN. ORIFICE. SERIES I.

Graph No.	Fluid	Density Sl/cf	Kinematic Viscosity Sf/S	Surface Tension P/f
1	Water	1.94	.000 0110	.00499
2	20.8% Su.	2.11	.000 0202	.00507
3	Furn. Oil	1.62	.000 0381	.00211
4	41.3% Su.	2.28	.000 0610	.00515
5	54.7% Su.	2.45	.000 226	.00526
6	Mixture	1.71	.000 678	.00226
7	Cyl. Oil	1.74	.00 227	.00233

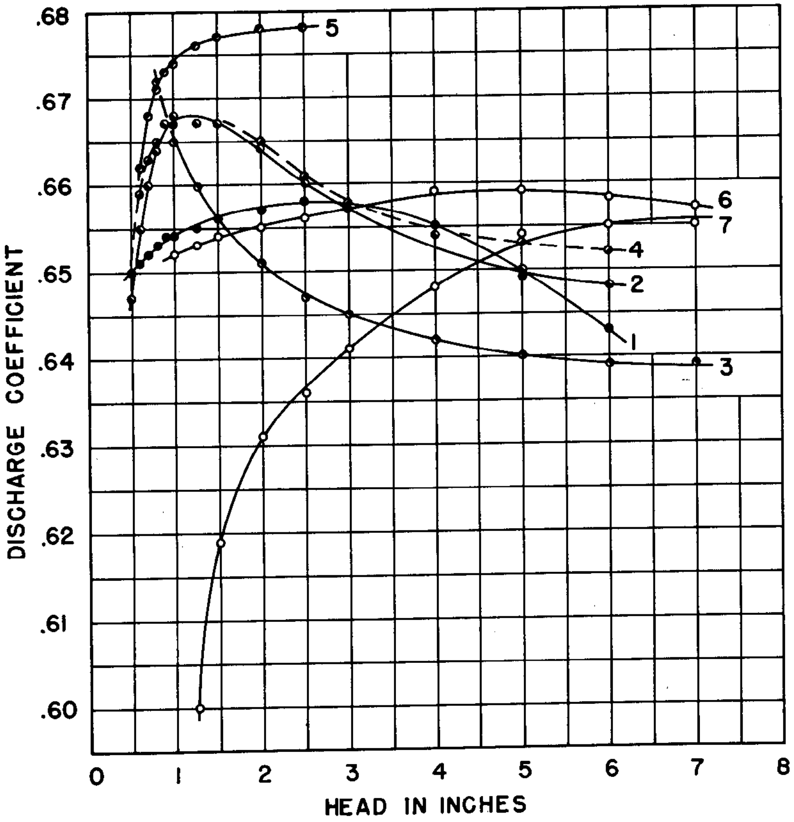

FIG. 5. RELATION OF DISCHARGE TO HEAD, 0.381-IN. ORIFICE. SERIES I.

Graph No.	Fluid	Density Sl/cf	Kinematic Viscosity Sf/S	Surface Tension P/f
1	Water	1.93	.000 0106	.00497
2	21.2% Su.	2.10	.000 0202	.00507
3	Furn. Oil	1.61	.000 0330	.00209
4	41.3% Su.	2.28	.000 0590	.00514
5	58% Su.	2.45	.000 310	.00524
6	Mixture	1.72	.000 702	.00228
7	Cyl. Oil	1.73	.00 185	.00229

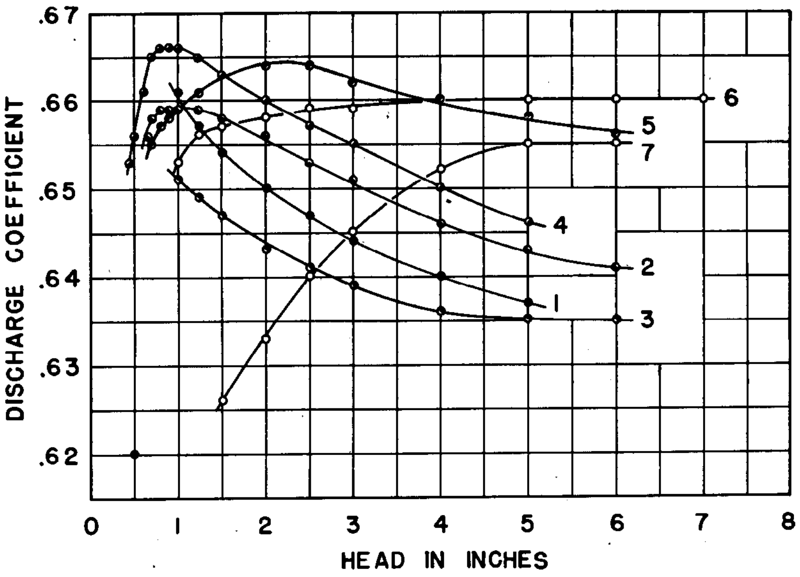

FIG. 6. RELATION OF DISCHARGE COEFFICIENT TO HEAD, 0.502-IN. ORIFICE. SERIES I.

Graph No.	Fluid	Density Sl/cf	Kinematic Viscosity Sf/S	Surface Tension P/f
1	Water	1.94	.000 0106	.00498
2	21.2% Su.	2.10	.000 0209	.00509
3	Furn. Oil	1.61	.000 0301	.00208
4	39.7% Su.	2.28	.000 0566	.00514
5	54.7% Su.	2.45	.000 232	.00526
6	Mixture	1.71	.000 692	.00227
7	Cyl. Oil	1.74	.00 204	.00232

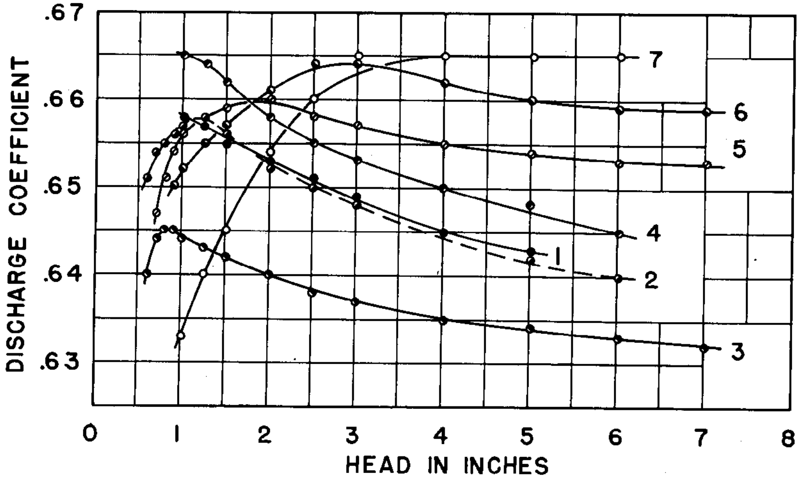

FIG. 7. RELATION OF DISCHARGE COEFFICIENT TO HEAD, 0.625-IN. ORIFICE. SERIES I.

Graph No.	Fluid	Density Sl/cf	Kinematic Viscosity Sf/S	Surface Tension P/f
1	Water	1.94	.000 0110	.00499
2	21.2% Su.	2.10	.000 0199	.00508
3	Furn. Oil	1.61	.000 0315	.00208
4	39.7% Su.	2.28	.000 0566	.00514
5	54.7% Su.	2.45	.000 226	.00526
6	Mixture	1.70	.000 628	.00224
7	Cyl. Oil	1.72	.00 177	.00225

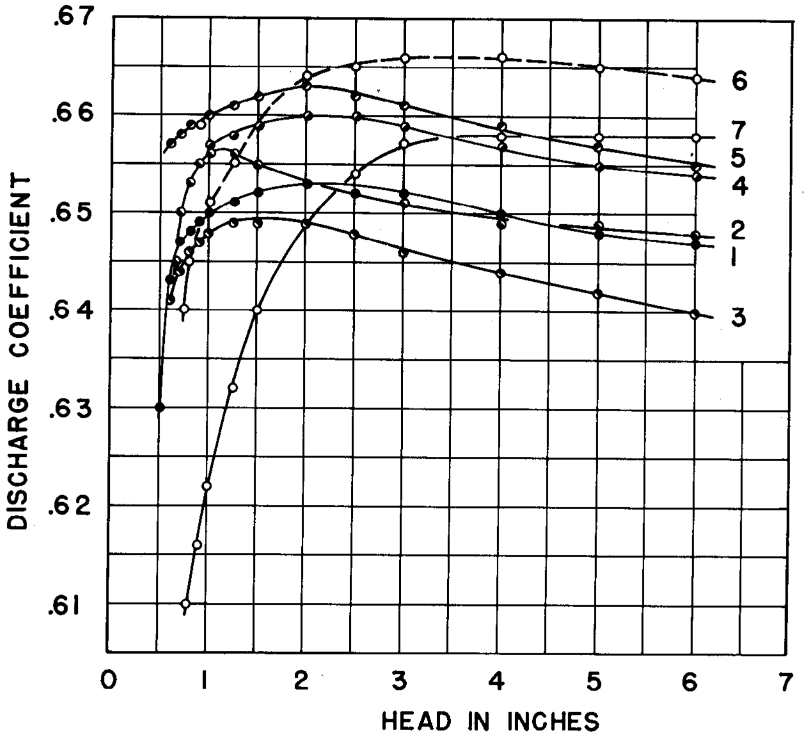

FIG. 8. RELATION OF DISCHARGE COEFFICIENT TO HEAD, 0.754-IN. ORIFICE. SERIES I.

Graph No.	Fluid	Density Sl/cf	Kinematic Viscosity Sf/S	Surface Tension P/f
1	Water	1.94	.000 0114	.00501
2	20.8% Su.	2.10	.000 0207	.00507
3	Furn. Oil	1.61	.000 0349	.00209
4	41.3% Su.	2.28	.000 0590	.00514
5	54.7% Su.	2.45	.000 213	.00526
6	Mixture	1.71	.000 648	.00225
7	Cyl. Oil	1.74	.00 249	.00234

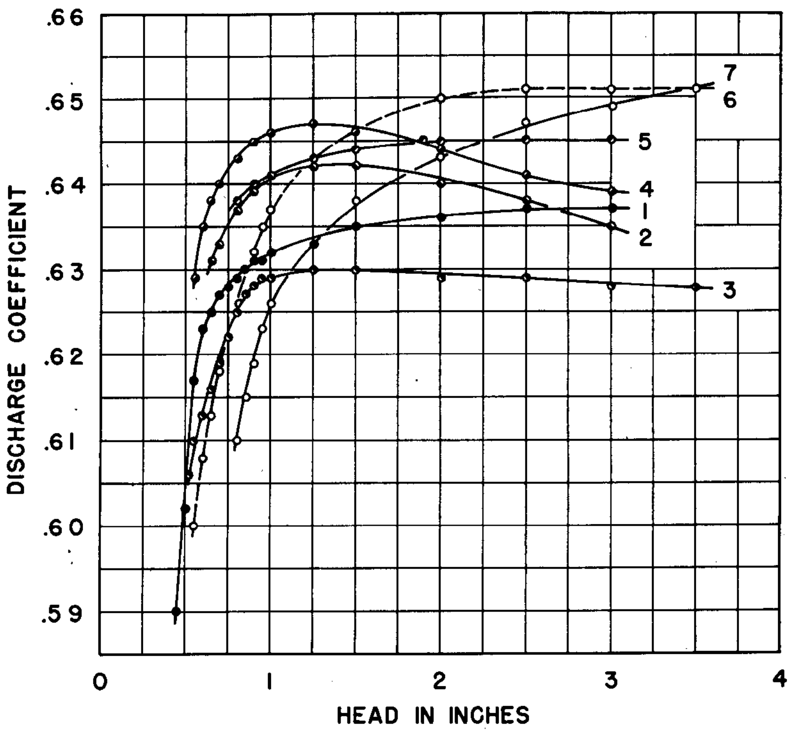

FIG. 9. RELATION OF DISCHARGE COEFFICIENT TO HEAD, 0.875-IN. ORIFICE. SERIES I.

