THE PIPE TEE AS A FLOW METER

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By

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INDEX

Appendix

LIST OF FIGURES

LIST OF TABLES

SUMMARY

The objectives of this project were three-fold, to design a flow meter which would (a) indicate within ±5% the true rate of flow of liquids, (b) not need calibrating, and (c) be inexpensive and easy to install. A system of standard pipe tees and connecting pipe was assembled such that the flow of fluid, water in this case, was directed into the run and out the branch of a tee. A total pressure tap was inserted in the plugged end of this tee. A static pressure tap was inserted in the branch opening of a second tee in which the fluid flowed through the run. The two pressure leads were connected to opposite sides of a manometer, and the differential obtained was a measure of the velocity pressure, turbulence and friction losses in the system. These losses were expressed in terms of the number of velocity heads of fluid flowing.

Sufficient data were secured with several variations of meter assembly to prepare correlations which are satisfactory in predicting coefficients for tee meters. Commonly known brands of tees were used and were found to be consistent in structural dimensions and friction characteristics. Nominal sizes of tees from 1/4 to 1 1/2 inches were investigated.

With the data presented, it is possible to construct and use an uncalibrated tee meter with an expected accuracy of ±5%. The meter arrangement is flexible, and the meter can be installed in locations where space is at a minimum. The meter is of simple construction, it becomes a part of the piping system, it introduces no major obstruction to flow, and it appears to be applicable to all types of fluids.

INTRODUCTION

The fundamental basis for several important devices for measuring fluid flow rates is the principle of a differential head loss due to restriction of the normal flow path. The orifice and venturi are classic examples. A second type of flow meter is the impact meter in which the velocity pressure of the moving fluid is an indication of the magnitude of flow. The pitot tube is of this type. Two standard pipe tees can be assembled into a meter which embodies the principle of operation of the impact type meter. The tee meter is unique in that openings for pressure tap leads are already present, the lead being attached to the unused opening of the tee. When the lead is facing the direction of flow, the pressure against it is the total pressure of the fluid. When the lead is attached to the branch of a tee in which the flow passes through the run, the static pressure is obtained. Now if these two pressure leads are attached to opposite sides of a manometer, the differential observed is the difference of the two pressures, the impact pressure. An additional head loss can be measured when the static tee is located on the downstream side of the impact tee, due to turbulence and friction losses in the tee and connecting pipe. An estimate of the differential that would be expected is as follows:

Impact pressure of fluid	1.0 velocity head
Turbulence loss in branched flow[4]	1.3 velocity heads
	2.3 velocity heads

The small additional head loss due to friction in the connecting pipe is not included since the magnitude of this head will vary with the dimensions of the system.

Very little information has been published on the use of tees as flow meters. In a recent article, Nord[7] has described an arrangement of 1/8 inch tees that closely approaches the system investigated. The static tee was located immediately upstream of the impact tee, and air was the fluid flowing. The results indicated that the flow coefficient, defined by C in the equation $V = C\sqrt{2g\Delta H}$, approached a constant value of 0.75 with Reynolds numbers in the turbulent flow range. It was suggested by Nord that each meter be calibrated prior to use. However, insufficient data were given to show that this was actually necessary.

Considerable information is available on the friction effects in piping systems which contain tees. Hoopes et al.[2] found that the extent of reaming of the nipples connecting the tees had a pronounced effect on the friction losses. The distance the nipple was screwed into the tee was not critical. A curve of velocity head loss versus Reynolds number indicated that the loss approached a constant value of 1.0 at Reynolds numbers above 10,000. Freeman[1] discovered that tees plugged with a short nipple and cap had approximately one-half the friction loss incurred when plugged with a conventional plug, an observation that turned out to be of interest in this investigation.

Elbow meters[5] and valve meters[3] have been described in the literature. The accuracy of the elbow meter limited its applicability, whereas the valve meter, upon calibration, was found to be an accurate means of measuring flow rates.

The emphasis of this investigation is on simplicity of construction and high accuracy without calibration. The elements to be studied are the variables introduced by the use of different size fittings, different brands, different arrangements, and the corrections to be applied to the flow coefficient when the system varies in physical form from an adopted standard arrangement, so selected because of its reproducibility and relative insensitivity to minor variations.

EQUIPMENT AND PROCEDURE

The system of pipes and fittings was so arranged that the flow of water from a constant head source was directed into the run and out the branch of one tee and through the run of a second tee located further downstream. The discharge was collected in a weigh tank. Figure 1 illustrates the arrangement.

To facilitate the investigation of the meter characteristics, the component parts of the test section, Figure 2, were numbered consecutively and studied individually in a standard horizontal arrangement. The initial experiments were conducted with 1 inch nominal pipe and fittings. The upstream calming section was 44 diameters in length and contained straightening vanes consisting of a bundle of 1/4 inch copper tubes 18 inches long. Fluid entered the run of the impact tee, and left through the branch opening. The impact pressure lead of 1/4 inch pipe was connected to the meter by means of a street elbow, a reducing bushing, a coupling and a short nipple. The nipple connecting the two tees was cut to 7 3/4 inches in length for compactness. The static pressure lead of 1/4 inch pipe was connected directly to the static tee by means of a 1 inch to 1/4 inch reducing bushing plugging the branch opening. The nipple on the exit side of the static tee was a 5 inch stock length.

The several pieces of auxiliary equipment are shown in Figure 1. A constant head tank was fabricated from a 55 gallon drum by attaching a 1 inch overflow pipe 5 inches from the tank top. The tank was supported 15 feet above the floor and fitted with a 2 inch pipe downspout. This source pipe was connected to a Tuthill Model 4M gear pump. The discharge from the pump passed through an orifice plate located at the entrance to the calming section. The weigh tank was fashioned from another 55 gallon drum by cutting out the top and fitting the drum with a drain connection. The tank rested on the platform of a 500 pound capacity Fairbanks scale. The Merriam 30 inch "clean out"

Figure 1

DIAGRAM OF EQUIPMENT

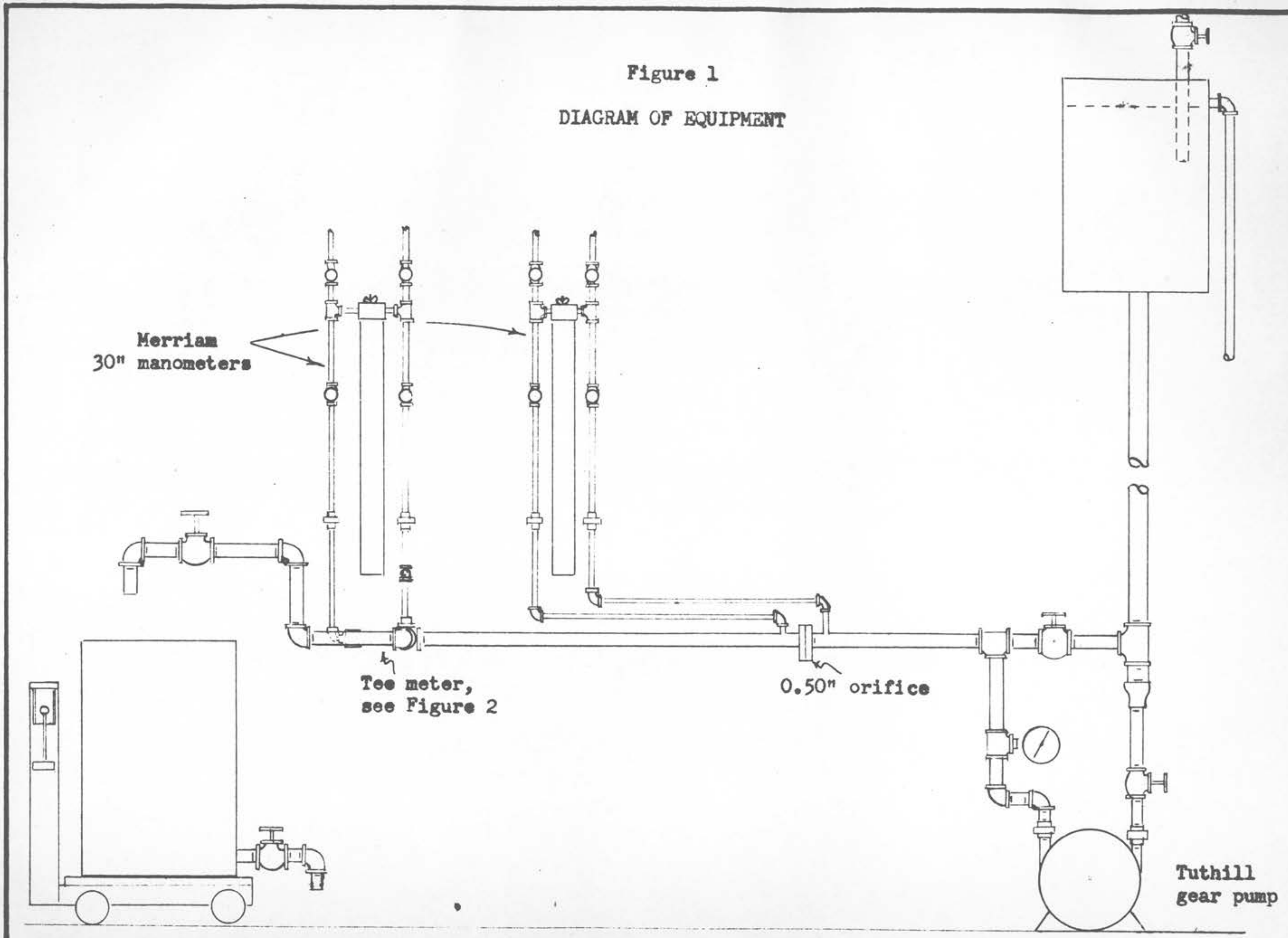


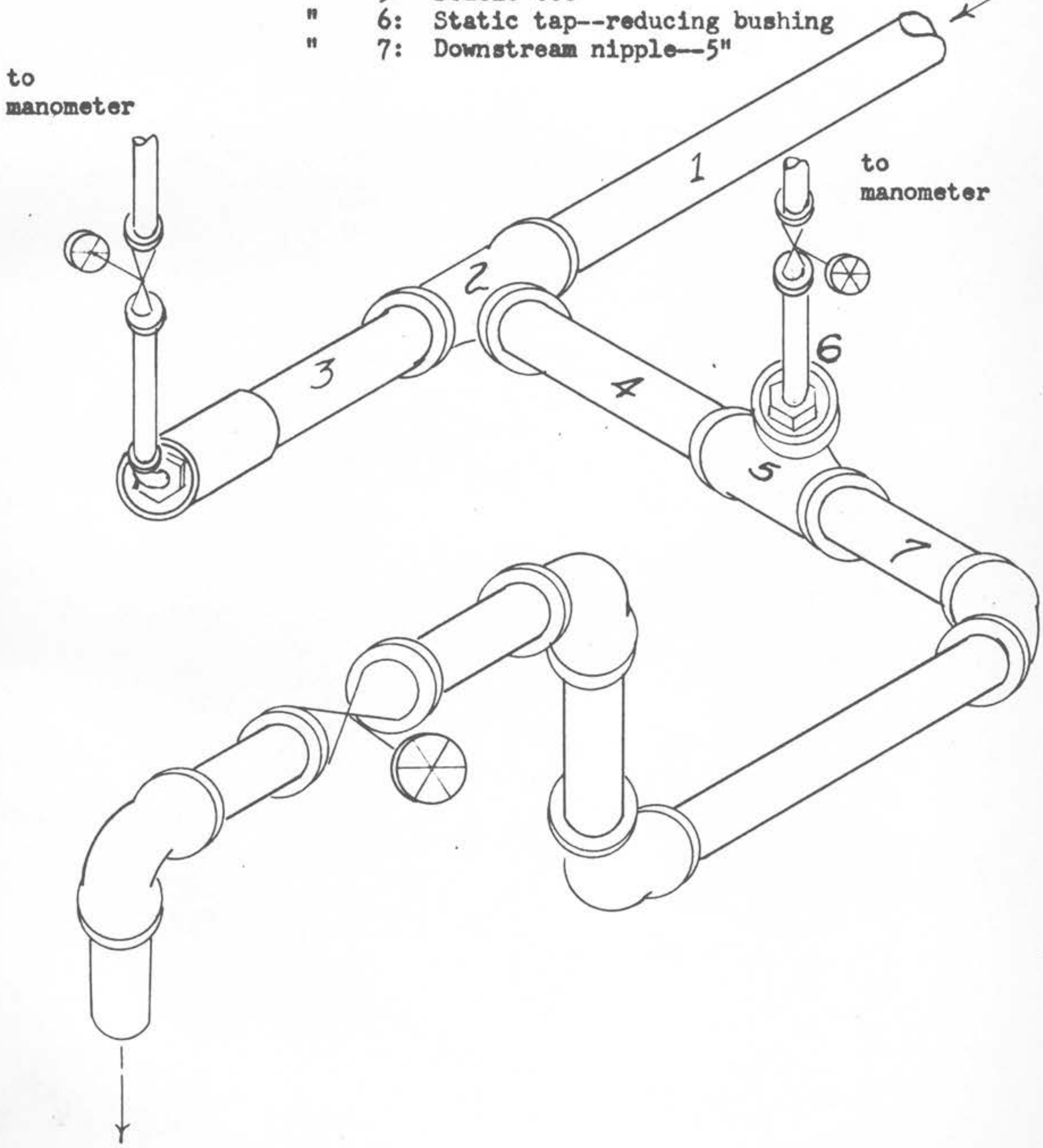
Figure 2

STANDARD ARRANGEMENT OF TEST SECTION

FLOW IN RUN

Legend:

Section 1: Calming section--44 pipe diameters
" 2: Impact tee
" 3: Impact tap, consisting of 5" nipple, coupling, reducing bushing and street elbow
" 4: Connecting nipple--7 3/4"
" 5: Static tee
" 6: Static tap--reducing bushing
" 7: Downstream nipple--5"



style manometers were fitted with air bleeder valves and mounted on a backboard. The meter manometer contained carbon tetrachloride, with a specific gravity of 1.584 at 70° F. The manometer leads were filled with the fluid flowing, i.e., water.

To accomplish a run, the tank was filled and the supply adjusted to allow an overflow throughout the duration of the run. The pump by-pass valve was opened, the pump started and flow rate through the meter adjusted by manual control of the discharge and by-pass valves. The manometer readings were recorded during the period in which a weight of water was being collected. Damping of manometer fluctuations was done by throttling the valve on the impact lead until large surges were eliminated. Timing was done with a stopwatch.

Pertinent data recorded included manometer readings, run number, time of run, tare and gross weights, temperature of water, and exact dimensions of the flow meter equipment under test.

RESULTS

As previously mentioned, the theory of the tee meter is based on the measurement of the combined impact head and friction head loss for a fluid flowing through the meter. The differential, in velocity heads, between the measuring points can be calculated by dividing the head loss, ΔH, in feet, by the value of one velocity head, $V^2/2g$. This number of velocity heads has been denoted by the letter K throughout this report. With this velocity head coefficient, K, readily calculable from manometer and weight readings, the variables can be analyzed in terms of the percentage variation of the coefficient obtained from that for the control or standard arrangement such as shown in Figure 2. The velocity head coefficients were compared at a Reynolds number of 40,000. It is in this range of flow rates that the K's approach a constant value. Examples are given in Figure 3.

In addition to the velocity head coefficients, orifice meter coefficients, defined as C in the equation $V = C\sqrt{2g\,\Delta H}$, were determined. Upon solving this equation for the head loss, $\Delta H = (1/C^2)(V^2/2g)$, it is seen that the relation between K and C is $K = 1/C^2$. Thus, the per cent variation in K will be twice the per cent variation in C. A complete sample calculation is shown in the appendix. Other convenient coefficients are defined to enable use of other manometer fluids, different flowing fluids, and other pipe sizes. They are: $Q = C'\sqrt{2g\,\Delta H}$ and $Q = C''\sqrt{2gR}$. Using the latter coefficient, plots of the volumetric flow rate versus the manometer reading were prepared for the various sizes of standard meters.

It is worthy of mention here that the inside pipe diameters as given in tables in Perry's handbook[8] were used to calculate the coefficients, regardless of how much the handbook and actual values differed. These diameters ordinarily agreed to 2%.

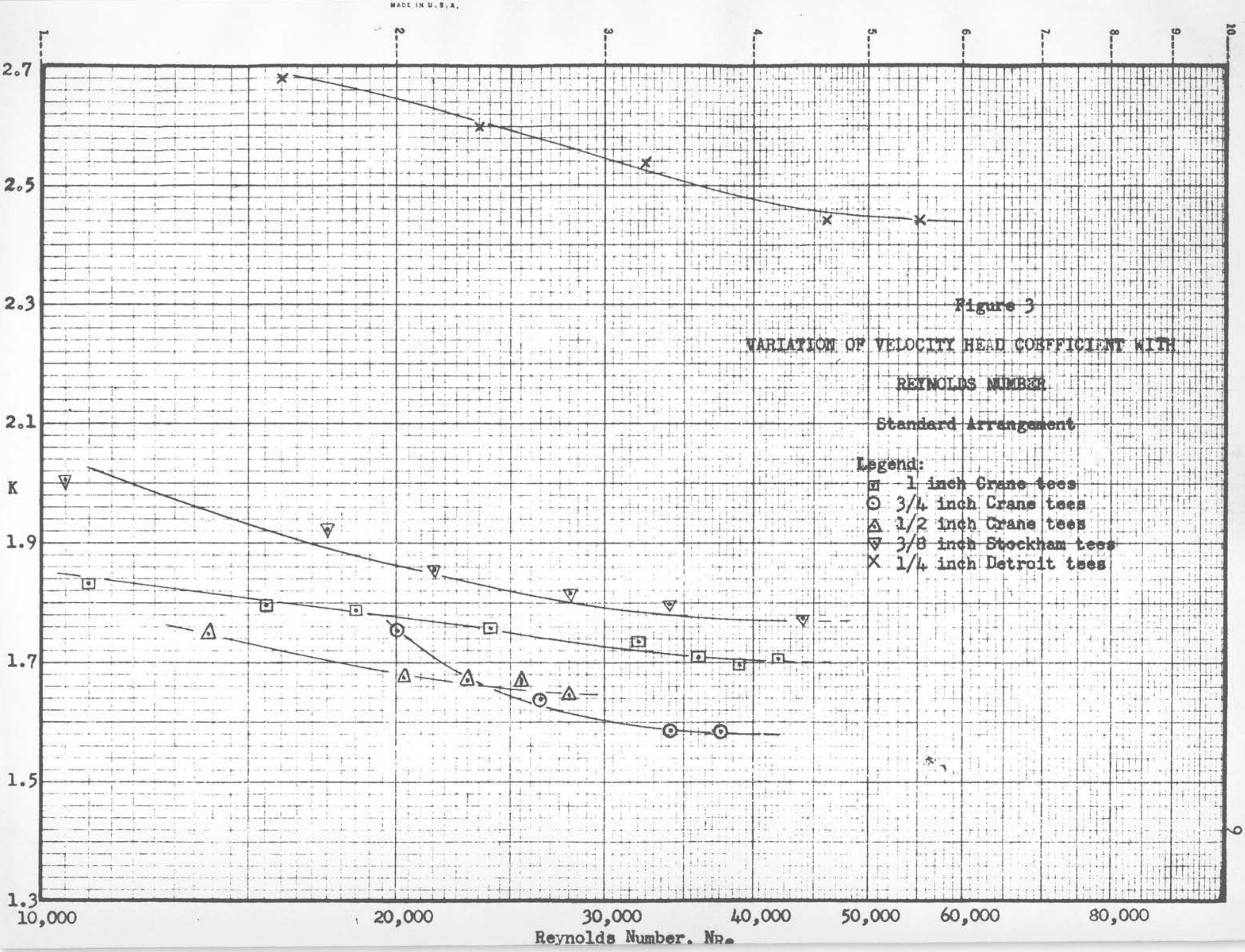


Figure 3

VARIATION OF VELOCITY HEAD COEFFICIENT WITH REYNOLDS NUMBER

Standard Arrangement

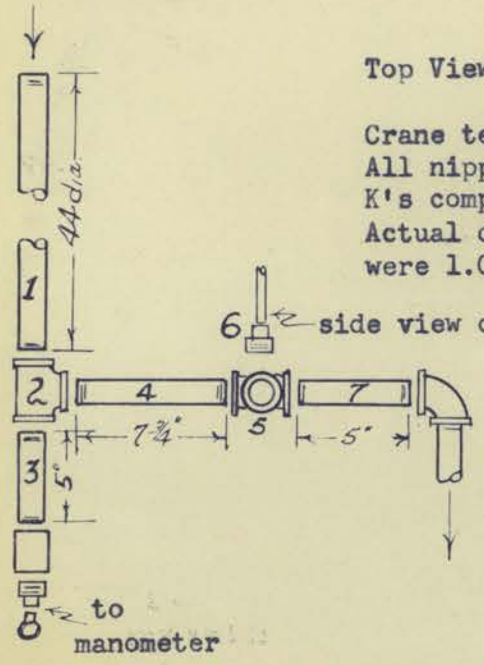
The experimental observations now can be discussed with greater understanding. A complete list of the variables studied is given in Table I. Although the table serves as a summary, some explanation is essential to point out the critical effects noted in the seven component parts of the meter.

Section three, the impact pressure tap, required considerable investigation in that numerous inconsistencies appeared during the early part of the problem. The bushing was found unsuitable as a plug. Large turbulence surges in the fluid stream were reflected in continuous fluctuation of the manometer differential making it almost impossible to determine the correct reading. A short nipple and a coupling inserted in front of the reducing bushing served as a buffering section which tended to absorb some of the surging. The length of the nipple was found to be unimportant (see Table II). However, the distance that this nipple was screwed into the impact tee was of consequence. The K decreased with increasing number of turns screwed in. Reaming the end of the nipple entering the tee caused an increase in the K. Evidently the turbulence loss in the tee is greater when the fluid has an opportunity to pass further into the plugged end. Additional data are given in Table II.