Graph No.	Fluid	Density Sl/cf	Kinematic Viscosity Sf/S	Surface Tension P/f
1	Water	1.94	.000 0107	.00498
2	21.2% Su.	2.10	.000 0187	.00505
3	Furn. Oil	1.61	.000 0292	.00207
4	39.7% Su.	2.28	.000 0508	.00512
5	54.7% Su.	2.45	.000 232	.00526
6	Mixture	1.70	.000 603	.00222
7	Cyl. Oil	1.73	.00 182	.00229

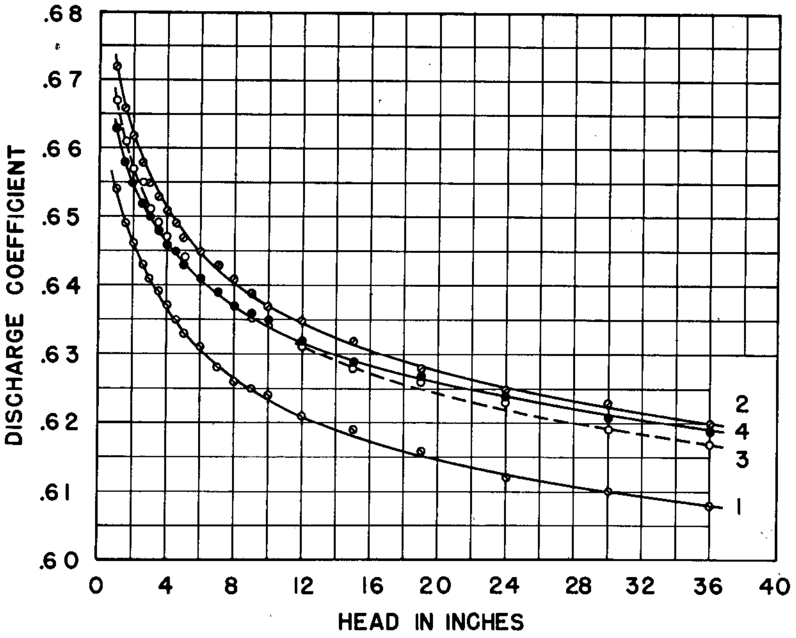

FIG. 10. RELATION OF DISCHARGE COEFFICIENT TO HEAD, 0.502-IN. ORIFICE. SERIES II.

Graph No.	Fluid	Temp. Deg.F	Density Sl/cf	Kinematic Viscosity Sf/S	Surface Tension P/f
1	Water	177	1.88	0.000 00393	0.00428
2	Alkanol Sol.	78	1.93	.000 00954	.00202
3	Water	64.4	1.93	.000 0114	.00500
4	Water	61.5	1.94	.000 0119	.00502

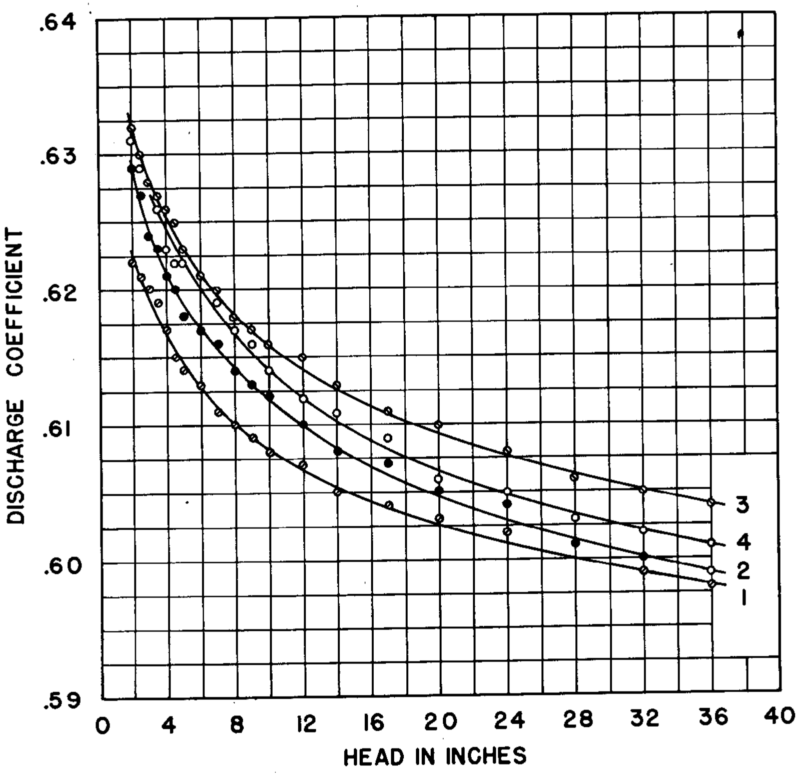

FIG. 11. RELATION OF DISCHARGE COEFFICIENT TO HEAD, 1.00-IN. ORIFICE. SERIES II.

Graph No.	Fluid	Temp. Deg.F	Density Sl/cf	Kinematic Viscosity Sf/S	Surface Tension P/f
1	Water	176	1.89	0.000 00396	0.00429
2	Water	98.1	1.93	.000 00755	.00480
3	Alkanol Sol.	62.6	1.94	.000 0117	.00252
4	Alkanol Sol.	61.7	1.94	.000 0119	.00256

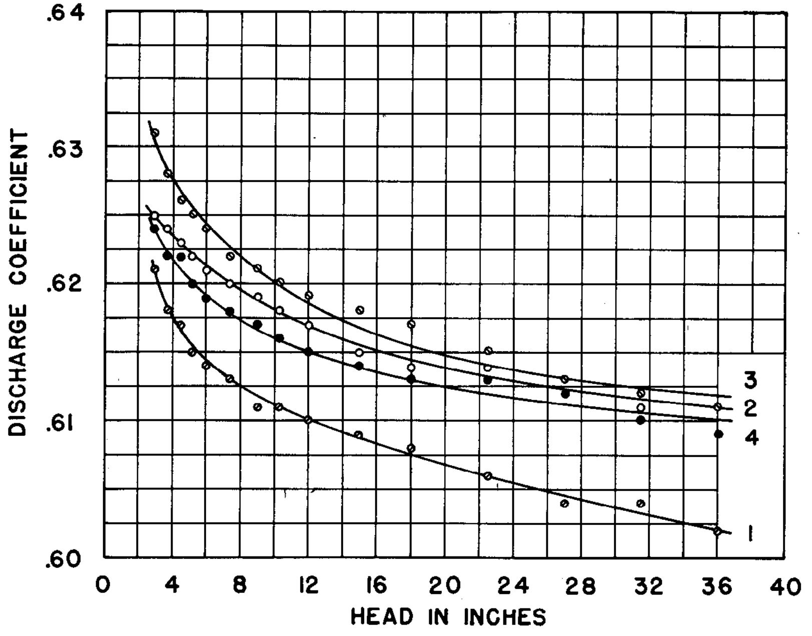

FIG. 12. RELATION OF DISCHARGE COEFFICIENT TO HEAD, 1.50-IN. ORIFICE. SERIES II.

Graph No.	Fluid	Temp. Deg.F	Density Sl/cf	Kinematic Viscosity Sf/S	Surface Tension P/f
1	Water	178	1.88	0.000 00391	0.00427
2	Alkanol Sol.	76.1	1.93	.000 00991	.00208
3	Alkanol Sol.	68.0	1.94	.000 0109	.00235
4	Water	61.7	1.94	.000 0119	.00502

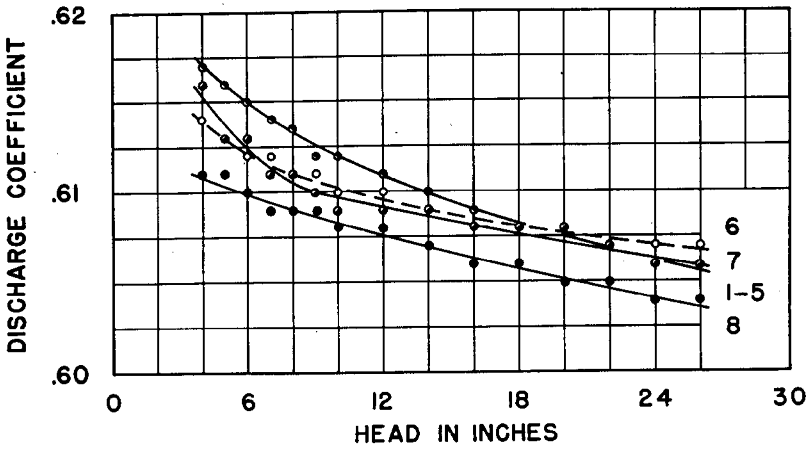

Fig. 13. Relation of Discharge Coefficient to Head, 2.00-in. Orifice. Series II.

Graph No.	Fluid	Temp. Deg.F	Density Sl/cf	Kinematic Viscosity Sf/S	Surface Tension P/f
1	.03% Soap	140	1.91	0.000 00497	0.00246
2	.06% Soap	142	1.91	.000 00571	.00202
3	.10% Soap	138	1.91	.000 00578	.00239
4	.06% Soap	120	1.92	.000 00641	.00351
5	.10% Soap	115	1.92	.000 00685	.00364
6	Water	112	1.92	.000 00687	.00396
7	Alkanol Sol.	74.3	1.93	.000 00991	.00214
8	Water	60.8	1.94	.000 0120	.00503

It will be noted in all experiments in Series I for which complete data were available that the discharge coefficient increased rapidly to a maximal value as the head was raised above the minimal height necessary to insure free discharge. The maximal coefficient is referred to as the *critical coefficient,* and the corresponding head is termed the *critical head.* Further increase in the head above its critical value resulted in a continual decrease in the coefficient. Similar results were observed by Hamilton Smith* in his study of the flow of water through vertical, thin-edge, circular orifices of diameters between 0.20 and 1.0 ft. It is evident from the present investigation that for any one orifice the critical head was dependent upon the kinematic viscosity of the liquid if the surface tension is considered ineffective, as is apparently demonstrated by the experiments comprising Series II. It is likewise evident that the maximal available head in apparatus A was too small to produce the critical coefficient for all liquids and orifices under test.

A brief experiment, quite apart from the investigation proper, was made to determine the relative minimal values of the parameter φ for both water and standard gear lubricant (S.A.E. 140) at which the jet would spring clear from a vertical, sharp, square-edged, 0.125-in. diameter orifice formed in the wall of a large glass vessel. The room temperature was 70 deg. F. The value of φ was approximately 5.6 for water. A maximal available φ equal to 488 was insufficient to create a jet of the oil.

The critical discharge coefficient, C_c, for any one liquid issuing from a particular orifice in Series I, did not vary by more than 2% from the average C_c for all liquids flowing through the same opening. Furthermore, the variation was unrelated to both the kinematic viscosity and surface tension of the fluids used. Hence, it is fair to assume that the critical coefficient of discharge was independent of both type and temperature of the discharged liquid. The relative constancy of this critical coefficient for a stated aperture was not anticipated because the difference in frictional resistance at a given head between the several liquids and the interior surface of an orifice plate, affecting the tangential

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* *Hydraulics,* by Hamilton Smith, Jr., page 58.

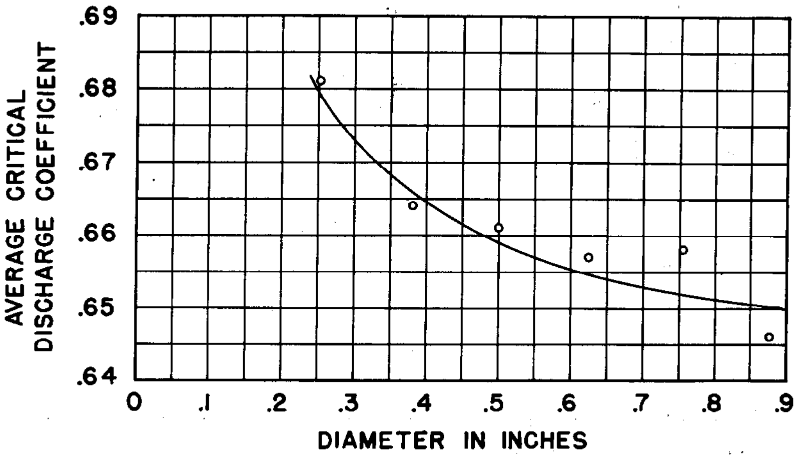

Fig. 14. Relation of Average Critical Discharge Coefficient for All Liquids to Diameter of Orifice. Series I.

d, in.	0.252	.381	.502	.625	.754	.875
C_c	.681	.664	.661	.657	.658	.646

velocities of approach, was expected to have a greater effect upon the discharge coefficient than was apparent.