TABLE I

PER CENT VARIATION IN VELOCITY HEAD COEFFICIENT FROM THE CONTROL FOR EACH VARIABLE OF THE SYSTEM: FLOW IN RUN

Section		Variable	Per cent variation in K from control Nominal size, inches 1	3/4	1/2
1	(1)[a]	Calming section of 6 pipe diameters, no straightening vanes	12.0	-	-
"	"	Calming section of 10 or more diameters, no vanes	0.0	-	0.0
"	(2)	Straightening vanes ending 5 diameters before impact tee	7.5	-	-
"	"	Straightening vanes ending 14 diameters before impact tee	0.0	-	-
"	(3)	Inclined a little from horizontal	0.0	-	-
"	(4)	End of pipe reamed to 1.14 inches	-1.7	-	-
"	(5)	Turned in 3, 5, or 6 threads in tee	0.0	0.0	-
2	(6)	Brands of tees--see Tables VII-XI			
3	(7)	Length of nipple and coupling-see Table II	0.0	-	-1.0
"	(8)	Threaded into section 2, per turn <5, see Table II	5.0	0.0	-
"	"	Threaded into section 2, per turn >5, see Table II	-5.3	-8.1	-
"	(9)	End of nipple in section 2 reamed to 1.14 inches	9.6	-	-
4	(10)	Diameter of nipple--see Table III			
"	(11)	Length of connecting nipple--see Table IV			
"	(12)	Nipple end into section 2 reamed to 1.14 inches--see Table VI	-2.4	-	-
"	(13)	Nipple end into section 5 reamed to 1.14 inches--see Table VI	-14.3	-	-
"	(14)	Threading nipple into section 2, per turn <5--see Table V	0.0	0.0	-
"	"	Threading nipple into section 2, per turn >5--see Table V	7.8	5.0	-
"	"	Threading nipple into section 5, per turn <5--see Table V	-5.1	-7.5	-
"	"	Threading nipple into section 5, per turn >5--see Table V	1.2	4.2	-
5	(15)	Brands of tees--see Tables VII-XI			
6	(16)	Bushing on static tee tap	control		
"	"	Short nipple before bushing on static tap	-2.5	0.0	-
"	(17)	Threading bushing 3 turns into static tap tee	1.3	-	-
7	(18)	Length of nipple from section 5 to elbow, from 1 3/4 to 7 inches	0.0	-	-
"	(19)	Threading nipple into section 5, from 3 to 6 turns	0.0	-	-
"	(20)	Reaming end into section 5 to 1.14 inches	-3.0	-	-
		Miscellaneous variables			
	(21)	Section 4 vertical upward, section 5 in line with section 3 tap	0.0	-	-
	"	Section 4 vertical upward, section 5 facing 90° from section 3 tap	0.0	-	-
	"	Section 4 vertical downward, section 5 tap in line with section 3	-0.6	-	-



Top View (Exploded) Of Control Meter

Crane tees
All nipples screwed up five turns in tees
K's compared at N_{Re} of 40,000
Actual diameters of connecting nipples were 1.040, 0.818 and 0.622

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[a] Numbers in parentheses correspond to those given in Table XVIII, Table of Experimental Data

TABLE II

VARIABLES AFFECTING THE VELOCITY HEAD COEFFICIENT: SECTION THREE

A. Length of nipple and coupling prior to reducing bushing

Runs	Length, inches	K
169-80	0.00	1.41
129-46	3.25	1.61
181-90	4.00	1.62
191-200	5.50	1.53
201-210	7.17	1.59

B. Number of threads nipple is screwed into impact tee

Runs	Length, inches	Number of threads	K
661-4	6.75	3	1.86
665-8	"	5	1.68
669-72	"	6	1.59
649-52	11.50	3	1.85
653-6	"	5	1.70

C. Reaming of nipple end into section 2

Runs	Length, inches	Number of threads	Reamed diameter, inches	K
665-8	6.75	5	1.040	1.68
673-6	"	"	1.140	1.88
653-6	11.50	"	1.040	1.70
657-60	"	"	1.140	1.88

The greatest number of critical variables is found in the connecting nipple, section 4. They are:

(1) The diameter of the connecting nipple, differences being due to variations in pipes of the same nominal size.

(2) The length of the nipple.

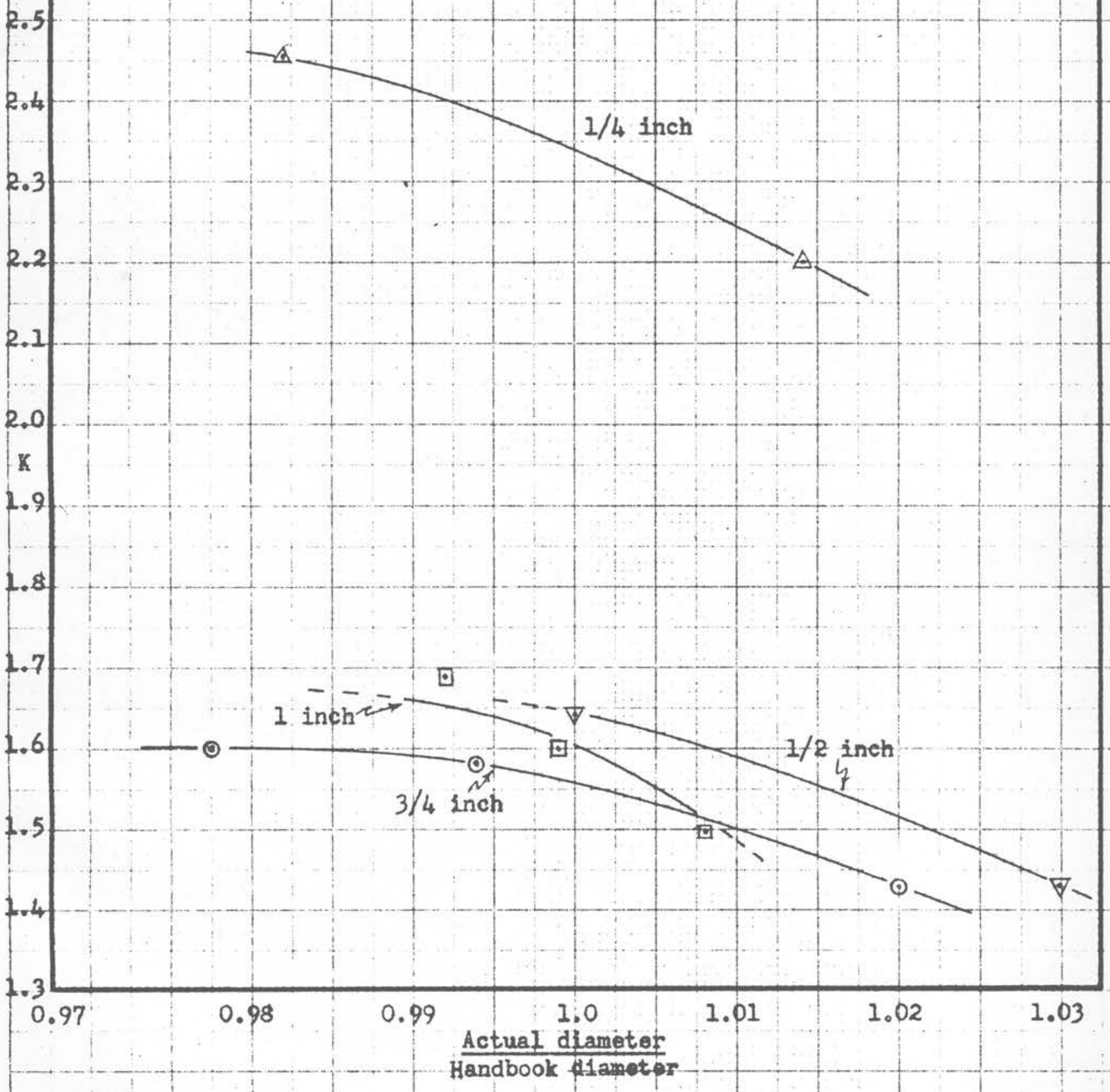
(3) Threading of the nipple.

(4) Reaming of the nipple.

The effect of using connecting nipples of the same nominal size but of slightly different diameters is illustrated in Figure 4. The numerical values of these variations are given in Table III. To restate a previously mentioned standard, the K's were calculated using the velocity value for a pipe of nominal

Figure 4

EFFECT OF CONNECTING NIPPLE DIAMETER ON THE VELOCITY HEAD COEFFICIENT



diameter. This calculation in itself tends to magnify the amount of the experimental variance between K's for slightly different diameter systems. A recalculation of the K's using the measured pipe diameter as a basis tended to reduce this variation. It was not deemed advisable to include the recalculated data but instead to continue to express the results in terms of the nominal inside diameter of the pipe (Schedule 40).

TABLE III

VARIABLES AFFECTING THE VELOCITY HEAD COEFFICIENT: SECTION FOUR

NIPPLE DIAMETER

Runs	Length, inches	Diameter, inches	K
751-4	7.75	1.054	1.48
853-6	"	1.048	1.60
771-9	"	1.040	1.68
1135-40	7.87	1.018	1.60
1055-8	7.75	0.840	1.43
1067-70	"	0.818	1.58
1071-4	"	0.803	1.62
1084-8	"	0.640	1.43
1079-83	"	0.622	1.65
1117-22	7.87	0.494	1.82
1123-8	"	0.491	1.78

Increasing the length of the nipple necessarily increases the head loss due to pipe wall friction. In Figure 5 it would appear that the effect with each nipple is approximately the same, causing the curves to be almost parallel. An average value of the slope is 0.03. With several of the sizes, the effect of length was determined with two different diameters of pipe to permit interpolation and extrapolation between the curves of Figure 5. Consideration must also be given to the relative smoothness of the nipple wall. (See Table IV.)

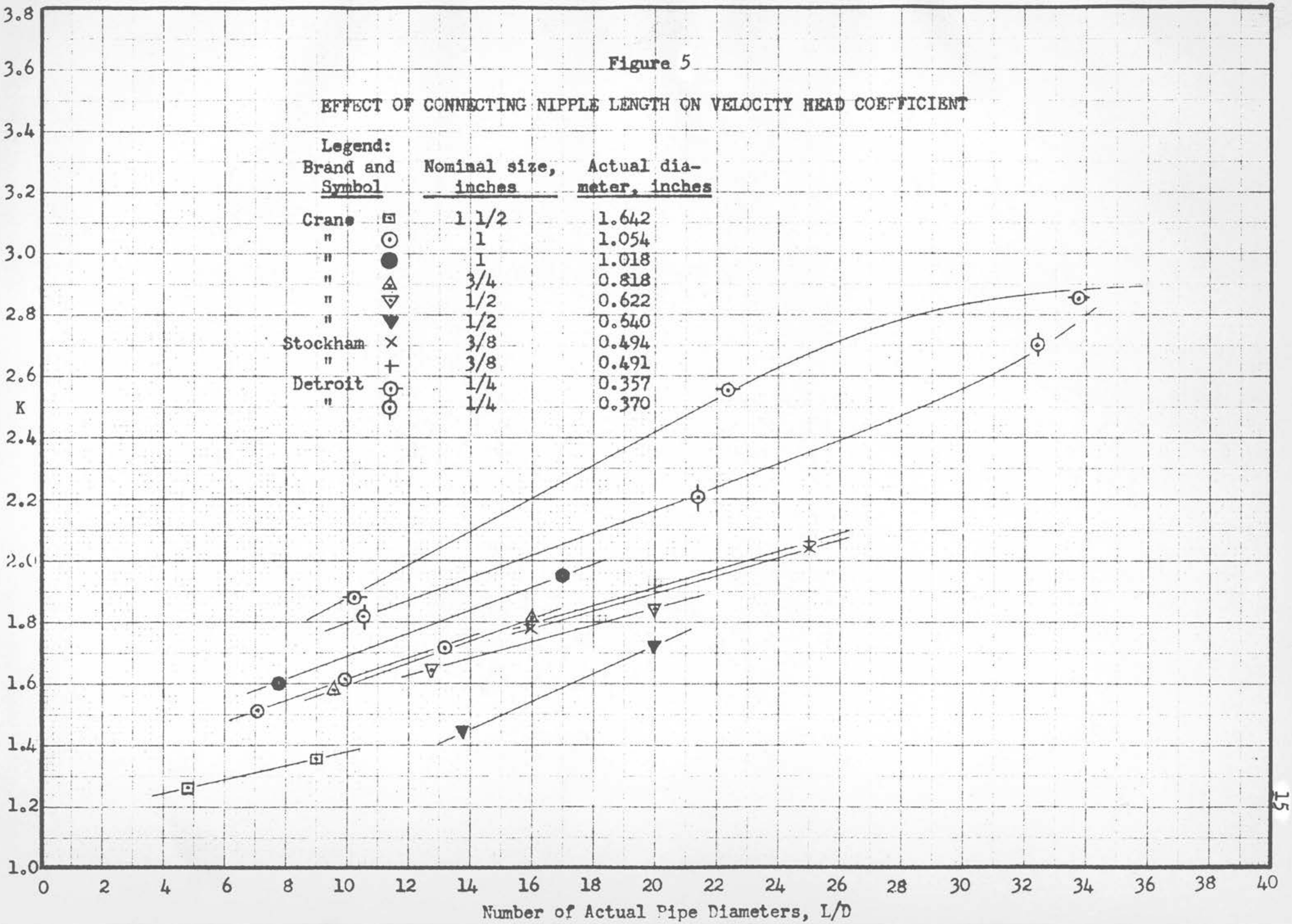


Figure 5

EFFECT OF CONNECTING NIPPLE LENGTH ON VELOCITY HEAD COEFFICIENT

TABLE IV

VARIABLES AFFECTING THE VELOCITY HEAD COEFFICIENT: SECTION FOUR

NIPPLE LENGTH

Runs	Length, inches	Diameter, inches	Type	K
747-50	7.75	1.054	Black	1.50
735-8	10.50	"	"	1.61
739-42	14.00	"	"	1.72
1135-40	7.87	1.018	Galv.	1.60
1129-34	14.00	"	"	1.89
1067-70	7.87	0.818	"	1.58
1063-6	13.12	0.818	"	1.82
1079-83	8.00	0.622	"	1.64
1089-96	13.12	0.622	"	1.81
1084-8	8.00	0.640	Black	1.40
1097-1104	13.12	0.640	"	1.70
1117-22	7.87	0.494	"	1.82
1105-10	12.12	0.494	"	2.01
1217-25	8.00	0.370	"	2.15
1233-39	12.00	0.370	"	2.84
1226-32	8.00	0.357	Galv.	2.45
1240-6	12.00	0.357	"	2.65

Threading is not as disturbing on the end of the connecting nipple into the impact tee as it is on the end into the static tee. Five or fewer turns into section 2 or five or more turns into section 5 do not materially affect the coefficient. However, threading in the opposite direction than that mentioned above produces significant departures. The standard procedure in all control runs was to thread all nipples into the tees five turns. (See Table V.)