The following data, graphed in Fig. 14 for Series I, establish a fairly consistent relation between the critical coefficient and the diameter of an orifice, irrespective of the discharging stream.

Fig. 15 was plotted in an endeavor to trace a possible correlation between the critical head, h_c, and the kinematic viscosity, λ, for each orifice in Series I. The connecting lines between points have been drawn to aid in the interpretation of the graphs and are not intended to show true relations between the critical head and the kinematic viscosity. Such true relations would be curvilinear, for there could be no such abrupt changes as drawn with incompressible fluids. Several additional points would have been added to the graphs had it been possible to obtain values of the critical head for cylinder oil flowing through orifices of diameter 0.50 in. and less. Apparently the minimal critical head occurred when the kinematic viscosity was equal to approximately 0.00003 sf/s.

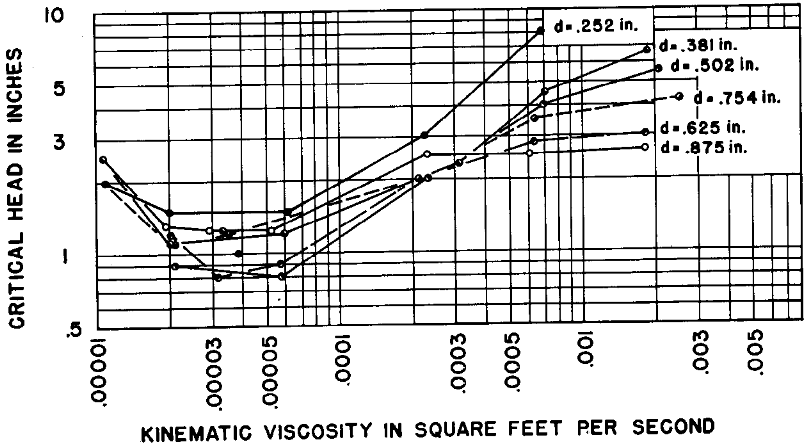

FIG. 15. RELATION OF CRITICAL HEAD TO KINEMATIC VISCOSITY. SERIES I.

The results failed to show a relation between the Reynolds number or the Weber number and the discharge coefficient. It has already been shown that the same coefficient may sometimes be applied at two different heads and consequently for two different Reynolds numbers, referred to the same orifice and the same liquid at given temperature. The Reynolds number as herein adapted to orifices has been evaluated by the expression

$$R = \frac{d\,V}{\lambda} = \frac{d\sqrt{2\,gh}}{\lambda} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (2)$$

where d is the diameter of the orifice in feet; g is equal to 32.2 feet per second per second; h is the head above the center of the orifice in feet; V is the theoretic velocity of the jet at the critical section in feet per second; and λ is the kinematic viscosity of the liquid in square feet per second.

Equation (2), in general use, is subject to criticism. For instance, d is measured in the plane of the orifice while V is computed at the critical section of the jet. Hence, the numerator of the fraction is inconsistent with the law governing the continuity of flow. It is often assumed as a matter of convenience that the jet issuing from a circular orifice is of the form and size of the aperture itself. This hypothesis is unwarranted, being in direct conflict with fact. Observation indicated that the jet for heads less than critical will be oval in cross-section.

The experiments in Series II were made at heads equal to or greater than critical values. Consequently, as shown in Figs. 10-13, the discharge coefficient decreased with increase in head in much the same manner as was demonstrated in Series I. No evidence was uncovered to disprove a previous statement that the coefficient of discharge was independent of Reynolds number as applied to a series of orifices. The kinematic viscosities of the soap solutions were very nearly equal to that of water, and, therefore, any difference in the discharge coefficients of the two types of fluids for like heads and diameters was attributable to surface tension. The admixtures of alkanol and water were identical with those of water except with respect to surface tension, the maximal range of which physical property was from 0.00202 p/f for the admixture to 0.00503 p/f for water. Inasmuch as the discharge coefficients for the admixture and the water, computed to three significant digits, did not differ by more than 1.50% with like conditions of diameter, head, and temperature, it became evident that the coefficient of discharge was uninfluenced by surface tension. Therefore, the coefficient could not be predicted from known values of the Weber number, which, as used herein, was calculated by the expression

$$W = \frac{V^2 d\varrho}{2\,\sigma} = \frac{ghd\varrho}{\sigma} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (3)$$

in which d, g, h, and V are expressed in the same terms as used in equation (2); ϱ is the density in slugs per cubic foot; and σ is the surface tension in pounds per foot. This expression is subject to the same general criticism as was applied to the formula for evaluation of the Reynolds number.

Substitution of the integrated theoretic velocity in lieu of the theoretic velocity based on the mean head would be unwarranted because the tedious mathematical process involved would produce a maximal change in the discharge coefficient of less than 3%, and then only for the smallest heads needed for free discharge.

8. CONCLUSIONS.

a. No definite correlation between the coefficient of discharge and either the Reynolds or the Weber number was obtained.

b. The critical, or maximal, discharge coefficient varied less than 2% for a given orifice, irrespective of the liquid issuing therefrom.

c. The critical discharge coefficient varied inversely with the diameter of orifice.

d. The critical discharge coefficient occurred at a critical head, which head was dependent upon the diameter of the orifice and the kinematic viscosity of the liquid.

e. The critical head for all orifices was a minimum when the kinematic viscosity of the liquid was approximately 0.00003 sf/s.

PART III. WEIRS

9. RESULTS. The coefficient of discharge decreased in every instance with increase in head as shown in Fig. 16-18. Therefore, the terms *critical head* and *critical coefficient* could not be employed with a free nappe. For reasons mentioned previously, it was impracticable to use liquids the kinematic viscosity of which differed essentially from that of water. Hence, the experiments afforded little evidence in the determination of a possible correlation between the discharge coefficient and the Reynolds number. The equation used for computation of the Reynolds number was

$$R = \frac{\sqrt{2g}\, h^{1.5} \tan 0.5 \alpha}{\lambda} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (4)$$

where g, h, and λ are defined and evaluated as used with equation (2) and α is the central angle of a weir expressed in degrees.

The formula may be criticized in much the same manner as was the expression for calculation of the Reynolds number applied to orifice flow. Also, it should be kept in mind that the cross-section of the nappe is not triangular in shape and therefore the central angle of the notch is not truly a measure of the cross-sectional area of the discharging stream.

The physical properties of water differed from those of the admixtures of alkanol and water at like temperature solely in surface tension. Consequently, it was possible to study the isolated effect of surface tension upon the discharge coefficient, using as an expression for the Weber number

$$W = \frac{g \varrho h^2 \tan 0.5 \alpha}{\sigma} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (5)$$

in which ϱ is the density in slugs per cubic foot; σ is the surface tension in pounds per foot; and g, h, and α are as previously defined.

The respective surface tensions of the admixture of alkanol and water and of water alone, both at 60 deg. F, were 0.00196 p/f and 0.00503 p/f, or in a ratio of about 1 to 2.6, which is about the same as that between heavy fuel oil and water. No graphical analysis was necessary to demonstrate that the coefficient of discharge was unaltered by change in the surface tension of a liquid.

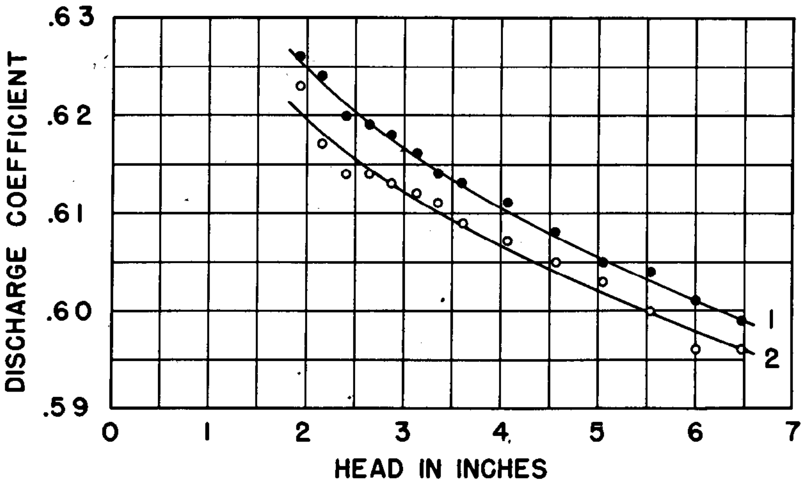

FIG. 16. RELATION OF DISCHARGE COEFFICIENT TO HEAD, 30-DEG. WEIR. SERIES III.

Graph No.	Fluid	Density Sl/cf	Kinematic Viscosity Sf/S	Surface Tension P/f
1	Water	1.93	.000 0106	.00497
2	Admixture	1.94	.000 0109	.00211

10. Conclusions.

a. The coefficient of discharge decreased with increase in head.

b. The data were insufficient as concerns a possible relation between the discharge coefficient and the Reynolds number.

c. The surface tension of a liquid and hence the Weber number as herein defined did not affect the discharge coefficient.

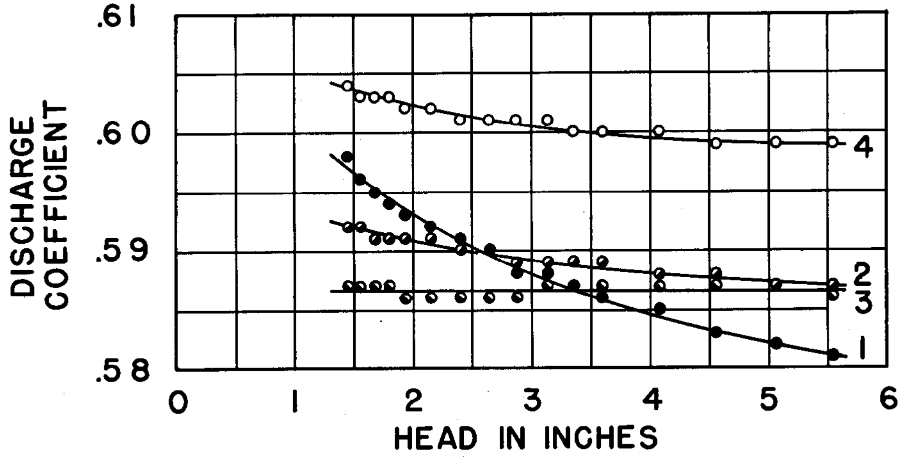

Fig. 17. Relation of Discharge Coefficient to Head, 60-Deg. Weir. Series III.

Graph No.	Fluid	Density Sl/cf	Kinematic Viscosity Sf/S	Surface Tension P/f
1	Water	1.94	.000 0124	.00504
2	Admixture	1.94	.000 0125	.00285
3	Admixture	1.94	.000 0122	.00196
4	Water	1.90	.000 00419	.00436

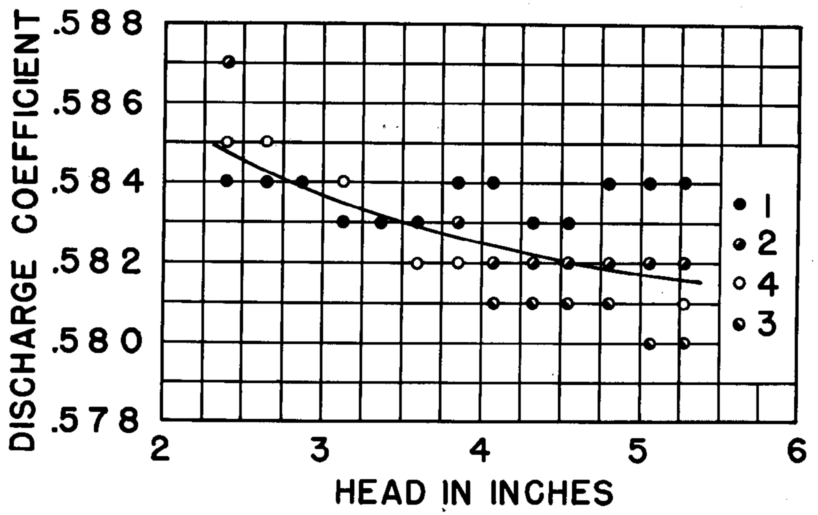

Fig. 18. Relation of Discharge Coefficient to Head, 90-Deg. Weir. Series III.

Graph No.	Fluid	Density Sl/cf	Kinematic Viscosity Sf/S	Surface Tension P/f
1	Water	1.94	.000 0118	.00502
2	Water	1.93	.000 00739	.00479
3	Water	1.92	.000 00609	.00466
4	Admixture	1.93	.000 0104	.00205

PART IV. APPENDIX

TABLE 1. FLOW OF WATER AT 67 DEG.F THROUGH 0.252-IN. ORIFICE

Series 1. Density = 1.94 sl/cf Surface tension = 0.00499 p/f
Kinematic viscosity = 0.000 0110 sf/s

Head *h* In.	φ	Discharge Coefficient *C*	Reynolds Number *R*	Weber Number *W*
.60	2.38	.639	3 420	13.1
.70	2.78	.645	3 700	15.3
.80	3.17	.650	3 950	17.5
.90	3.57	.654	4 190	19.7
1.00	3.97	.658	4 410	21.9
1.25	4.96	.665	4 940	27.4
1.50	5.95	.668	5 420	32.8
2.0	7.94	.669	6 250	43.8
2.5	9.92	.668	6 990	54.8
3	11.9	.667	7 660	65.7
4	15.9	.663	8 840	87.6
5	19.8	.660	9 890	109
6	23.8	.656	10 800	131
7	27.8	.652	11 700	153

TABLE 2. FLOW OF 20.8% SUCROSE SOLUTION AT 67 DEG.F THROUGH 0.252-IN. ORIFICE

Series I. Density = 2.11 sl/cf Surface tension = 0.00507 p/f
Kinematic viscosity = 0.000 0202 sf/s

Head *h* In.	φ	Discharge Coefficient *C*	Reynolds Number *R*	Weber Number *W*
.60	2.38	.667	1 870	14.1
.70	2.78	.670	2 020	16.4
.80	3.17	.672	2 150	18.8
.90	3.57	.673	2 290	21.1
1.00	3.97	.673	2 410	23.5
1.25	4.96	.674	2 690	29.4
1.50	5.95	.674	2 950	35.2
2.0	7.94	.673	3 410	47.0
2.5	9.92	.673	3 810	58.7
3	11.9	.672	4 170	70.5
4	15.9	.670	4 820	94.0
5	19.8	.667	5 380	117
6	23.8	.665	5 900	141
7	27.8	.662	6 380	164

TABLE 3. FLOW OF 41.3% SUCROSE SOLUTION AT 69 DEG.F ±1.7 THROUGH 0.252-IN. ORIFICE

Series I. Density = 2.28 sl/cf Surface tension = 0.00515 p/f
Kinematic viscosity = 0.000 0610 sf/s

Head *h* In.	φ	Discharge Coefficient *C*	Reynolds Number *R*	Weber Number *W*
.60	2.38	.679	618	14.9
.70	2.78	.683	668	17.4
.80	3.17	.686	714	19.9
.90	3.57	.688	757	22.4
1.00	3.97	.690	798	24.9
1.25	4.96	.692	892	31.1
1.50	5.95	.692	977	37.4
2.0	7.94	.691	1 130	49.8
2.5	9.92	.690	1 260	62.2
3	11.9	.688	1 380	74.7
4	15.9	.684	1 600	99.8
5	19.8	.680	1 780	124
6	23.8	.676	1 950	149
7	27.8	.671	2 110	174

TABLE 4. FLOW OF 54.7% SUCROSE SOLUTION AT 67 DEG.F THROUGH 0.252-IN. ORIFICE

Series I. Density = 2.45 sl/cf Surface density = 0.00526 p/f
Kinematic viscosity = 0.000 226 sf/s

Head *h* In.	φ	Discharge Coefficient *C*	Reynolds Number *R*	Weber Number *W*
.60	2.38	.658	167	15.7
.70	2.78	.668	180	18.3
.80	3.17	.673	192	20.9
.90	3.57	.677	204	23.6
1.00	3.97	.680	215	26.2
1.25	4.96	.684	240	32.7
1.50	5.95	.687	263	39.3
2.0	7.94	.691	304	52.4
2.5	9.92	.692	340	65.5
3	11.9	.693	373	78.6
4	15.9	.691	430	105
5	19.8	.689	481	131
6	23.8	.686	527	157
7	27.8	.683	570	183

TABLE 5. FLOW OF FURNACE OIL AT 66 DEG.F ±1 THROUGH 0.252-IN. ORIFICE

Series I. Density = 1.62 sl/cf Surface tension = 0.00211 p/f
Kinematic viscosity = 0.000 0381 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
1.25	4.96	.682	1 430	54.1
1.50	5.95	.681	1 560	65.0
2.0	7.94	.680	1 810	86.6
2.5	9.92	.677	2 020	108
3	11.9	.675	2 210	130
4	15.9	.669	2 550	173
5	19.8	.663	2 850	216
6	23.8	.657	3 130	260
7	27.8	.650	3 380	303

TABLE 6. FLOW OF MIXTURE OF CYLINDER AND FURNACE OILS AT 76 DEG.F ±1 THROUGH 0.252-IN. ORIFICE

Series I. Density = 1.71 sl/cf Surface tension = 0.00226 p/f
Kinematic viscosity = 0.000 678 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
1.5	5.95	.666	87.6	63.9
2.0	7.94	.668	101	85.2
2.5	9.92	.669	113	107
3	11.9	.670	124	128
4	15.9	.671	143	170
5	19.8	.672	160	213
6	23.8	.673	176	256
7	27.8	.674	190	298

TABLE 7. FLOW OF CYLINDER OIL AT 71 DEG.F ±1 THROUGH 0.252-IN. ORIFICE

Series I. Density = 1.74 sl/cf Surface tension = 0.00233 p/f
Kinematic viscosity = 0.00227 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
2.0	7.94	.578	30.2	84
2.5	9.92	.587	33.9	105
3	11.9	.594	37.1	126
4	15.9	.605	42.8	168
5	19.8	.614	47.8	210
6	23.8	.622	52.5	252
7	27.8	.629	56.7	294

TABLE 8. FLOW OF WATER AT 70 DEG.F ±1.2 THROUGH 0.381-IN. ORIFICE

Series I. Density = 1.93sl/cf Surface tension = 0.00497 p/f
Kinematic viscosity = 0.000 0106 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
.50	1.31	.650	4 910	16.5
.60	1.57	.651	5 380	19.9
.70	1.84	.652	5 810	23.2
.80	2.10	.653	6 210	26.5
.90	2.36	.654	6 590	29.8
1.00	2.63	.654	6 940	33.1
1.25	3.28	.655	7 760	41.4
1.50	3.94	.656	8 500	49.7
2.0	5.25	.657	9 810	66.2
2.5	6.56	.658	11 000	82.8
3	7.88	.657	12 000	99.3
4	10.5	.655	13 900	132
5	13.1	.649	15 500	165
6	15.7	.643	17 000	199

TABLE 9. FLOW OF 21.2% SUCROSE SOLUTION AT 68.7 DEG.F THROUGH 0.381-IN. ORIFICE

Series I. Density = 2.10 sl/cf Surface tension = 0.00507 p/f
Kinematic viscosity = 0.000 0202 sf/s

Head *h* In.	φ	Discharge Coefficient *C*	Reynolds Number *R*	Weber Number *W*
.50	1.31	.647	2 570	17.6
.60	1.57	.655	2 820	21.2
.70	1.84	.660	3 050	24.7
.80	2.10	.664	3 250	28.2
.90	2.36	.667	3 450	31.8
1.00	2.63	.668	3 640	35.3
1.25	3.28	.667	4 070	44.1
1.50	3.94	.667	4 460	52.9
2.0	5.25	.664	5 150	70.6
2.5	6.56	.660	5 760	88.2
3	7.88	.657	6 300	106
4	10.5	.654	7 280	141
5	13.1	.650	8 140	176
6	15.7	.648	8 920	212

TABLE 10. FLOW OF 41.3% SUCROSE SOLUTION AT 70.9 DEG.F THROUGH 0.381-IN. ORIFICE

Series I. Density= 2.28 sl/cf Surface tension= 0.00514 f/f
Kinematic viscosity = 0.000 0590 sf/s

Head *h* In.	φ	Discharge Coefficient *C*	Reynolds Number *R*	Weber Number *W*
.50	1.31	.647	883	18.8
.60	1.57	.659	968	22.6
.70	1.84	.663	1 040	26.4
.80	2.10	.665	1 110	30.4
.90	2.36	.666	1 180	33.9
1.00	2.63	.667	1 250	37.7
1.25	3.28	.667	1 390	47.2
1.50	3.94	.667	1 530	56.6
2.0	5.25	.665	1 760	75.4
2.5	6.56	.661	1 970	94.3
3	7.88	.658	2 160	113
4	10.5	.655	2 490	151
5	13.1	.653	2 790	188
6	15.7	.652	3 050	226

TABLE 11. FLOW OF 58% SUCROSE SOLUTION AT 72.2 DEG.F THROUGH 0.381-IN. ORIFICE

Series I. Density = 2.45 sl/cf Surface tension = 0.00524 p/f
Kinematic viscosity= 0.000 310 sf/s

Head *h* In.	φ	Discharge Coefficient *C*	Reynolds Number *R*	Weber Number *W*
.60	1.57	.662	184	23.9
.70	1.84	.668	199	27.8
.80	2.10	.671	212	31.8
.90	2.36	.673	225	35.8
1.00	2.63	.674	237	39.8
1.25	3.28	.676	266	49.8
1.50	3.94	.677	291	59.7
2.0	5.25	.678	336	79.6
2.5	6.56	.678	375	99.5

TABLE 12. FLOW OF FURNACE OIL AT 69.8 DEG.F ±4 THROUGH 0.381-IN. ORIFICE

Series I. Density = 1.61 sl/cf Surface tension = 0.00209 p/f
Kinematic viscosity = 0.000 0330 sf/s

Head *h* In.	φ	Discharge Coefficient *C*	Reynolds Number *R*	Weber Number *W*
.80	2.10	.672	1 990	52.5
.90	2.36	.667	2 120	59.0
1.00	2.63	.665	2 230	65.6
1.25	3.28	.660	2 490	82.0
1.50	3.94	.656	2 730	98.4
2.0	5.25	.651	3 150	131
2.5	6.56	.647	3 530	164
3	7.88	.645	3 860	197
4	10.5	.642	4 460	262
5	13.1	.640	4 990	328
6	15.7	.639	5 460	394
7	18.4	.639	5 900	459

TABLE 13. FLOW OF MIXTURE OF CYLINDER AND FURNACE OILS AT 74.5 DEG.F ±2 THROUGH 0.381-IN. ORIFICE

Series I. Density = 1.72 sl/cf Surface tension = 0.00228 p/f
Kinematic viscosity = 0.000 702 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
1.00	2.63	.652	105	64.3
1.25	3.28	.653	117	80.4
1.50	3.94	.654	128	96.4
2.0	5.25	.655	148	129
2.5	6.56	.656	166	161
3	7.88	.657	181	193
4	10.5	.659	210	257
5	13.1	.659	234	322
6	15.7	.658	257	386
7	18.4	.657	277	450

TABLE 14. FLOW OF CYLINDER OIL AT 75.5 DEG.F ±2 THROUGH 0.381-IN. ORIFICE

Series I. Density = 1.73 sl/cf Surface tension = 0.00229 p/f
Kinematic viscosity = 0.001 85 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
1.25	3.28	.600	44.5	80.6
1.50	3.94	.619	48.8	96.5
2.0	5.25	.631	56.3	129
2.5	6.56	.636	62.9	161
3	7.88	.641	69.0	193
4	10.5	.648	79.6	257
5	13.1	.654	89.0	322
6	15.7	.655	97.4	386
7	18.4	.655	105	451