TABLE V

VARIABLES AFFECTING THE VELOCITY HEAD COEFFICIENT: SECTION FOUR THREADING INTO SECTIONS 2 AND 5

Runs	Nominal size, inches	Threads turned in	Section	K
677-80	1	3	2	1.64
681-4	"	5	2	1.66
685-8	"	6	2	1.79
689-92	"	3	5	1.49
692-6	"	5	5	1.64
697-9	"	6	5	1.65
876-9	3/4	4	2	1.52
857-63	"	5	2	1.51
880-3	"	6	2	1.59
884-7	"	4	5	1.42
888-91	"	6	5	1.58

Excessive reaming of the end of the connecting nipple into the impact tee is not serious. Reaming of the other end of the nipple into the static tee can be a cause of great variations in the K. The standard procedure for finishing the end of the nipple was to ream the burr to approximately the pipe inside diameter with a regular pipe reamer, then to smooth the remaining ridge with a round file and emery cloth. The nipples were gauged with an inside caliper to check for hidden ridges. From experience it was found that the eye was not a satisfactory judge of complete burr removal. Although the preparation of the connecting nipple is a time consuming step, it is probably one of the most important means of securing accurate results. The magnitude of the variations observed appear in Table VI.

TABLE VI

VARIABLES AFFECTING THE VELOCITY HEAD COEFFICIENT: SECTION FOUR

REAMING

Runs	Reamed diameter, inches		Nipple end	K
514-20	1.040	(pipe id)	impact	1.68
521-4	1.078		"	1.61
525-8	1.140		"	1.64
541-4	1.040	(pipe id)	Static	1.61
545-8	1.093		"	1.48
549-52	1.140		"	1.39
553-6	1.182		"	1.38

One of the points of interest in the investigation was the tees, the similarity within brands, between brands, and correlations of coefficient with structure. In Tables VII-XI, various sizes of the several brands have been listed along with the data obtained with them. It was usually necessary to compare both impact and static tees together in a single installation by switching them since an insufficient number of tees was available in each size to test a group of them against one as a control. Although the number of samples examined in each size was small, it is believed from the consistency of the data that additional samples would not materially change the experimental average deviation in the velocity head coefficients. One might point out an exception to this assumption for the 1 inch Crane tee No. 3 (Table VIII). This tee was tested merely to determine whether visual inspection of the tees would be sufficient to weed out bad samples. The shoulders of this tee were grooved and sloped, unlike the control tees, which would indicate that it may have been cast in an imperfect mold. The pronounced deviation from the control for this tee verifies that visual inspection is important here.

TABLE VII

VELOCITY HEAD COEFFICIENTS FOR DETROIT BRASS STANDARD TEES IN CONTROL ARRANGEMENT[a]

Runs	Size inches	Type	Tee No.	Section location	Variable	K
641-4	1	Black	1	2	Control[b]	1.75
			2	5	Control	
629-32	"	"	1	5	Interchanged[c]	1.65
			2	2	Interchanged	
1008-11	3/8	"	1	2	Control	1.81
			2	5	Control	
1012-15	"	"	1	5	Interchanged	1.91
			2	2	Interchanged	
1016-20	"	"	1	2	Control	2.14
			2	5	Control	
1021-4	1/4	"	1	2	Control	2.15
			3	5	New tee[d]	
1025-8	"	"	3	2	New tee	2.20
			1	5	Control	
1029-32	"	"	1	5	Interchanged	2.30
			2	2	Interchanged	
1033-6	"	"	1	2	Reversed[e]	2.35
			2	5	Reversed	

[a] Connecting nipple diameters of 1.040, 0.491, and 0.370 inches

[b] Control position, tee No. 1 in impact position, tee No. 2 in static position

[c] Tees interchanged in section location

[d] A third sample of the same brand and size

[e] The direction of this tee reversed, location not changed

TABLE VIII

VELOCITY HEAD COEFFICIENTS FOR CRANE STANDARD TEES IN CONTROL ARRANGEMENT[a]

Runs	Nominal size, inches	Type	Tee No.	Section location	Variable	K
605-8	1	Galv.	1 2	2 5	Control[b] Control	1.65
601-4	"	"	1 2	2 5	Control Reversed[c]	1.66
609-12	"	"	1 2	2 5	Reversed Control	1.67
613-16	"	"	1 2	2 5	Reversed Reversed	1.70
617-20	"	"	1 2	5 2	Interchanged[d] Interchanged	1.65
621-24	"	"	1 3	2 5	Control New tee[e]	1.56
925-28	3/4	"	1 2	2 5	Control Control	1.45
929-32	"	"	1 3	2 5	Control New tee	1.46
933-36	"	"	3 2	2 5	New tee Control	1.52
937-40	"	"	1 2	5 2	Interchanged Interchanged	1.52
941-45	1/2	"	1 2	2 5	Control Control	1.66
946-49	"	"	1 2	2 5	Control Reversed	1.67
951-54	"	"	1 2	2 5	Reversed Control	1.63
955-58	"	"	1 2	5 2	Interchanged Interchanged	1.71

a Connecting nipple diameters of 1.040, 0.840 and 0.622 inches

b Control position, tee No. 1 in impact position, tee No. 2 in static position

c The direction of this tee reversed, location not changed

d Tees interchanged in section locations

e A third sample of the same brand and size

TABLE IX

VELOCITY HEAD COEFFICIENTS FOR STOCKHAM STANDARD TEES IN CONTROL ARRANGEMENT[a]

Runs	Nominal size, inches	Type	Tee No.	Section location	Variable	K
1258-63	1 1/2	Galv.	1 2	2 5	Control[b] Control	1.28
1264-9	"	"	1 2	5 2	Interchanged[c] Interchanged	1.34
857-63	3/4	Black	1 2	2 5	Control Control	1.51
908-11	"	"	1 3	2 5	Control New tee[d]	1.55
912-15	"	"	3 2	2 5	New tee Control	1.58
917-20	"	"	1 2	5 2	Interchanged Interchanged	1.48
967-70	1/2	"	1 2	2 5	Control Control	1.79
971-4	"	"	1 2	2 5	Control Reversed[e]	1.82
975-8	"	"	1 2	2 5	Reversed Control	1.82
979-82	"	"	1 2	5 2	Interchanged Interchanged	1.89
986-91	3/8		1 2	2 5	Control Control	1.82
992-5	"	"	1 3	2 5	Control New tee	1.86
996-9	"	"	3 2	2 5	New tee Control	1.88
1000-3	"	"	1 2	5 2	Interchanged Interchanged	1.84

a Connecting nipple diameters of 1.595, 0.840, 0.622, and 0.491 inches

b Control positions, tee No. 1 in impact position, tee No. 2 in static position

c Tees interchanged in section locations

d A third sample of the same brand and size

e The direction of this tee reversed, location not changed

An indication of the variation that can be expected when combinations of two brands of tees are employed is given in Table X. With the 1 inch nominal size, the combinations of Crane and Detroit Brass tees yielded a range of deviations from -1.2% to +5.9% from the Crane controls. The variation was of greater magnitude for the 1 1/2 inch tees, being ±13%. The increased variation can be attributed to the differences in the shapes of the larger tees. For instance, the body of the Stockham tee showed sharp contours which can be compared to the appearance of a tee joint of two cylindrical sheet metal ducts. The Crane and Walworth tees were devoid of these striking lineations. In general the dimensions for the smaller sizes of tees, 1 inch and smaller, were constant between brands (see Table XVII, appendix). The small amount of deviation among brands of tees did not warrant a very extensive study of the effects of minor change in physical structure on the velocity head coefficient.

The average values of the velocity head coefficients for the brands of tees studied appear in Table XI. For the 1/2 inch Crane and Stockham tees, an 8.8% difference was obtained. For the other sizes in which two brands were tested, the deviation was below 2% per cent in each instance.

The miscellaneous variables that were investigated are worthy of mention. Straightening vanes in the upstream calming section are unnecessary. They will also cause deviations when located close to the impact tee. The leveling of the test section was carefully controlled. However, it is not a critical requirement when held within a ±2 degrees from the horizontal. The meter can be located in a horizontal or vertical plane without change of characteristics. The direction of a plane through the static tap in relation to one through the impact tap is not important.

TABLE X

COMBINATIONS OF DIFFERENT BRAND TEES IN THE STANDARD ARRANGEMENT[a]

Runs	Size, inches	Brand	Tee No.	Section location	Variable	K
1264-9	1 1/2	Stockham	2	2	Control[b]	1.34
		Stockham	1	5	Control	
1270-4	"	Stockham	2	2	Control	1.54
		Walworth	1	5	New brand[c]	
1275-9	"	Walworth	1	2	New brand	1.28
		Stockham	2	5	Interchanged[d]	
1280-3	"	Crane	1	2	New brand	1.18
		Stockham	2	5	Interchanged	
1284-8	"	Stockham	2	2	Control	1.44
		Crane	1	5	New brand	
779-802	1	Crane	1	2	Control	1.70
		Crane	2	5	Control	
807-10	"	Crane	1	2	Control	1.75
		Detroit	2	5	New brand	
811-14	"	Crane	1	2	Control	1.68
		Detroit	1	5	New brand	
819-22	"	Detroit	1	2	New brand	1.80
		Crane	2	5	Control	
823-5	"	Detroit	2	2	New brand	1.78
		Crane	2	5	Control	

[a] Connecting nipple diameters of 1.595 and 1.040 inches

[b] Control position

[c] Other brand of tee

[d] Control brand that was interchanged from impact to static location or vice versa

TABLE XI

AVERAGE VALUES OF VELOCITY HEAD COEFFICIENTS FOR BRANDS STUDIED

Nominal size, inches	Average K for brands of tees		
	Crane	Stockham	Detroit Brass
1/4	-	-	2.22
3/8	-	1.86	1.86
1/2	1.67	1.83	-
3/4	1.58	1.58	-
1	1.67	-	1.70
1 1/2	-	1.30	-

Branch-to-run Flow

The impact tee may be used such that the fluid flows into the branch opening and out the run, the remainder of the test section being as shown in Figure 2 for the standard arrangement. A summary of the results of the investigations conducted with flow into the branch is given in Tables XII and XIII.