TABLE 15. FLOW OF WATER AT 70 DEG.F THROUGH 0.502-IN. ORIFICE

Series I. Density = 1.94 sl/cf Surface tension = 0.00498 p/f
Kinematic viscosity = 0.000 0106 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
.50	.996	.620	6 470	21.8
1.00	1.99	.661	9 150	43.6
1.25	2.49	.657	10 200	54.5
1.50	2.99	.654	11 200	65.4
2.0	3.99	.650	12 900	87.2
2.5	4.98	.647	14 500	109
3	5.98	.644	15 800	131
4	7.97	.640	18 300	174
5	9.96	.637	20 500	218

TABLE 16. FLOW OF 21.2% SUCROSE SOLUTION AT 66 DEG.F ±1.3 THROUGH 0.502-IN. ORIFICE

Series I. Density = 2.10 sl/cf Surface tension = 0.00509 p/f
Kinematic viscosity = 0.000 0209 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
.65	1.29	.656	3 740	30.1
.70	1.39	.658	3 880	32.4
.80	1.59	.659	4 150	37.0
.90	1.79	.659	4 400	41.7
1.00	1.99	.659	4 640	46.3
1.25	2.49	.659	5 180	57.8
1.50	2.99	.658	5 680	69.4
2.0	3.99	.656	6 560	92.5
2.5	4.98	.653	7 330	116
3	5.98	.651	8 030	139
4	7.97	.646	9 280	185
5	9.96	.643	10 400	231
6	12.0	.641	11 400	278

TABLE 17. FLOW OF 39.7% SUCROSE SOLUTION AT 67.3 DEG.F ±2.2 THROUGH 0.502-IN. ORIFICE

Series I. Density = 2.28 sl/cf Surface tension = 0.00514 p/f
Kinematic viscosity = 0.000 0566 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
.45	.897	.653	1 150	22.4
.50	.997	.656	1 210	24.9
.60	1.20	.661	1 330	29.9
.70	1.39	.665	1 430	34.9
.80	1.59	.666	1 530	39.8
.90	1.79	.666	1 620	44.8
1.00	1.99	.666	1 710	49.8
1.25	2.49	.665	1 910	62.3
1.50	2.99	.663	2 100	74.8
2.0	3.99	.660	2 420	99.6
2.5	4.98	.657	2 710	124
3	5.98	.655	2 970	149
4	7.97	.650	3 420	199
5	9.96	.646	3 820	249

TABLE 18. FLOW OF 54.7% SUCROSE SOLUTION AT 66 DEG.F THROUGH 0.502-IN. ORIFICE

Series I. Density = 2.45 sl/cf Surface tension = 0.00526 p/f
Kinematic viscosity = 0.000 232 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
.70	1.39	.655	349	36.6
.80	1.59	.657	374	41.8
.90	1.79	.658	396	47.0
1.00	1.99	.659	417	52.3
1.25	2.49	.661	467	65.4
1.50	2.99	.663	511	78.4
2.0	3.99	.664	591	105
2.5	4.98	.664	660	131
3	5.98	.662	723	157
4	7.97	.660	835	209
5	9.96	.658	933	261
6	12.0	.656	1 020	314

TABLE 19. FLOW OF FURNACE OIL AT 72 DEG.F ±3 THROUGH 0.502-IN. ORIFICE

Series I. Density = 1.61 sl/cf Surface tension = 0.00208 p/f
Kinematic viscosity = 0.000 0301 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
1.00	1.99	.651	3 220	86.9
1.25	2.49	.649	3 600	109
1.50	2.99	.647	3 940	130
2.0	3.99	.643	4 550	174
2.5	4.98	.641	5 090	217
3	5.98	.639	5 570	261
4	7.97	.636	6 440	347
5	9.96	.635	7 200	434
6	12.0	.635	7 880	521

TABLE 20. FLOW OF MIXTURE OF CYLINDER AND FURNACE OILS AT 75.4 DEG.F THROUGH 0.502-IN. ORIFICE

Series I. Density = 1.71 sl/cf Surface tension = 0.00227 p/f
Kinematic viscosity = 0.000 692 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
1.00	1.99	.653	140	84.6
1.25	2.49	.656	157	106
1.50	2.99	.657	172	127
2.0	3.99	.658	198	169
2.5	4.98	.659	221	211
3	5.98	.659	242	254
4	7.97	.660	280	338
5	9.96	.660	313	423
6	12.0	.660	343	507
7	13.9	.660	370	592

TABLE 21. FLOW OF CYLINDER OIL AT 72.6 DEG.F THROUGH 0.502-IN. ORIFICE

Series I. Density = 1.74 sl/cf Surface tension = 0.00232 p/f
Kinematic viscosity = 0.00204 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
1.5	2.99	.626	58.2	126
2.0	3.99	.633	67.2	168
2.5	4.98	.640	75.1	210
3	5.98	.645	82.2	252
4	7.97	.652	95.0	337
5	9.96	.655	106	421
6	12.0	.655	116	505

TABLE 22. FLOW OF WATER AT 67.4 DEG.F ±1.4 THROUGH 0.625-IN. ORIFICE

Series I. Density = 1.94 sl/cf Surface tension = 0.00499 p/f
Kinematic viscosity = 0.000 0110 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
1.00	1.60	.658	11 000	54.3
1.25	2.00	.657	12 300	67.9
1.50	2.40	.655	13 400	81.5
2.0	3.20	.653	15 500	109
2.5	4.00	.651	17 400	136
3	4.80	.649	19 000	163
4	6.40	.645	22 000	217
5	8.00	.643	24 500	272

TABLE 23. FLOW OF 21.2% SUCROSE SOLUTION AT 69.2 DEG.F ±1.2 THROUGH 0.625-IN. ORIFICE

Series I. Density = 2.10 sl/cf Surface tension = 0.00508 p/f
Kinematic viscosity = 0.000 0199 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
.60	.96	.651	4 710	34.7
.70	1.12	.654	5 070	40.5
.80	1.28	.655	5 420	46.3
.90	1.44	.656	5 750	52.0
1.00	1.60	.657	6 060	57.8
1.25	2.00	.658	6 780	72.2
1.50	2.40	.656	7 430	86.6
2.0	3.20	.653	8 580	116
2.5	4.00	.650	9 590	145
3	4.80	.648	10 500	173
4	6.40	.645	12 100	231
5	8.00	.642	13 600	289
6	9.60	.640	14 900	347

TABLE 24. FLOW OF 39.7% SUCROSE SOLUTION AT 66.9 DEG.F ±3 THROUGH 0.625-IN. ORIFICE

Series I. Density = 2.28 sl/cf Surface tension = 0.00514 p/f
Kinematic viscosity = 0.000 0566 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
1.00	1.60	.665	2 130	62.1
1.25	2.00	.664	2 390	77.6
1.50	2.40	.662	2 610	93.1
2.0	3.20	.658	3 020	124
2.5	4.00	.655	3 370	155
3	4.80	.653	3 700	186
4	6.40	.650	4 260	248
5	8.00	.648	4 770	311
6	9.60	.645	5 220	373

TABLE 25. FLOW OF 54.7% SUCROSE SOLUTION AT 67.3 DEG.F ±1.3 THROUGH 0.625-IN. ORIFICE

Series I. Density = 2.45 sl/cf Surface tension = 0.00526 p/f
Kinematic viscosity = 0.000 226 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
.70	1.12	.647	447	45.7
.80	1.28	.651	478	52.2
.90	1.44	.654	507	58.7
1.00	1.60	.656	534	65.2
1.25	2.00	.658	597	81.5
1.50	2.40	.659	654	97.8
2.0	3.20	.660	755	130
2.5	4.00	.658	845	163
3	4.80	.657	925	196
4	6.40	.655	1 070	261
5	8.00	.654	1 190	326
6	9.60	.653	1 310	391
7	11.20	.653	1 410	457

TABLE 26. FLOW OF FURNACE OIL AT 70.9 DEG.F ±1.9 THROUGH 0.625-IN. ORIFICE

Series I. Density = 1.61 sl/cf Surface tension = 0.00208 p/f
Kinematic viscosity = 0.000 0315 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
.60	.96	.640	2 970	64.9
.70	1.12	.644	3 210	75.7
.80	1.28	.645	3 430	86.5
.90	1.44	.645	3 640	97.4
1.00	1.60	.644	3 830	108
1.25	2.00	.643	4 290	135
1.50	2.40	.642	4 690	162
2.0	3.20	.640	5 420	216
2.5	4.00	.638	6 060	270
3	4.80	.637	6 640	324
4	6.40	.635	7 660	433
5	8.00	.634	8 560	541
6	9.60	.633	9 390	649
7	11.2	.632	10 100	757

TABLE 27. FLOW OF MIXTURE OF CYLINDER AND FURNACE OILS AT 78.6 DEG.F THROUGH 0.625-IN. ORIFICE

Series I. Density = 1.70 sl/cf Surface tension = 0.00224 p/f
Kinematic viscosity = 0.000 628 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
.90	1.44	.650	182	95.5
1.00	1.60	.652	192	106
1.25	2.00	.655	215	133
1.50	2.40	.657	235	159
2.0	3.20	.661	272	212
2.5	4.00	.664	304	265
3	4.80	.664	333	318
4	6.40	.662	384	424
5	8.00	.660	430	530
6	9.60	.659	471	636
7	11.2	.659	509	742

TABLE 28. FLOW OF CYLINDER OIL AT 77 DEG.F THROUGH 0.625-IN. ORIFICE

Series I. Density = 1.72 sl/cf Surface tension = 0.00225 p/f
Kinematic viscosity = 0.00177 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
1.00	1.60	.633	68.1	107
1.25	2.00	.640	76.2	134
1.50	2.40	.645	83.5	160
2.0	3.20	.654	96.4	214
2.5	4.00	.660	108	267
3	4.80	.660	118	321
4	6.40	.660	136	428
5	8.00	.660	152	535
6	9.60	.660	167	642

TABLE 29. FLOW OF WATER AT 64.2 DEG.F THROUGH 0.754-IN. ORIFICE

Series I. Density = 1.94 sl/cf Surface tension = 0.00501 p/f
Kinematic viscosity = 0.000 0114 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
.50	.663	.630	9 030	32.6
.60	.796	.643	9 890	39.2
.70	.929	.647	10 700	45.7
.80	1.06	.648	11 400	52.2
.90	1.19	.649	12 100	58.7
1.00	1.33	.650	12 800	65.3
1.25	1.66	.651	14 300	81.6
1.50	1.99	.652	15 700	97.9
2.0	2.65	.653	18 100	131
2.5	3.31	.652	20 200	163
3	3.98	.652	22 100	196
4	5.30	.650	25 500	261
5	6.63	.648	28 500	326
6	7.96	.647	31 300	392

TABLE 30. FLOW OF 20.8% SUCROSE SOLUTION AT 66 DEG.F ±1.3 THROUGH 0.754-IN. ORIFICE

Series I. Density = 2.10 sl/cf Surface tension = 0.00507 p/f
Kinematic viscosity = 0.000 0207 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
.65	.861	.645	5 670	45.4
.70	.929	.650	5 880	48.9
.80	1.06	.653	6 280	55.9
.90	1.19	.655	6 670	62.8
1.00	1.33	.656	7 030	69.8
1.25	1.66	.656	7 860	87.2
1.50	1.99	.655	8 610	105
2.0	2.65	.653	9 940	140
2.5	3.31	.652	11 100	175
3	3.98	.651	12 200	209
4	5.30	.649	14 100	279
5	6.63	.649	15 700	349
6	7.96	.648	17 200	419

TABLE 31. FLOW OF 41.3% SUCROSE SOLUTION AT 71 DEG.F THROUGH 0.754-IN. ORIFICE

Series I. Density = 2.28 sl/cf Surface tension = 0.00514 p/f
Kinematic viscosity = 0.000 0590 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
.55	.729	.639	1 830	41.1
.60	.796	.644	1 910	44.9
.70	.929	.650	2 070	52.3
.80	1.06	.653	2 210	59.8
.90	1.19	.655	2 340	67.3
1.00	1.33	.657	2 470	74.8
1.25	1.66	.658	2 760	93.5
1.50	1.99	.659	3 020	112
2.0	2.65	.660	3 490	149
2.5	3.31	.660	3 900	187
3	3.98	.659	4 270	224
4	5.30	.657	4 930	299
5	6.63	.655	5 510	374
6	7.96	.654	6 040	449