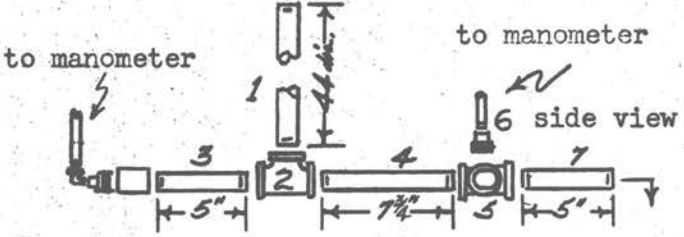
TABLE XII

PER CENT VARIATION IN VELOCITY HEAD COEFFICIENT FROM THE CONTROL FOR EACH VARIABLE OF THE SYSTEM: FLOW IN BRANCH[a]

Section	Variable		Per cent variation in K from control
1	(22)[b]	Threading pipe into section 2 four turns	0.0
"	"	" " " " " five "	0.0 (control)
"	"	" " " " " six "	0.5
2	(23)	Brands of tees--see Table XIII	
3	(24)	Threading nipple into section 2 four turns	0.0
"	"	" " " " " six "	0.0
"	(25)	Bushing replacing short nipple into impact tee	-11.0
4	(26)	Threading nipple into section 2 four turns	-5.8
"	"	" " " " " six "	3.2
5	(23)	Brands of tees--see Table XIII	
		Miscellaneous variables	
	(27)	Section 4 vertical upward	-3.2
	"	" " " downward	-2.6

[a] For 1 inch tees as shown below. Remainder of arrangement is shown in Figure 2.

[b] Numbers in parentheses correspond to those given in Table XVIII, Table of Experimental Data



Top View (Exploded)
Of Control Meter

TABLE XIII

VELOCITY HEAD COEFFICIENTS FOR CRANE AND DETROIT BRASS STANDARD TEES

FLOW INTO BRANCH[a]

Runs	Size, inches	Brand	Tee No.	Section location	Variable	K
1147-51	1	Crane	1	2	Control	1.55
			2	5	Control	
1177-81	"	"	1	5	Interchanged	1.55
			2	2	Interchanged	
1207-11	"	Detroit	1	2	Control	1.37
			2	5	Control	
1212-16	"	"	1	5	Interchanged	1.46
			2	2	Interchanged	

[a] Arrangement is shown under Table XII. Connecting nipple id = 1.040"

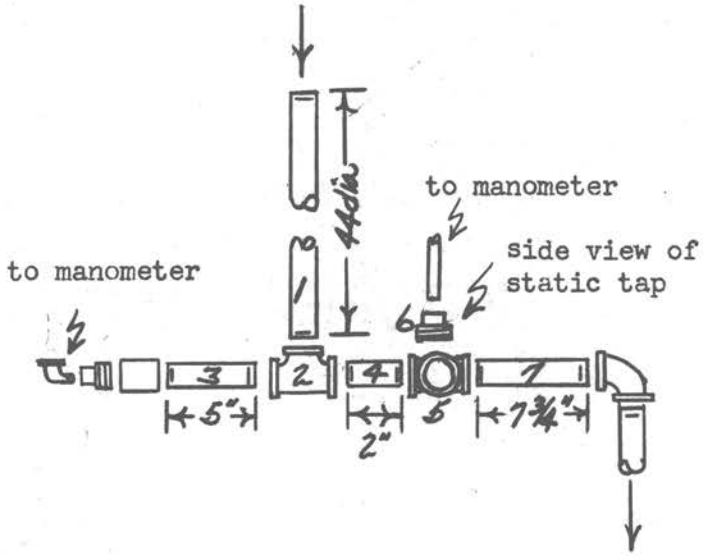
Another interesting observation from branch-to-run flow is that the threading of the nipple of section 3 has little effect on the K. However, the threading of the connecting nipple into the run of the impact tee becomes important. This behavior is different from that previously obtained with run-to-branch flow. The magnitude of these variations are less than for the standard arrangement, and the thought immediately arose as to methods of improving the overall basic arrangement. Since section 4 contains the greatest number of sensitive variables, the choice would be to eliminate this section. This would require a new method of holding the tees together, such as using flanged fittings, or brazing the screwed fittings together. Shortening the length of the connecting nipple might diminish the effect of diameter and length on the velocity head loss. Several runs were made to determine the feasibility of this suggestion. A glance at the results in Table XIV indicates that a short connecting nipple is a satisfactory means of reducing the effects of nipple length and diameter. Stock nipples of 2, 2 1/2, or 3 inches and of diameter of 1.040 and 1.054 inches give comparable K's in this system. The K for this arrangement, 1.17, agrees favorably with the expected value of 1.23 obtained by extrapolation of the L/D correlation of Figure 5 and noting that the K for branch flow is approximately 10% lower than the K for flow into the run (Crane tees, Tables XI and XIII). The effects due to structural dissimilarity of the tees may become of greater relative importance with the lower K.

TABLE XIV

PER CENT VARIATION IN VELOCITY HEAD COEFFICIENT FROM THE CONTROL FOR EACH VARIABLE IN SYSTEM: FLOW IN BRANCH WITH SHORT NIPPLE[a]

Section			Per cent variation in K from control
3	(28)	Threading nipple into section 2 four turns	0.0
"	"	" " " " " 2 five "	0.0 (control)
"	"	" " " " " 2 six "	4.5
4	"	" " " " " 2 four and one-half turns	-5.4
"	"	Threading nipple into section 2 five and one-half turns	5.7
"	"	End of nipple into section 2 reamed to 1.088 inches	-1.0
"	"	" " " " " 5 " " " "	-8.5
"	"	Connecting nipple diameter 1.040 inches	-2.5
"	"	Connecting nipple length 2 1/2 inches	-2.5
"	"	Connecting nipple length 3 inches	1.7

a. The arrangement is drawn below. Connecting nipple diameter is 1.054 inches, and all assemblies are 5 turns except section 4 end into section 5 is 4 1/2 turns. The K for the control is 1.17.



Top View (Exploded)
Of Control Meter

Flow Coefficients

Although most of the previous discussion has been devoted to the expression of the meter characteristics in terms of velocity head losses, it should be stated that this method of expression was selected purely for convenience. Conversion factors for velocity head loss to flow coefficients are given below:

TABLE XV

CONVERSION FACTORS FOR VELOCITY HEAD LOSS TO FLOW COEFFICIENT

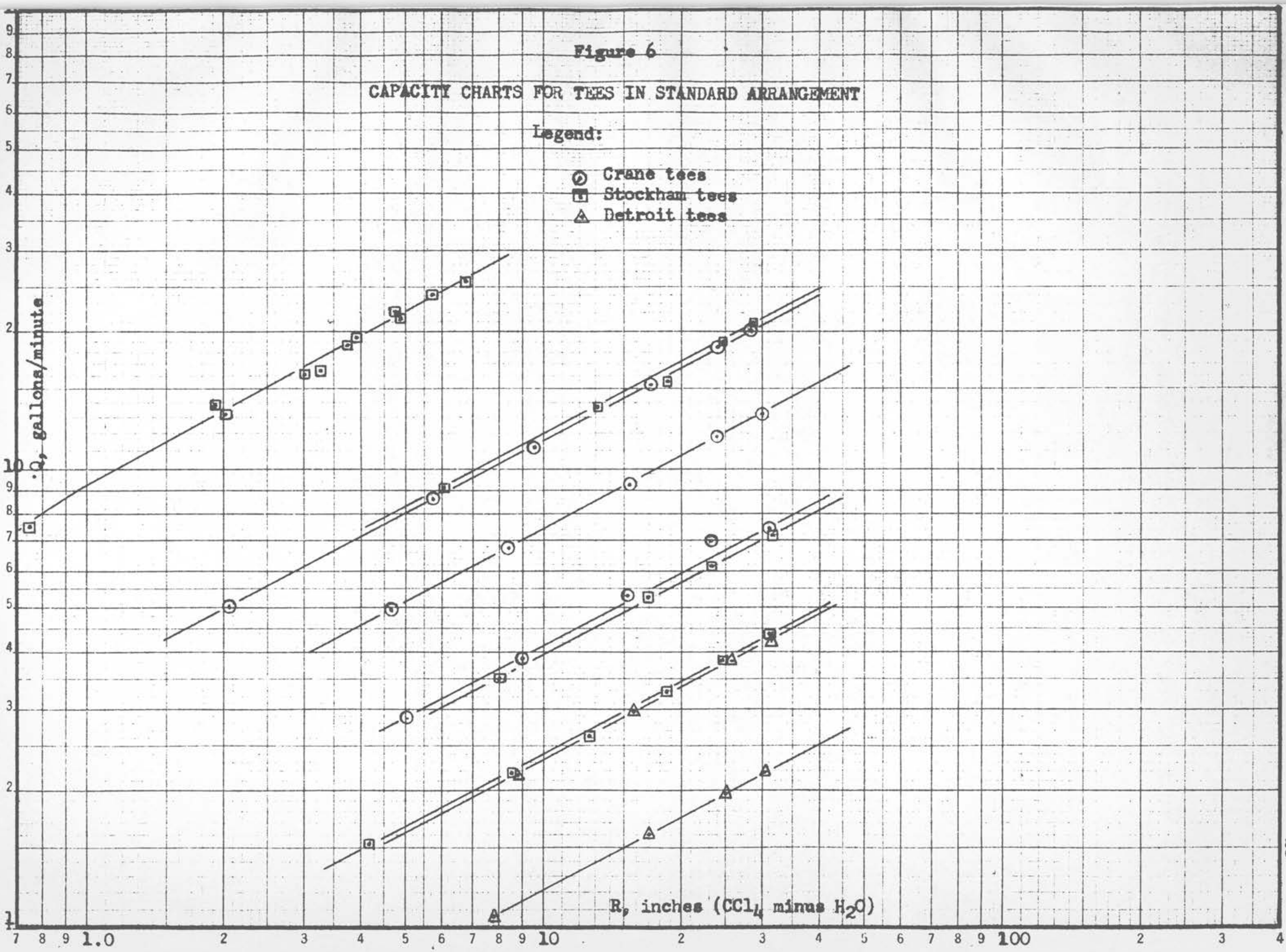
Fitting size, inches	Multiply $K^{-1/2}$ by factor in table to give corresponding flow coefficient C	C'	C''
1 1/2	1.0	6.36	1.401
1	"	2.68	0.595
3/4	"	1.66	0.369
1/2	"	0.942	0.210
3/8	"	0.598	0.127
1/4	"	0.324	0.0718

The method of development of these conversion factors may be found in the sample calculations. The conversion factors for C' and C'' vary with pipe size because the pipe cross sectional area is included in the factor. The flow coefficients vary inversly as the square root of the velocity head coefficient, therefore the percentage variations for flow coefficients should be one-half those determined for the velocity head K's given in Tables I, XII and XIV. Thus, the flow coefficient (a direct measure of the linear velocity) is twice as accurate (percentagewise) as the K value.

Figure 6 is a working chart for standard arrangement tee meters from 1/4 to 1 1/2 inch. Figure 7 indicates the change in the coefficient C'' with increasing flow rate.

Figure 6

CAPACITY CHARTS FOR TEES IN STANDARD ARRANGEMENT



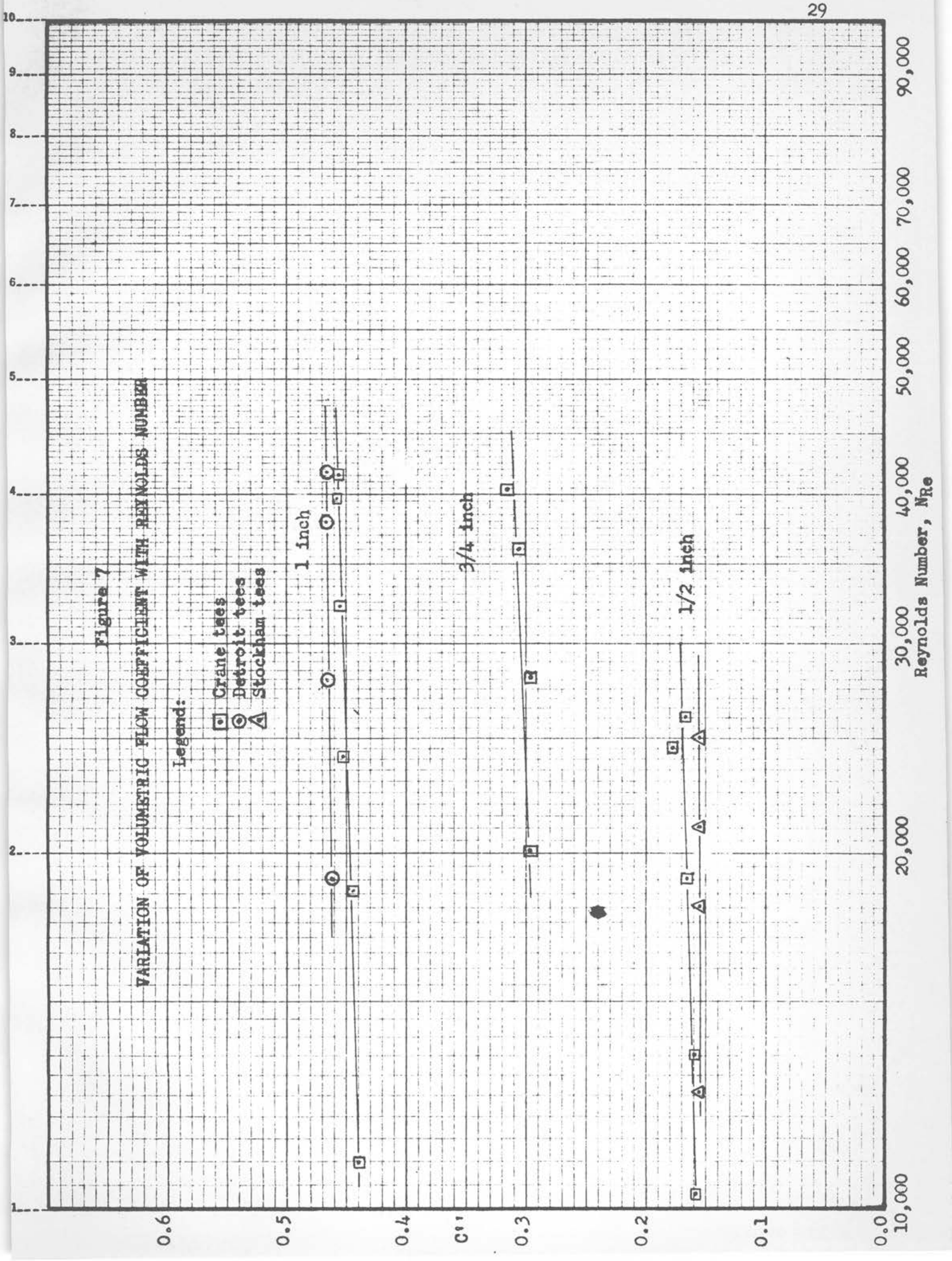


Figure 7

VARIATION OF VOLUMETRIC FLOW COEFFICIENT WITH REYNOLDS NUMBER

CONCLUSIONS AND RECOMMENDATIONS

The satisfactory completion of two of the objects of the research is shown in the summary table, given below, of coefficients for tee meters in the standard arrangement. The coefficients are useful with standard meters with an expected accuracy of ± 5% in C (±10% in K) without prior calibration.

TABLE XVI

FLOW AND VELOCITY HEAD COEFFICIENTS FOR STANDARD METERS[a]

Tee size	Tee brand	Inside diameter of connecting nipple, Actual, inches	Nominal in tables, inches	K	C	C'	C''
1 1/2	Stockham	1.595	1.610	1.30	0.877	5.57	1.22
1	Crane	1.040	1.049	1.67	0.775	2.07	0.466
"	Detroit	"	"	1.70	0.767	2.05	0.461
3/4	Crane	0.818	0.824	1.58	0.797	1.32	0.315
"	Stockham	"	"	1.58	0.797	1.32	0.315
1/2	Crane	0.622	0.622	1.67	0.775	0.726	0.165
"	Stockham	"	"	1.83	0.741	0.695	0.156
3/8	"	0.491	0.493	1.85	0.735	0.440	0.0936
"	Detroit	"	"	1.86	0.735	0.440	0.0936
1/4	"	0.357	0.364	2.30	0.660	0.214	0.0474

[a] Reynolds number of 40,000

The average values of the linear flow coefficient C, as given in the table above, vary from 0.877 for 1 1/2 inch fittings to 0.660 for 1/4 inch tees. Extrapolation to 1/8 inch tees indicates a coefficient of about 0.55 for water, as compared to the coefficient of 0.75 for air as obtained by Nord[7]. It should be noted that Nord's system of tees was so arranged that the static tee was located upstream of the impact tee, and thus a higher flow coefficient would be expected for the arrangement he used.

The ease of installation of the meter developed in this work may be ascertained from the discussion of the itemized conclusions regarding the component parts of the meter.

Section 1. The upstream calming section should be at least 10 pipe diameters

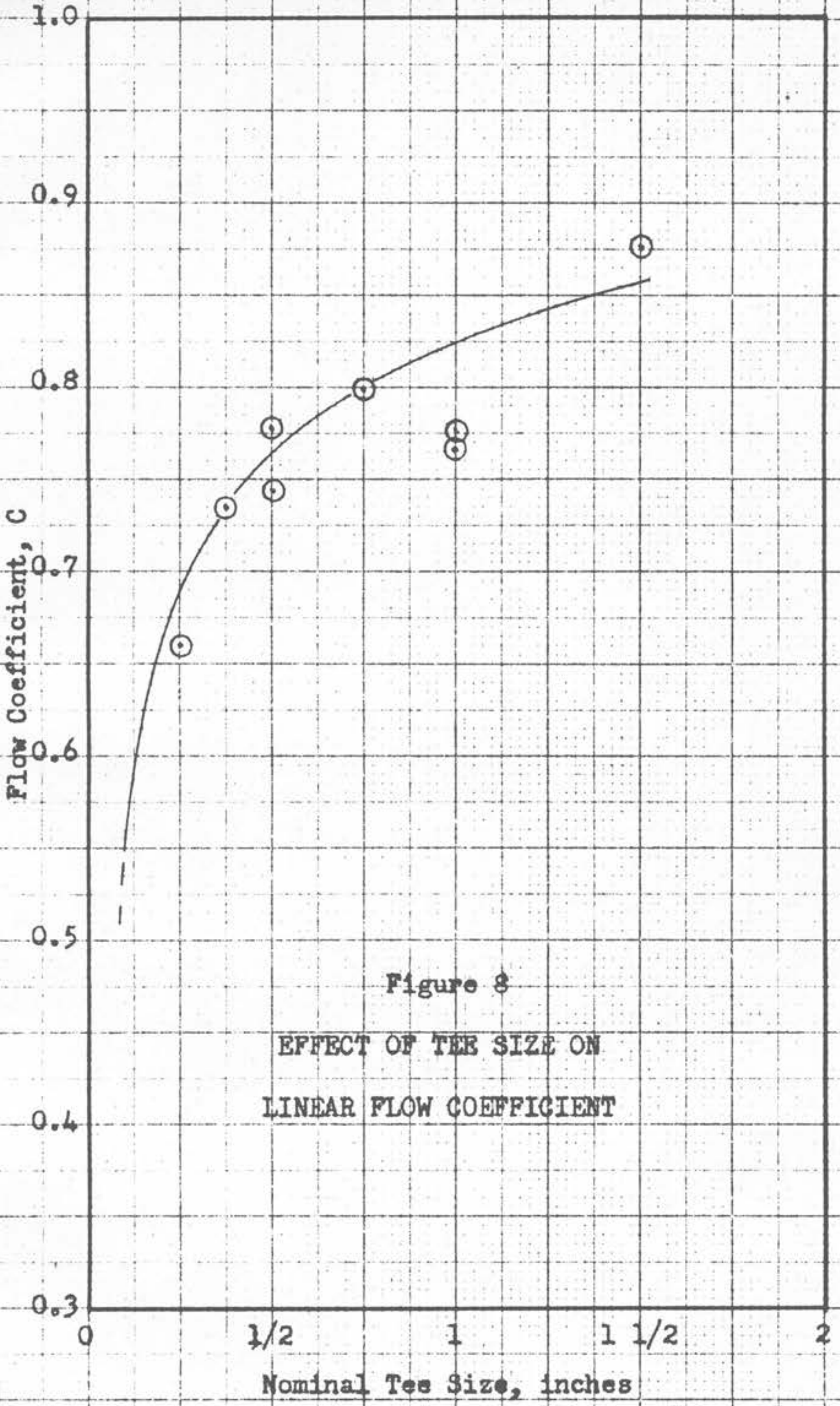


Figure 8

EFFECT OF TEE SIZE ON

LINEAR FLOW COEFFICIENT

one-half turn, or the end into section 5 may be taken up one-half turn or less, the movement being determined by the direction desired. The coefficient will not be affected by this maneuver.

Section 7. Neither the length nor the degree of threading of the nipple on the downstream side is important. Reaming has a slight effect.

The charts and tables are applicable to standard fittings when arranged in a manner similar to Figure 2. Tees of unknown brand may be employed provided their dimensions check those of the tees studied herein, and their inner surfaces are regular. It is suggested that the brands calibrated in this study be used whenever they are available. Addresses of the tee manufacturers have been listed at the end of the Bibliography.

in length. Straightening vanes are not required. The system need not be exactly level.

<u>Section 2.</u> Tees of the same brand have been found to be very constant in characteristics and in form dimensions. The maximum deviation from the average K for all tees of the same brand and size was 5.6%. It should be emphasized that whereas the velocity head coefficient, K, varies directly as the first power of the differential head, the flow coefficient, C, varies inversely as the square root of the differential head. Thus the flow coefficients (directly related to the velocity) will deviate to a lesser degree from the average value than will the velocity head coefficients.

<u>Section 3.</u> The impact tap should consist of a short nipple, coupling, and reducing bushing. The end of the nipple into the tee must be carefully reamed to the same diameter as the pipe and screwed into the tee five turns. The length of the nipple has no effect on the coefficient.

<u>Section 4.</u> The diameter, length, reaming, and threading of the nipple are critical variables. The nipple should be reamed to exact pipe diameter. Threading should be 5 turns on both ends. Figures 4 and 5 are useful for applying corrections for diameter and length of the connecting nipple.

<u>Section 5.</u> Brand of tees in the static tap position--see section 2 above.

<u>Section 6.</u> The method of attachment of the static tap lead is optional. Either a reducing bushing, or a short nipple, coupling and bushing combination is satisfactory. The direction in which the branch opening of the static tee faces is immaterial. For ease of piping, the branch opening may always be faced upward. To do this when the threads on the connecting nipple (section 4) ends do not begin at the same point, the end into section 2 may be backed off

EXAMPLE OF USE OF FLOW METER DATA

As an example of the use of the data and plots, assume that a meter is to be installed in a 1/2 inch line with Stockham tees. The location is such that the connecting nipple is to be 10 inches long, and the diameter of the nipple is 0.632 inch.