TABLE 32. FLOW OF 54.7% SUCROSE SOLUTION AT 69.3 DEG.F THROUGH 0.754-IN. ORIFICE

Series I. Density = 2.45 sl/cf Surface tension = 0.00526 p/f
Kinematic viscosity = 0.000 213 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
.60	.796	.657	530	47.1
.70	.929	.658	572	54.9
.80	1.06	.659	612	62.8
.90	1.19	.659	648	70.6
1.00	1.33	.660	683	78.5
1.25	1.66	.661	764	98.0
1.50	1.99	.662	837	118
2.0	2.65	.663	966	157
2.5	3.31	.662	1 080	196
3	3.98	.661	1 180	235
4	5.30	.659	1 370	314
5	6.63	.657	1 530	392
6	7.96	.655	1 670	471

TABLE 33. FLOW OF FURNACE OIL AT 68.2 DEG.F ±2.2 THROUGH 0.754-IN. ORIFICE

Series I. Density = 1.61 sl/cf Surface tension = 0.00209 p/f
Kinematic viscosity = 0.000 0349 sf/s

Head *h* In.	φ	Discharge Coefficient *C*	Reynolds Number *R*	Weber Number *W*
.60	.796	.641	3 230	78
.70	.929	.644	3 490	91
.80	1.06	.646	3 730	104
.90	1.19	.647	3 960	117
1.00	1.33	.648	4 170	130
1.25	1.66	.649	4 670	163
1.50	1.99	.649	5 110	195
2.0	2.65	.649	5 900	260
2.5	3.31	.648	6 590	325
3	3.98	.646	7 220	390
4	5.30	.644	8 340	520
5	6.63	.642	9 330	650
6	7.96	.640	10 200	780

TABLE 34. FLOW OF MIXTURE OF CYLINDER AND FURNACE OILS AT 77 DEG.F THROUGH 0.754-IN. ORIFICE

Series I. Density = 1.71 sl/cf Surface tension = 0.00225 p/f
Kinematic viscosity = 0.000 648 sf/s

Head *h* In.	φ	Discharge Coefficient *C*	Reynolds Number *R*	Weber Number *W*
.75	.995	.640	194	96
.80	1.06	.645	201	102
.90	1.19	.649	213	115
1.00	1.33	.651	224	128
1.25	1.66	.655	251	160
1.50	1.99	.659	275	192
2.0	2.65	.664	318	256
2.5	3.31	.665	355	320
3	3.98	.666	389	384
4	5.30	.666	449	512
5	6.63	.665	502	640
6	7.96	.664	550	768

TABLE 35. FLOW OF CYLINDER OIL AT 69.5 DEG.F THROUGH 0.754-IN. ORIFICE

Series I. Density = 1.74 sl/cf Surface tension = 0.00234 p/f
Kinematic viscosity = 0.002 49 sf/s

Head *h* In.	φ	Discharge Coefficient *C*	Reynolds Number *R*	Weber Number *W*
.80	1.06	.610	52.3	100
.90	1.19	.616	55.5	113
1.00	1.33	.622	58.5	125
1.25	1.66	.632	65.4	157
1.50	1.99	.640	71.7	188
2.0	2.65	.649	82.7	251
2.5	3.31	.654	92.5	313
3	3.98	.657	101	376
4	5.30	.658	117	502
5	6.63	.658	131	627
6	7.96	.658	143	752

TABLE 36. FLOW OF WATER AT 69.1 DEG.F ±2.1 THROUGH 0.875-IN. ORIFICE

Series I. Density = 1.94 sl/cf Surface tension = 0.00498 p/f
Kinematic viscosity = 0.000 0107 sf/s

Head *h* In.	φ	Discharge Coefficient *C*	Reynolds Number *R*	Weber Number *W*
.45	.514	.590	10 600	34.3
.50	.571	.604	11 200	38.1
.55	.628	.617	11 700	41.9
.60	.686	.623	12 200	45.7
.65	.743	.625	12 700	49.5
.70	.800	.627	13 200	53.3
.75	.857	.628	13 700	57.2
.80	.914	.629	14 100	61.0
.85	.971	.630	14 600	64.8
.90	1.03	.631	15 000	68.6
.95	1.09	.631	15 400	72.4
1.00	1.14	.632	15 800	76.2
1.25	1.43	.633	17 700	95.5
1.50	1.71	.635	19 400	114
2.0	2.29	.636	22 300	152
2.5	2.86	.637	25 000	191
3.0	3.43	.637	27 400	229

TABLE 37. FLOW OF 21.2% SUCROSE SOLUTION AT 72.8 DEG.F ±1.2 THROUGH 0.875-IN. ORIFICE

Series I. Density = 2.10 sl/cf Surface tension = 0.00505 p/f
Kinematic viscosity = 0.000 0187 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
.65	.743	.631	7 280	53.0
.70	.800	.633	7 560	57.0
.80	.914	.637	8 080	65.2
.90	1.03	.639	8 580	73.2
1.00	1.14	.641	9 040	81.4
1.25	1.43	.642	10 100	102
1.50	1.71	.642	11 100	122
2.0	2.29	.640	12 800	163
2.5	2.86	.638	14 300	204
3.0	3.43	.635	15 600	244

TABLE 38. FLOW OF 39.7% SUCROSE SOLUTION AT 72.2 DEG.F THROUGH 0.875-IN. ORIFICE

Series I. Density = 2.28 sl/cf Surface tension = 0.00512 p/f
Kinematic viscosity = 0.000 0508 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
.55	.628	.629	2 470	48.0
.60	.686	.635	2 580	52.3
.65	.743	.638	2 680	56.6
.70	.800	.640	2 780	61.0
.80	.914	.643	2 970	69.7
.90	1.03	.645	3 160	78.5
1.00	1.14	.646	3 330	87.1
1.25	1.43	.647	3 720	109
1.50	1.71	.646	4 070	131
2.0	2.29	.644	4 700	174
2.5	2.86	.641	5 260	218
3.0	3.43	.639	5 760	262

TABLE 39. FLOW OF 54.7% SUCROSE SOLUTION AT 66.2 DEG.F THROUGH 0.875-IN. ORIFICE

Series I. Density = 2.45 sl/cf Surface tension = 0.00526 p/f
Kinematic viscosity = 0.000 232 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
.80	.914	.638	651	73.0
.90	1.03	.640	691	82.1
1.00	1.14	.641	729	91.1
1.25	1.43	.643	815	114
1.50	1.71	.644	893	137
2.0	2.29	.645	1 030	182
2.5	2.86	.645	1 150	228
3.0	3.43	.645	1 260	273

TABLE 40. FLOW OF FURNACE OIL AT 72.3 DEG.F THROUGH 0.875-IN. ORIFICE

Series I. Density = 1.61 sl/cf Surface tension = 0.00207 p/f
Kinematic viscosity = 0.000 0292 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
.50	.571	.606	4 090	76.2
.55	.628	.610	4 300	83.9
.60	.686	.613	4 490	91.5
.65	.743	.616	4 660	99.2
.70	.800	.619	4 840	107
.75	.857	.622	5 010	115
.80	.914	.625	5 180	122
.85	.971	.627	5 340	130
.90	1.03	.628	5 490	138
.95	1.09	.629	5 640	145
1.00	1.14	.629	5 790	152
1.25	1.43	.630	6 470	190
1.50	1.71	.630	7 090	230
2.0	2.29	.629	8 180	305
2.5	2.86	.629	9 150	381
3.0	3.43	.628	10 000	457
3.5	4.00	.628	10 800	534

TABLE 41. FLOW OF MIXTURE OF CYLINDER AND FURNACE OILS AT 80.6 DEG.F ±1.4 THROUGH 0.875-IN. ORIFICE

Series I. Density = 1.70 sl/cf Surface tension = 0.00222 p/f
Kinematic viscosity = 0.000 603 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
.55	.628	.600	208	82.5
.60	.686	.608	217	90.0
.65	.743	.613	226	97.5
.70	.800	.618	235	105
.75	.857	.622	243	112
.80	.914	.626	251	120
.85	.971	.630	258	127
.90	1.03	.632	266	135
.95	1.09	.635	273	142
1.00	1.14	.637	280	150
1.25	1.43	.643	313	188
1.50	1.71	.646	343	225
2.0	2.29	.650	396	300
2.5	2.86	.651	443	375
3.0	3.43	.651	485	450
3.5	4.00	.651	524	525

TABLE 42. FLOW OF CYLINDER OIL AT 75.9 DEG.F THROUGH 0.875-IN. ORIFICE

Series I. Density = 1.73 sl/cf Surface tension = 0.00229 p/f
Kinematic viscosity = 0.00182 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
.80	.914	.610	83.0	118
.85	.971	.615	85.6	126
.90	1.03	.619	88.1	133
.95	1.09	.623	90.6	141
1.00	1.14	.626	92.9	148
1.25	1.43	.633	104	185
1.50	1.71	.638	114	222
2.0	2.29	.643	131	296
2.5	2.86	.647	147	370
3.0	3.43	.649	161	444
3.5	4.00	.651	174	518

TABLE 43. FLOW OF WATER AT 61.5 DEG.F THROUGH 0.502-IN. ORIFICE

Series II. Density = 1.94 sl/cf Surface tension = 0.00502 p/f
Kinematic viscosity = 0.000 0119 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
1.0	1.99	.663	8 140	43.3
1.5	2.99	.658	9 970	64.9
2.0	3.98	.655	11 500	86.6
2.5	4.98	.652	12 900	108
3.0	5.98	.650	14 100	130
3.5	6.97	.648	15 200	152
4.0	7.97	.646	16 300	173
4.5	8.96	.645	17 300	195
5	9.96	.643	18 200	216
6	12.0	,641	20 000	260
7	13.9	.639	21 600	303
8	15.9	.637	23 000	346
9	17.9	636	24 400	390
10	19.9	.635	25 700	433
12	23.9	.632	28 200	519
15	29.9	.629	31 500	649
19	37.8	.627	35 500	823
24	47.8	.624	39 900	1 040
30	59.8	.621	44 700	1 300
36	71.7	.619	48 900	1 560

TABLE 44. FLOW OF WATER AT 64.4 DEG.F THROUGH 0.502-IN. ORIFICE

Series II. Density = 1.93 sl/cf Surface tension = 0.00500 p/f
Kinematic viscosity = 0.000 0114 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
1.0	1.99	.667	8 510	43.3
1.5	2.99	.661	10 400	64.9
2.0	3.98	.657	12 000	86.6
2.5	4.98	.654	13 400	108
3.0	5.98	.651	14 700	130
3.5	6.97	.649	15 900	152
4.0	7.97	.647	17 000	173
4.5	8.96	.645	18 000	195
5	9.96	.644	19 000	216
6	12.0	.641	20 800	260
7	13.9	.639	22 500	303
8	15.9	.637	24 000	346
9	17.9	.635	25 500	390
10	19.9	.634	26 900	433
12	23.9	.631	29 500	519
15	29.9	.628	32 900	649
19	37.8	.626	37 000	823
24	47.8	.623	41 600	1 040
30	59.8	.619	46 500	1 300
36	71.7	.617	51 000	1 560

TABLE 45. FLOW OF WATER AT 177 DEG.F THROUGH 0.502-IN. ORIFICE

Series II. Density = 1.88 sl/cf Surface tension = 0.00428 p/f
Kinematic viscosity = 0.000 00393 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
1.0	1.99	.654	24 700	49.2
1.5	2.99	.649	30 200	73.8
2.0	3.98	.646	34 900	98.4
2.5	4.98	.643	39 000	123
3.0	5.98	.641	42 700	148
3.5	6.97	.639	46 200	172
4.0	7.97	.637	49 400	197
4.5	8.96	.635	52 300	221
5	9.96	.633	55 100	246
6	12.0	.631	60 400	295
7	13.9	.628	65 300	344
8	15.9	.626	69 700	394
9	17.9	.625	74 000	443
10	19.9	.624	78 000	492
12	23.9	.621	85 400	590
15	29.9	.619	95 500	737
19	37.8	.616	107 000	934
24	47.8	.612	121 000	1 180
30	59.8	.610	135 000	1 480
36	71.7	.608	148 000	1 770

TABLE 46. FLOW OF ADMIXTURE OF ALKANOL AND WATER AT 78 DEG.F THROUGH 0.502-IN. ORIFICE

Series II. Density = 1.93 sl/cf Surface tension = 0.00202 p/f
Kinematic viscosity = 0.000 00954 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
1.0	1.99	.672	10 200	107
1.5	2.99	.666	12 400	161
2.0	3.98	.662	14 400	214
2.5	4.98	.658	16 100	268
3.0	5.98	.655	17 600	322
3.5	6.97	.653	19 000	375
4.0	7.97	.651	20 300	429
4.5	8.96	.649	21 500	483
5	9.96	.647	22 700	536
6	12.0	.645	24 900	644
7	13.9	.643	26 900	751
8	15.9	.641	28 700	858
9	17.9	.639	30 500	966
10	19.9	.637	32 100	1 070
12	23.9	.635	35 200	1 290
15	29.9	.632	39 400	1 600
19	37.8	.628	44 300	2 040
24	47.8	.625	49 800	2 570
30	59.8	.623	55 700	3 220
36	71.7	.620	60 900	3 860

TABLE 47. FLOW OF WATER AT 98.1 DEG.F THROUGH 1.00-IN. ORIFICE

Series II. Density = 1.93 sl/cf Surface tension = 0.00480 p/f
Kinematic viscosity = 0.000 00755 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
2.0	2.0	.629	36 200	180
2.5	2.5	.627	40 500	224
3.0	3.0	.624	44 300	269
3.5	3.5	.623	47 800	314
4.0	4.0	.621	51 100	359
4.5	4.5	.620	54 200	404
5	5	.618	57 100	449
6	6	.617	62 700	539
7	7	.616	67 700	628
8	8	.614	72 300	718
9	9	.613	76 700	808
10	10	.612	80 900	898
12	12	.610	88 600	1 080
14	14	.608	95 700	1 260
17	17	.607	106 000	1 530
20	20	.605	114 000	1 800
24	24	.604	125 000	2 150
28	28	.601	135 000	2 520
32	32	.600	145 000	2 880
36	36	.599	154 000	3 240

TABLE 48. FLOW OF WATER AT 176 DEG.F THROUGH 1.00-IN. ORIFICE

Series II. Density = 1.89 sl/cf Surface tension = 0.00429 p/f
Kinematic viscosity = 0.000 00396 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
2.0	2.0	.622	69 000	197
2.5	2.5	.621	77 200	246
3.0	3.0	.620	84 500	295
3.5	3.5	.619	91 300	344
4.0	4.0	.617	97 500	394
4.5	4.5	.615	103 000	443
5	5	.614	109 000	492
6	6	.613	120 000	590
7	7	.611	129 000	689
8	8	.610	138 000	787
9	9	.609	146 000	886
10	10	.608	154 000	984
12	12	.607	169 000	1 180
14	14	.605	183 000	1 380
17	17	.604	202 000	1 670
20	20	.603	218 000	1 970
24	24	.602	239 000	2 360
28	28	.601	258 000	2 750
32	32	.599	276 000	3 150
36	36	.598	293 000	3 540

TABLE 49. FLOW OF ADMIXTURE OF ALKANOL AND WATER AT 61.7 DEG.F THROUGH 1.00-IN. ORIFICE

Series II. Density = 1.94 sl/cf Surface tension = 0.00256 p/f
Kinematic viscosity = 0.000 0119 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
2.0	2.0	.631	22 900	338
2.5	2.5	.629	25 700	423
3.0	3.0	.628	28 100	508
3.5	3.5	.626	30 400	592
4.0	4.0	.623	32 400	677
4.5	4.5	.622	34 400	762
5	5	.622	36 200	846
6	6	.621	39 800	1 020
7	7	.619	42 900	1 180
8	8	.617	45 900	1 350
9	9	.616	48 700	1 520
10	10	.614	51 300	1 690
12	12	.612	56 200	2 030
14	14	.611	60 700	2 370
17	17	.609	67 200	2 880
20	20	.606	72 500	3 380
24	24	.605	79 500	4 060
28	28	.603	85 800	4 740
32	32	.602	91 800	5 420
36	36	.601	97 300	6 090

TABLE 50. FLOW OF ADMIXTURE OF ALKANOL AND WATER AT 62.6 DEG.F THROUGH 1.00-IN. ORIFICE

Series II. Density = 1.94 sl/cf Surface tension = 0.00252 p/f
Kinematic viscosity = 0.000 0117 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
2.0	2.0	.632	23 400	344
2.5	2.5	.630	26 100	430
3.0	3.0	.628	28 600	516
3.5	3.5	.627	30 900	602
4.0	4.0	.626	33 000	688
4.5	4.5	.625	35 000	774
5	5	.623	36 900	860
6	6	.621	40 400	1 030
7	7	.620	43 700	1 200
8	8	.618	46 700	1 380
9	9	.617	49 500	1 550
10	10	.616	52 200	1 720
12	12	.615	57 200	2 060
14	14	.613	61 700	2 410
17	17	.611	68 300	2 920
20	20	.610	73 700	3 440
24	24	.608	80 800	4 120
28	28	.606	87 300	4 820
32	32	.605	93 400	5 500
36	36	.604	99 000	6 190

TABLE 51. FLOW OF WATER AT 61.7 DEG.F THROUGH 1.50-IN. ORIFICE

Series II. Density = 1.94 sl/cf Surface tension = 0.00502 p/f
Kinematic viscosity = 0.000 0119 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
3.00	2.0	.624	42 200	388
3.75	2.5	.622	47 200	486
4.50	3.0	.622	51 600	583
5.25	3.5	.620	55 700	680
6.00	4	.619	59 600	777
7.50	5	.618	66 700	971
9.0	6	.617	73 200	1 170
10.5	7	.616	78 800	1 360
12.0	8	.615	84 300	1 550
15.0	10	.614	94 200	1 940
18.0	12	.613	103 000	2 330
22.5	15	.613	115 000	2 920
27.0	18	.612	126 000	3 500
31.5	21	.610	137 000	4 080
36.0	24	.609	146 000	4 660

TABLE 52. FLOW OF WATER AT 178 DEG.F THROUGH 1.50-IN. ORIFICE

Series II. Density = 1.88 sl/cf Surface tension = 0.00427 p/f
Kinematic viscosity = 0.000 00391 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
3.00	2.0	.621	128 000	442
3.75	2.5	.618	143 000	553
4.50	3.0	.617	157 000	664
5.25	3.5	.615	170 000	774
6.00	4	.614	181 000	885
7.50	5	.613	203 000	1 110
9.0	6	.611	222 000	1 330
10.5	7	.611	240 000	1 550
12.0	8	.610	257 000	1 770
15.0	10	.609	287 000	2 210
18.0	12	.608	314 000	2 650
22.5	15	.606	351 000	3 320
27.0	18	.604	385 000	3 980
31.5	21	.604	416 000	4 650
36.0	24	.602	444 000	5 310

TABLE 53. FLOW OF ADMIXTURE OF ALKANOL AND WATER AT 68 DEG.F THROUGH 1.50-IN. ORIFICE

Series II. Density = 1.94 sl/cf Surface tension = 0.00235 p/f
Kinematic viscosity = 0.000 0109 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
3.00	2.0	.631	46 000	831
3.75	2.5	.628	51 400	1 040
4.50	3.0	.626	56 400	1 240
5.25	3.5	.625	60 900	1 450
6.00	4	.624	65 100	1 660
7.50	5	.622	72 800	2 080
9.0	6	.621	79 800	2 490
10.5	7	.620	86 100	2 910
12.0	8	.619	92 000	3 320
15.0	10	.618	103 000	4 160
18.0	12	.617	113 000	4 980
22.5	15	.615	126 000	6 230
27.0	18	.613	138 000	7 480
31.5	21	.612	149 000	8 730
36.0	24	.611	159 000	9 980

TABLE 54. FLOW OF ADMIXTURE OF ALKANOL AND WATER AT 76.1 DEG.F THROUGH 1.50-IN. ORIFICE

Series II. Density = 1.93 sl/cf Surface tension = 0.00208 p/f
Kinematic viscosity = 0.000 00991 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
3.00	2.0	.625	50 700	933
3.75	2.5	.624	56 600	1 170
4.50	3.0	.623	62 000	1 400
5.25	3.5	.622	66 900	1 630
6.00	4	.621	71 600	1 860
7.50	5	.620	80 100	2 330
9.0	6	.619	87 700	2 800
10.5	7	.618	94 700	3 270
12.0	8	.617	101 000	3 730
15.0	10	.615	113 000	4 670
18.0	12	.614	124 000	5 600
22.5	15	.614	139 000	7 000
27.0	18	.613	152 000	8 390
31.5	21	.612	164 000	9 800
36.0	24	.611	176 000	11 200

TABLE 55. FLOW OF WATER AT 60.8 DEG.F THROUGH 2.00-IN. ORIFICE

Series II. Density = 1.94 sl/cf Surface tension = 0.00503 p/f
Kinematic viscosity = 0.000 0120 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
4	2.0	.611	64 100	690
5	2.5	.611	72 000	862
6	3.0	.610	78 900	1 030
7	3.5	.609	85 200	1 210
8	4.0	.609	91 100	1 380
9	4.5	.609	96 600	1 550
10	5	.608	102 000	1 720
12	6	.608	111 000	2 070
14	7	.607	120 000	2 410
16	8	.606	129 000	2 760
18	9	.606	137 000	3 100
20	10	.605	144 000	3 450
22	11	.605	151 000	3 790
24	12	.604	158 000	4 140
26	13	.604	164 000	4 480

TABLE 56. FLOW OF WATER AT 112 DEG.F ±1.3 THROUGH 2.00-IN. ORIFICE

Series II. Density = 1.92 sl/cf Surface tension = 0.00396 p/f
Kinematic viscosity = 0.000 00687 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
4	2.0	.614	112 000	867
5	2.5	.613	126 000	1 080
6	3.0	.612	138 000	1 300
7	3.5	.612	149 000	1 520
8	4.0	.611	159 000	1 730
9	4.5	.611	169 000	1 950
10	5	.610	178 000	2 170
12	6	.610	195 000	2 600
14	7	.609	210 000	3 030
16	8	.608	225 000	3 470
18	9	.608	239 000	3 900
20	10	.608	251 000	4 330
22	11	.607	264 000	4 770
24	12	.607	275 000	5 200
26	13	.607	286 000	5 640

TABLE 57. FLOW OF ADMIXTURE OF ALKANOL AND WATER AT 74.3 DEG.F THROUGH 2.00-IN. ORIFICE

Series II. Density = 1.93 sl/cf Surface tension = 0.00214 p/f
Kinematic viscosity = 0.000 00991 sf/s

Head *h* In.	*φ*	Discharge Coefficient *C*	Reynolds Number *R*	Weber Number *W*
4	2.0	.616	77 600	1 610
5	2.5	.613	87 200	2 010
6	3.0	.613	95 600	2 420
7	3.5	.611	103 000	2 820
8	4.0	.611	110 000	3 220
9	4.5	.610	117 000	3 630
10	5	.609	123 000	4 030
12	6	.609	135 000	4 830
14	7	.609	146 000	5 650
16	8	.608	156 000	6 450
18	9	.608	165 000	7 260
20	10	.608	174 000	8 070
22	11	.607	183 000	8 880
24	12	.606	191 000	9 680
26	13	.606	199 000	10 500

TABLE 58. FLOW OF 0.03% SOAP SOLUTION AT 140 DEG.F ±2 THROUGH 2.00-IN. ORIFICE

Series II. Density = 1.91 sl/cf Surface tension = 0.00246 p/f
Kinematic viscosity = 0.000 00497 sf/s

Head *h* In.	*φ*	Discharge Coefficient *C*	Reynolds Number *R*	Weber Number *W*
4	2.0	.618	155 000	1 390
5	2.5	.616	174 000	1 730
6	3.0	.615	190 000	2 080
7	3.5	.614	205 000	2 430
8	4.0	.613	220 000	2 770
9	4.5	.612	233 000	3 120
10	5	.611	246 000	3 470
12	6	.610	269 000	4 160
14	7	.608	290 000	4 860
16	8	.607	310 000	5 550
18	9	.606	329 000	6 240
20	10	.606	347 000	6 940
22	11	.605	364 000	7 630
24	12	.604	380 000	8 330
26	13	.604	396 000	9 030