From Figure 5, for a 10 inch nipple and Crane tees, interpolation for a L/D of 15.9 gives a K of:

$$1.54 + (0.008/0.018)(0.20) = 1.63$$

From Table XV, the conversion factor for $K^{-1/2}$ to C'' is 0.210. The corresponding value of C'' is:

$$\begin{aligned} C'' &= 0.210(1.63)^{-1/2} \\ &= 0.164 \end{aligned}$$

To convert this coefficient to one for Stockham tees, refer to Table XVI and note that the average Stockham tee C'' is smaller than for the Crane tee by:

$$(0.156 - 0.165)/0.165 \times 100 = -5.45\%$$

The corrected C'' for the meter for a Reynolds number of 40,000 is

$$C'' = 0.164 \times 0.945 = 0.154$$

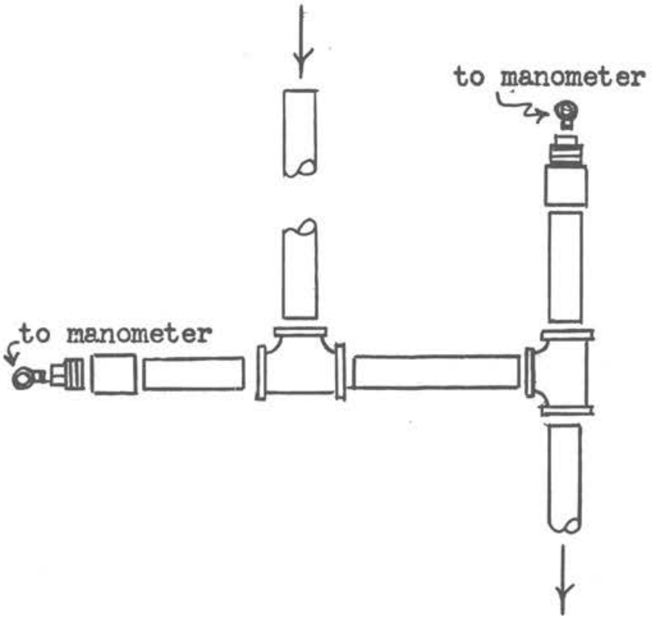
The flow coefficient, C'', as computed can be used with an accuracy of ±5% over the range of Reynolds numbers from 20,000 to 60,000. If greater accuracy is desired at lower flow rates, a C'' versus N_{Re} curve can be constructed parallel to the ones in Figure 7.

FUTURE WORK

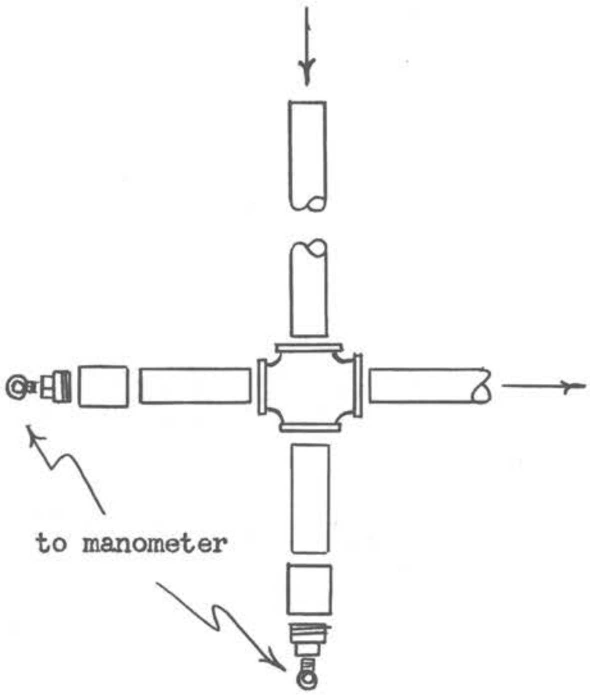
Further work with this type of meter would appear to be desirable. It was noted that the second general arrangement in which the flow enters the branch of the impact tee was less influenced by variables in sections 3 and 4. This would indicate that a meter constructed such that the flow enters the branch of both tees would not be as sensitive to variations in pipe fitting size and assembly as the standard arrangement which has been studied.

Another type of meter could be formed from the cross fitting. Here the two pressure taps would be inserted in the two extra openings. The diagrams below illustrate the two types of meters mentioned.

Meter with Flow Into
Branch of Both Tees



Flow Meter from
Cross Fitting



NOMENCLATURE

A	Pipe cross sectional area, feet^2
C	Linear flow coefficient, dimensionless
C'	Volumetric flow coefficient, gallons-seconds/minute-feet
C''	Volumetric flow coefficient, gallons-seconds/minute $(\text{feet-inches})^{1/2}$
D	Diameter of pipe, feet
g	Conversion factor, pounds mass-feet/seconds^2-pounds force
H	Head, feet of fluid flowing
K	Velocity head coefficient, dimensionless
N_{Re}	Reynolds number
Q	Volumetric rate of flow, gallons/minute
R	Manometer differential, inches of carbon tetrachloride-water
T	Temperature, °F
V	Linear velocity in pipe, feet/second
w	Weight rate of flow, pounds/minute
ρ	Density, pounds/feet^3
μ	Viscosity, pounds/second-feet

EQUATIONS

$$K = 2g\Delta H/V^2$$

$$C = V/\sqrt{2g\Delta H}$$

$$C' = Q/\sqrt{2g\Delta H}$$

$$C'' = Q/\sqrt{2gR}$$

APPENDIX

SAMPLE CALCULATIONS

Calculations for 1 inch tees.

1. Calculation of the velocity head coefficient, K.

$$V = \#/\text{min} \times \text{min/sec} \times \text{ft}^3/\# \times 1/\text{ft}^2 = \text{ft/sec}$$

$$= w \times 1/60 \times 1/62.4 \times 1/\left(\frac{1.049}{12}\right)^2(0.785)$$

$$= 0.0446\ w$$

$$\Delta H = R/12 \times \frac{(\text{Sp. G. } CCl_4 - \text{Sp. G. } H_2O)}{\text{Sp. G. } H_2O}$$

$$= R/12 \times \left(\frac{1.584 - 1.0}{1.0}\right)$$

$$= 0.0487\ R$$

$$K = 2g \times \Delta H/V^2$$

$$= 64.4 \times 0.487\ R/(0.0446\ w)^2$$

$$= 3.13\ R/(0.0446\ w)^2$$

For run 771, $w = 42.5$
$R = 2.1$

$$K = 3.13 \times 2.1/(0.0446 \times 42.5)^2$$

$$= 1.82$$

2. Calculation of Reynolds number, N_{Re}.

$$N_{Re} = DV\rho/\mu$$

For run 771, $D = 1.049$ (Ref. No. 8)
$V = 0.0446 \times 42.5 = 1.895$
$\rho = 62.4$
$\mu = 1.3$ cp (Ref. No. 6)

$$N_{Re} = \frac{1.049/12 \times 1.895 \times 62.4}{1.3 \times 0.000672}$$

$$= 11,800$$

3. Calculation of the flow rate coefficient, C'', from experimental data.

$$C'' = Q/\sqrt{2gR}$$

where $Q = w/8.33$
for run 771, $w = 42.5$, and $R = 2.1$

3. Continued

$$C'' = 5.11/(8.02)(2.1)^{1/2}$$
$$= 0.44$$

4. Conversion factor for K to C.

$K = 2g\Delta H/V^2$, from item 1

$C = V/\sqrt{2g\Delta H}$, by definition

$C = 1.0\ K^{-1/2}$

5. Conversion factor for K to C'.

By definition, $C' = Q/\sqrt{2g\Delta H}$, gallons-seconds/minute-feet

Squaring gives $(C')^2 = Q^2/2g\Delta H$

It is noted that Q can be expressed in terms of the velocity, V

$$Q = V \times 60 \times 62.4 \times A/8.33$$
$$\frac{\text{ft/sec} \times \text{sec/min} \times \#/\ \text{ft}^3 \times \text{ft}^2}{\#/\text{gal}}$$

Thus, $(C')^2 = (60 \times 62.4 \times A/8.33)^2 \times V^2/2g\Delta H$

$C' = 449\ A\ K^{-1/2}$

Note: The cross sectional areas of the pipe nipples were calculated using the approximate diameters listed in Perry[8]. The areas are:

Nominal size, inches	Area, square feet
1 1/2	0.0142
1	0.00597
3/4	0.00369
1/2	0.00210
3/8	0.00133
1/4	0.00072

6. Conversion factor for K to C''

By definition, $C'' = Q/\sqrt{2gR}$, gallons seconds/minutes (feet inches)$^{1/2}$

Squaring gives $(C'')^2 = Q^2/2gR$

Substituting for Q as in item 5, and noting the relation between R and ΔH from item 1, $R = \Delta H/0.0487$

6. Continued

$$(C'')^2 = (60 \times 62.4 \times A/8.33)^2 \times V^2/(2g\Delta H/0.0487)$$

$$(C'') = (60 \times 62.4/8.33)(0.0487)^{1/2}\ A\ K^{-1/2}$$

$$= 99\ A\ K^{-1/2}$$

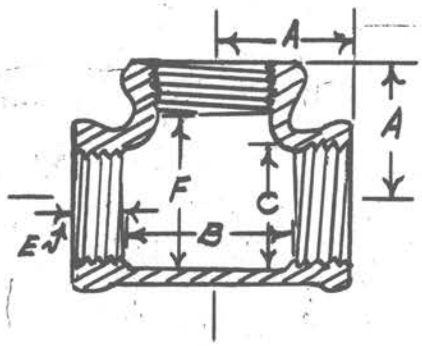
The cross sectional areas are listed under item 5.

TABLE XVII

FITTING DIMENSIONS (BY ACTUAL MEASUREMENT)[a]

		Tee	Dimension, inches					
Brand	**Size**	**No.**	**A**	**B**	**C**	**D**	**E**	**F**
Crane	1 1/2	1	1.94	2.41	1.84	2.06	0.75	2.18
Stockham	"	1	"	2.47	1.97	1.91	"	"
"	"	2	"	"	"	1.93	"	"
Walworth	"	1	"	2.41	1.84	1.87	"	"
Crane	1	1	1.45	1.70	1.28	1.34	0.65	1.55
"	"	2	"	1.72	"	"	0.63	1.56
"	"	3	1.48	1.68	1.22	1.25	0.65	1.60
Detroit	"	1	"	1.59	1.24	1.21	0.75	1.44
"	"	2	"	1.52	1.19	1.22	"	"
Crane	3/4	1	1.30	1.53	1.08	1.10	0.63	1.31
"	"	2	"	1.50	"	"	0.65	"
"	"	3	"	1.48	1.06	1.08	0.67	"
Stockham	"	1	1.28	1.47	1.05	1.06	0.62	1.25
"	"	2	"	"	"	"	"	1.22
"	"	3	"	1.50	1.03	"	"	"
Crane	1/2	1	1.13	1.33	0.83	0.83	0.56	1.10
"	"	2	"	"	0.84	0.84	"	1.09
Stockham	"	1	1.10	1.31	0.87	0.87	0.55	1.06
"	"	2	"	1.30	"	"	"	"
"	3/8	1	0.95	1.03	0.67	0.69	0.44	0.86
"	"	2	"	1.07	"	0.72	"	0.94
"	"	3	"	"	0.69	0.71	"	0.84
Detroit	"	1	0.97	1.00	0.61	0.62	0.45	0.87
"	"	2	"	1.02	"	0.66	"	0.83
"	1/4	1	0.805	0.66	0.52	0.56	0.47	0.62
"	"	2	"	"	"	"	0.46	0.63
"	"	3	"	"	0.51	0.51	0.45	"

[a] Dimensions lettered on the cross-sectional views shown below



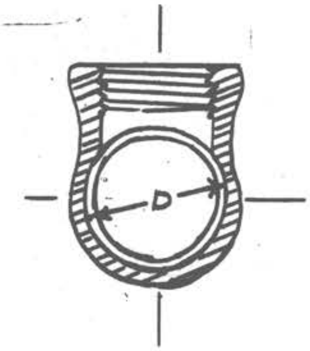


TABLE XVIII

EXPERIMENTAL AND CALCULATED DATA

(Values of the variables investigated in each of these tables are given in the corresponding summary tables in the text, Tables I, XII and XIV.)