TABLE 59. FLOW OF 0.06% SOAP SOLUTION AT 120 DEG.F THROUGH 2.00-IN. ORIFICE

Series II. Density = 1.92 sl/cf Surface tension = 0.00351 p/f
Kinematic viscosity = 0.000 00641 sf/s

Head *h* In.	*φ*	Discharge Coefficient *C*	Reynolds Number *R*	Weber Number *W*
4	2.0	.616	120 000	979
5	2.5	.615	135 000	1 220
6	3.0	.614	148 000	1 460
7	3.5	.613	159 000	1 710
8	4.0	.613	171 000	1 950
9	4.5	.612	181 000	2 200
10	5	.612	190 000	2 440
12	6	.610	208 000	2 930
14	7	.609	225 000	3 420
16	8	.608	241 000	3 910
18	9	.608	256 000	4 400
20	10	.608	269 000	4 890
22	11	.608	282 000	5 380
24	12	.607	295 000	5 870
26	13	.606	307 000	6 360

TABLE 60. FLOW OF 0.06% SOAP SOLUTION AT 142 DEG.F ±5 THROUGH 2.00-IN. ORIFICE

Series II. Density = 1.91 sl/cf Surface tension = 0.00202 p/f
Kinematic viscosity = 0.000 00571 sf/s

Head *h* In.	*φ*	Discharge Coefficient *C*	Reynolds Number *R*	Weber Number *W*
4	2.0	.618	135 000	1 690
5	2.5	.616	151 000	2 110
6	3.0	.616	166 000	2 540
7	3.5	.614	179 000	2 960
8	4.0	.613	191 000	3 380
9	4.5	.613	203 000	3 800
10	5	.613	214 000	4 230
12	6	.611	234 000	5 070
14	7	.611	253 000	5 920
16	8	.610	268 000	6 760
18	9	.609	287 000	7 610
20	10	.609	302 000	8 450
22	11	.608	317 000	9 300
24	12	.608	331 000	10 100
26	13	.607	345 000	11 000

TABLE 61. FLOW OF 0.10% SOAP SOLUTION AT 115 DEG.F THROUGH 2.00-IN. ORIFICE

Series II. Density = 1.92 sl/cf Surface tension = 0.00364 p/f
Kinematic viscosity = 0.000 00685 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
4	2.0	.616	112 000	942
5	2.5	.616	126 000	1 180
6	3.0	.615	138 000	1 410
7	3.5	.613	149 000	1 650
8	4.0	.613	159 000	1 880
9	4.5	.612	169 000	2 120
10	5	.612	178 000	2 360
12	6	.611	195 000	2 830
14	7	.610	211 000	3 300
16	8	.609	226 000	3 770
18	9	.608	239 000	4 240
20	10	.608	252 000	4 710
22	11	.607	264 000	5 180
24	12	.606	276 000	5 650
26	13	.606	287 000	6 120

TABLE 62. FLOW OF 0.10% SOAP SOLUTION AT 138 DEG.F ±1.3 THROUGH 2.00-IN. ORIFICE

Series II. Density = 1.91 sl/cf Surface tension = 0.00239 p/f
Kinematic viscosity = 0.000 00578 sf/s

Head h In.	φ	Discharge Coefficient C	Reynolds Number R	Weber Number W
4	2.0	.618	133 000	1 430
5	2.5	.616	149 000	1 780
6	3.0	.615	164 000	2 140
7	3.5	.614	177 000	2 500
8	4.0	.614	189 000	2 850
9	4.5	.613	200 000	3 210
10	5	.612	211 000	3 570
12	6	.611	232 000	4 280
14	7	.611	250 000	5 000
16	8	.610	267 000	5 710
18	9	.609	284 000	6 420
20	10	.608	297 000	7 140
22	11	.607	313 000	7 850
24	12	.607	327 000	8 570
26	13	.606	341 000	9 280

TABLE 63. FLOW OF WATER AT 69.8 DEG.F THROUGH 30-DEG. WEIR

Series III. Density = 1.93 sl/cf Surface tension = 0.00497 p/f
Kinematic viscosity = 0.000 0106 sf/s

Head h In.	Discharge Coefficient C	Reynolds Number R	Weber Number W
1.92	.626	13 000	85.8
2.16	.624	15 600	109
2.40	.620	18 100	134
2.64	.619	21 000	162
2.88	.618	23 900	193
3.12	.616	26 900	226
3.36	.614	30 000	263
3.60	.613	33 400	300
4.08	.611	40 200	386
4.56	.608	47 500	483
5.04	.605	55 200	590
5.52	.604	63 400	707
6.00	.601	71 800	836
6.48	.599	80 500	976

TABLE 64. FLOW OF ADMIXTURE OF ALKANOL AND WATER AT 68 DEG.F THROUGH 30-DEG. WEIR

Series III. Density = 1.94 sl/cf Surface tension = 0.00211 p/f
Kinematic viscosity = 0.000 0109 sf/s

Head h In.	Discharge Coefficient C	Reynolds Number R	Weber Number W
1.92	.623	12 600	203
2.16	.617	15 100	257
2.40	.614	17 700	316
2.64	.614	20 400	383
2.88	.613	23 200	458
3.12	.612	26 200	536
3.36	.611	29 300	622
3.60	.609	32 400	716
4.08	.607	39 100	917
4.56	.605	46 300	1 140
5.04	.603	53 800	1 400
5.52	.600	61 600	1 680
6.00	.596	69 800	1 980
6.48	.596	78 300	2 300

TABLE 65. FLOW OF WATER AT 59 DEG.F THROUGH 60-DEG. WEIR

Series III. Density = 1.94 sl/cf Surface tension = 0.00504 p/f
Kinematic viscosity = 0.000 0124 sf/s

Head *h* In.	Discharge Coefficient *C*	Reynolds Number *R*	Weber Number *W*
1.44	.598	15 600	103
1.56	.596	17 500	121
1.68	.595	19 500	140
1.80	.594	21 600	161
1.92	.593	23 900	183
2.16	.592	28 600	232
2.40	.591	33 400	286
2.64	.590	38 500	346
2.88	.588	43 900	412
3.12	.588	49 500	484
3.36	.587	55 300	561
3.60	.586	61 400	646
4.08	.585	74 000	825
4.56	.583	87 500	1 030
5.04	.582	102 000	1 260
5.52	.581	117 000	1 520

TABLE 66. FLOW OF WATER AT 167 DEG.F THROUGH 60-DEG. WEIR

Series III. Density = 1.90 sl/cf Surface tension = 0.00436 p/f
Kinematic viscosity = 0.000 00419 sf/s

Head *h* In.	Discharge Coefficient *C*	Reynolds Number *R*	Weber Number *W*
1.44	.604	46 000	117
1.56	.603	51 800	137
1.68	.603	57 900	159
1.80	.603	64 200	182
1.92	.602	70 800	207
2.16	.602	84 500	263
2.40	.601	98 800	324
2.64	.601	114 000	392
2.88	.601	130 000	466
3.12	.601	147 000	548
3.36	.600	164 000	635
3.60	.600	181 000	727
4.08	.600	219 000	935
4.56	.599	259 000	1 170
5.04	.599	302 000	1 430
5.52	.599	345 000	1 710

TABLE 67. FLOW OF ADMIXTURE OF ALKANOL AND WATER AT 58.1 DEG.F THROUGH 60-DEG. WEIR

Series III. Density = 1.94 sl/cf Surface tension = 0.00285 p/f
Kinematic viscosity = 0.000 0125 sf/s

Head *h* In.	Discharge Coefficient *C*	Reynolds Number *R*	Weber Number *W*
1.44	.592	15 400	182
1.56	.592	17 400	213
1.68	.591	19 400	247
1.80	.591	21 500	284
1.92	.591	23 800	323
2.16	.591	28 300	409
2.40	.590	33 100	505
2.64	.590	38 200	612
2.88	.589	43 600	727
3.12	.589	49 100	854
3.36	.589	54 900	993
3.60	.589	60 800	1 140
4.08	.588	73 400	1 460
4.56	.588	86 900	1 820
5.04	.587	101 000	2 230
5.52	.587	116 000	2 670

TABLE 68. FLOW OF ADMIXTURE OF ALKANOL AND WATER AT 60 DEG.F THROUGH 60-DEG. WEIR

Series III. Density = 1.94 sl/cf Surface tension = 0.00196 p/f
Kinematic viscosity = 0.000 0122 sf/s

Head *h* In.	Discharge Coefficient *C*	Reynolds Number *R*	Weber Number *W*
1.44	.587	15 700	265
1.56	.587	17 800	311
1.68	.587	20 000	361
1.80	.587	22 100	414
1.92	.586	24 300	471
2.16	.586	29 000	595
2.40	.586	34 000	734
2.64	.586	39 100	888
2.88	.586	44 600	1 060
3.12	.587	50 200	1 240
3.36	.587	56 200	1 440
3.60	.587	62 300	1 660
4.08	.587	75 200	2 130
4.56	.587	88 900	2 660
5.04	.587	103 000	3 240
5.52	.586	118 000	3 890

TABLE 69. FLOW OF WATER AT 62.2 DEG.F ±1.4 THROUGH 90-DEG. WEIR

Series III. Density = 1.94 sl/cf Surface tension = 0.00502 p/f
Kinematic viscosity = 0.000 0118 sf/s

Head *h* In.	Discharge Coefficient *C*	Reynolds Number *R*	Weber Number *W*
2.40	.584	60 700	498
2.64	.584	70 200	602
2.88	.584	80 000	717
3.12	.583	90 200	841
3.36	.583	101 000	976
3.60	.583	112 000	1 120
3.84	.584	123 000	1 275
4.08	.584	135 000	1 440
4.32	.583	147 000	1 610
4.56	.583	160 000	1 800
4.80	.584	171 000	1 990
5.04	.584	185 000	2 190
5.28	.584	198 000	2 400

TABLE 70. FLOW OF WATER AT 99.5 DEG.F THROUGH 90-DEG. WEIR

Series III. Density = 1.93 sl/cf Surface tension = 0.00479 p/f
Kinematic viscosity = 0.000 00739 sf/s

Head *h* In.	Discharge Coefficient *C*	Reynolds Number *R*	Weber Number *W*
2.40	.587	97 100	519
2.64	.584	112 000	628
2.88	.584	128 000	748
3.12	.583	144 000	877
3.36	.583	161 000	1 020
3.60	.583	178 000	1 170
3.84	.583	197 000	1 330
4.08	.582	215 000	1 500
4.32	.582	235 000	1 680
4.56	.582	255 000	1 870
4.80	.582	274 000	2 070
5.04	.582	296 000	2 290
5.28	.582	317 000	2 510

TABLE 71. FLOW OF WATER AT 120 DEG.F THROUGH 90-DEG. WEIR

Series III. Density = 1.92 sl/cf Surface tension = 0.00466 p/f
Kinematic viscosity = 0.000 00609 sf/s

Head *h* In.	Discharge Coefficient *C*	Reynolds Number *R*	Weber Number *W*
2.40	.584	118 000	531
2.64	.584	136 000	642
2.88	.584	154 000	764
3.12	.583	174 000	897
3.36	.583	195 000	1 040
3.60	.583	216 000	1 190
3.84	.583	239 000	1 360
4.08	.581	262 000	1 530
4.32	.581	284 000	1 720
4.56	.581	309 000	1 920
4.80	.581	334 000	2 120
5.04	.580	358 000	2 340
5.28	.580	385 000	2 570

TABLE 72. FLOW OF ADMIXTURE OF ALKANOL AND WATER AT 71.6 DEG.F THROUGH 90-DEG. WEIR

Series III. Density = 1.93 sl/cf Surface tension = 0.00205 p/f
Kinematic viscosity = 0.000 0104 sf/s

Head *h* In.	Discharge Coefficient *C*	Reynolds Number *R*	Weber Number *W*
2.40	.585	48 800	1 210
2.64	.585	56 400	1 470
2.88	.584	64 200	1 750
3.12	.584	72 400	2 050
3.36	.583	80 900	2 370
3.60	.582	89 600	2 730
3.84	.582	98 700	3 100
4.08	.582	108 000	3 500
4.32	.582	118 000	3 930
4.56	.582	128 000	4 380
4.80	.582	138 000	4 850
5.04	.582	149 000	5 340
5.28	.581	159 000	5 870

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