(1) Length of calming section, std. arrangement

Run	w	R	V	K	N_{Re} x 10^{-3}	T
633	72.0	5.65	3.2	1.72	19.2	48
4	109.0	12.9	5.29	1.72	31.8	
5	136.5	20.3	6.06	1.70	36.4	
6	149.0	24.0	6.62	1.69	39.7	
7	71.0	6.0	3.16	1.85	19.0	
8	108.5	14.8	5.26	1.99	31.6	
9	136.5	23.0	6.06	1.92	36.4	
40	149.5	27.9	6.64	1.95	39.8	
1	72.5	5.9	3.32	1.77	19.4	
2	110.0	13.9	4.89	1.80	29.4	
3	137.0	21.2	6.09	1.78	36.6	
4	151.0	25.3	6.72	1.75	40.3	

(2) Distance between straightening vane end and impact tee

Run	w	R	V	K	N_{Re} x 10^{-3}	T
360	30.2	1.1	1.35	1.89	9.4	57
1	43.2	2.1	2.1	1.76	13.4	
2	59.7	4.3	2.66	1.89	18.5	
3	72.5	6.3	3.24	1.93	22.7	
4	94.0	10.6	4.19	1.88	29.1	
5	111.5	14.9	4.96	1.88	34.5	
6	125.0	19.1	5.58	1.92	38.8	
7	137.5	23.5	6.13	1.96	42.6	
8	152.0	27.9	6.78	1.90	47.1	
9	158.0	29.6	7.05	1.87	49.0	
80	41.2	2.0	1.83	1.87	12.7	
1	61.7	4.4	2.76	1.83	19.2	
2	73.2	6.5	3.26	1.90	22.6	

(2) Continued

Run	w	R	V	K	N_{Re} x 10^{-3}	T
683	94.5	10.7	4.21	1.89	29.3	57
4	112.5	15.0	5.00	1.88	34.8	
5	126.5	19.2	5.64	1.89	39.2	
6	138.5	23.5	6.17	1.92	42.2	
7	153.0	27.4	6.81	1.85	47.4	
8	158.0	29.3	7.05	1.85	49.0	
9	42.2	2.4	1.88	2.49	13.1	
390	60.5	5.0	2.70	2.14	18.8	
1	74.0	6.9	3.30	1.98	22.9	
2	95.0	11.5	4.23	2.00	29.4	
3	111.0	14.5	4.95	1.98	34.5	
4	126.0	21.2	5.61	2.10	39.0	
5	140.0	25.0	6.24	2.01	43.4	
6	152.0	29.5	6.76	2.01	47.0	

(3) Angle of calming section from horizontal

Run	w	R	V	K	N_{Re} x 10^{-3}	T
751	74.5	5.5	3.32	1.55	20.1	44
2	112.0	12.0	4.98	1.51	30.1	
3	141.5	18.5	6.30	1.46	38.0	
4	153.0	21.5	6.80	1.47	41.0	
5	76.0	5.6	3.38	1.53	20.5	
6	112.0	12.1	4.98	1.51	30.3	
7	139.0	18.4	6.19	1.51	37.4	
8	151.0	21.9	6.72	1.51	40.6	
9	76.0	5.7	3.38	1.54	20.5	
60	111.5	11.8	4.96	1.50	30.0	
1	138.5	18.1	6.16	1.49	37.3	
2	152.5	21.8	6.79	1.49	41.1	

TABLE XVIII (Cont.)

(4) End of nipple reamed to 1.14 inches

Run	w	R	V	K	N_{Re} x 10^{-3}	T
701	73.0	5.8	3.25	1.70	19.6	45
2	110.0	13.1	4.92	1.69	29.6	
3	140.5	20.7	6.25	1.65	37.7	
4	151.0	24.2	6.72	1.67	40.5	
719	75.5	6.2	3.36	1.72	20.2	
20	113.5	13.7	5.05	1.67	30.4	
1	140.0	20.9	6.23	1.68	37.6	
2	152.5	24.5	6.79	1.67	40.9	

(5) Threading into section 2

Run	w	R	V	K	N_{Re} x 10^{-3}	T
723	75.0	6.3	3.34	1.74	20.1	45
4	112.0	13.9	4.98	1.75	30.0	
5	142.0	21.6	6.32	1.69	38.1	
6	151.0	25.1	6.71	1.74	40.5	
7	73.5	6.1	3.28	1.77	19.8	
8	112.0	13.4	4.98	1.69	30.0	
9	139.5	20.6	6.20	1.69	37.3	
30	152.0	25.1	6.74	1.71	40.6	
1	74.5	6.2	3.32	1.76	20.0	
2	111.0	12.7	4.94	1.75	29.7	
3	139.5	21.2	6.21	1.72	37.4	
4	152.0	25.3	6.75	1.72	40.6	

temperature 45 F.

(6) Brands of Tees--Crane

Run	w	R	V	K	N_{Re} x 10^{-3}	T
605	73.5	5.8	3.28	1.68	18.7	48
6	111.5	13.0	4.96	1.65	28.3	
7	138.0	20.6	6.14	1.71	35.0	
8	151.5	23.9	6.74	1.63	38.4	
601	72.5	5.9	3.23	1.76	18.4	
2	110.5	13.1	4.92	1.69	38.0	
603	139.5	20.2	6.21	1.64	35.4	48
4	153.0	24.8	6.81	1.67	38.7	
609	74.5	6.2	3.32	1.76	18.9	
10	111.5	13.0	4.96	1.65	28.3	
1	139.5	20.8	6.21	1.69	35.4	
2	152.0	24.5	6.76	1.66	38.5	
3	74.0	6.0	3.30	1.72	18.8	
4	110.5	13.9	4.92	1.79	38.0	
5	138.0	20.5	6.40	1.70	36.5	
6	150.5	25.0	6.69	1.74	38.0	
7	74.0	5.7	3.30	1.63	18.8	
8	111.0	12.9	4.94	1.65	28.2	
9	136.0	19.8	6.06	1.68	34.5	
20	152.0	23.1	6.76	1.58	38.6	
1	75.5	5.5	3.36	1.52	19.1	
2	110.0	12.0	4.89	1.56	27.8	
3	139.0	19.3	6.21	1.56	35.4	
4	151.0	22.5	6.72	1.56	38.3	
5	41.0	4.7	2.95	1.68	13.0	44
6	60.0	9.1	4.32	1.50	19.1	
7	88.0	19.0	6.34	1.48	28.0	
8	107.0	27.3	7.69	1.44	34.0	
9	41.0	4.7	2.95	1.69	13.0	
30	68.5	10.8	4.93	1.38	21.8	
1	89.0	19.3	6.4	1.47	28.3	
2	105.5	27.1	7.59	1.48	33.5	
3	43.0	4.3	3.09	1.40	13.6	
4	65.5	11.4	4.71	1.60	20.8	
5	88.5	20.8	6.36	1.57	28.1	
6	106.0	28.4	7.62	1.53	33.7	
7	43.5	4.7	3.13	1.54	13.8	
8	66.5	11.4	4.78	1.56	21.2	
9	89.5	20.0	6.44	1.51	28.4	

TABLE XVIII (Cont.)

(6) Continued

Run	w	R	V	K	N_{Re} x 10^{-3}	T
940	106.0	28.4	7.62	1.53	33.5	44
1	25.3	5.5	3.20	1.70	11.0	46
2	36.5	9.9	4.62	1.45	15.8	
3	43.6	15.6	5.51	1.60	18.9	
4	49.5	21.1	6.26	1.68	21.5	
5	60.0	20.7	7.60	1.66	26.0	
6	23.5	5.0	2.97	1.77	10.2	
7	31.2	8.9	3.45	1.78	13.6	
8	43.5	16.3	5.50	1.68	18.9	
9	56.5	23.4	7.15	1.46	24.4	
50	60.0	30.9	7.59	1.67	26.0	
1	31.2	9.5	3.95	1.89	13.6	
2	44.0	16.2	5.56	1.63	19.1	
3	52.2	23.2	6.60	1.68	22.7	
4	60.5	30.5	7.65	1.63	26.2	
5	31.8	9.2	4.02	1.78	13.8	
6	42.2	16.3	5.33	1.78	18.3	
7	52.5	24.1	6.64	1.71	22.8	
8	59.5	31.1	7.53	1.71	25.8	
841	74.0	5.9	3.30	1.69	18.5	43
2	109.5	13.2	4.87	1.74	27.2	
3	137.0	21.3	6.10	1.79	34.2	
4	151.0	25.4	6.72	1.75	37.6	
629	72.0	5.9	3.21	1.79	18.0	
30	112.0	13.6	4.98	1.70	27.9	
1	141.0	20.5	6.27	1.64	34.1	
2	152.5	24.6	6.80	1.66	38.1	
1008	17.8	8.7	3.72	1.96	10.9	51
9	24.5	15.9	5.14	1.88	15.0	
10	30.9	24.7	6.48	1.83	19.0	
1	35.1	31.3	7.35	1.81	21.5	
2	16.7	8.1	3.49	2.07	10.4	
3	25.2	17.4	5.28	1.95	15.5	
4	31.1	25.5	6.52	1.87	19.1	
5	33.4	30.4	7.00	1.94	20.5	

(6) Continued

Run	w	R	V	K	N_{Re} x 10^{-3}	T
1016	6.3	4.6	2.32	2.66	5.04	51
7	8.7	7.9	3.21	2.38	6.95	
8	13.2	17.3	4.88	2.26	10.6	
9	16.2	24.6	5.96	2.18	12.9	
20	18.2	30.4	6.71	2.11	14.5	
1	8.97	8.3	3.32	2.34	7.2	
2	13.2	16.7	4.89	2.17	10.6	
3	16.3	24.9	6.03	2.14	13.1	
4	18.0	30.5	6.65	2.15	14.4	
5	8.77	7.9	3.24	2.35	7.04	48
6	13.1	16.8	4.84	2.24	10.5	
7	16.2	25.0	5.99	2.17	13.0	
8	17.7	30.3	6.74	2.20	14.2	
9	8.4	7.9	3.11	2.55	6.74	
30	12.4	16.5	4.58	2.35	9.9	
1	15.7	24.7	5.78	2.30	12.5	
2	17.2	30.7	6.34	2.37	13.7	
3	8.6	8.1	3.16	2.52	6.9	
4	12.5	17.0	4.59	2.52	10.0	
5	15.7	25.2	5.78	2.35	12.5	
6	16.8	30.5	6.23	2.35	13.5	
8	47.3	0.60	0.89	2.36	7.5	42
9	112.3	1.96	2.12	1.36	18.0	
60	141.0	3.06	2.65	1.36	22.5	
1	160.3	3.95	3.10	1.29	26.4	
2	181.5	4.73	3.42	1.26	29.0	
3	198.8	5.85	3.74	1.30	31.7	
4	62.3	0.76	1.18	1.72	10.0	42
5	109.0	2.05	2.07	1.49	17.7	
6	133.8	3.30	2.53	1.61	21.5	
7	152.8	3.80	2.89	1.42	24.5	
8	178.5	4.90	3.38	1.33	28.7	
9	209.5	6.85	4.00	1.34	34.0	
857	42.2	4.67	3.13	1.49	13.8	44
8	59.7	9.50	4.30	1.59	19.0	

TABLE XVIII (Cont.)

(6) **Continued**

Run	**w**	**R**	**V**	**K**	N_{Re} x 10^{-3}	**T**
859	72.5	13.7	5.21	1.57	23.0	44
60	84.0	17.9	6.05	1.53	26.7	
1	93.5	22.2	6.73	1.52	29.6	
2	103.5	26.7	7.44	1.51	32.8	
3	108.0	30.1	7.75	1.56	34.2	
912	42.0	4.83	3.02	1.66	13.3	44
3	66.5	11.8	4.79	1.60	21.2	
4	88.5	20.5	6.36	1.57	28.1	
5	105.0	28.8	7.55	1.58	33.3	
7	42.0	4.4	3.02	1.52	13.3	44
8	60.0	9.9	4.32	1.50	19.1	
9	93.0	21.3	6.69	1.48	29.8	
20	106.5	27.6	7.65	1.47	33.6	
967	27.5	7.3	3.48	1.87	12.4	48
8	42.5	16.7	5.37	1.80	19.1	
9	47.9	21.4	6.05	1.83	21.5	
70	58.3	20.9	7.37	1.78	26.2	
1	27.3	7.5	3.44	1.97	12.2	
2	42.8	17.4	5.40	1.86	19.2	
3	19.8	23.6	6.28	1.87	22.3	
4	58.0	31.3	7.33	1.81	26.0	
5	28.9	8.0	3.65	1.86	12.9	
6	42.5	16.8	5.37	1.81	19.1	
7	49.5	23.1	6.25	1.85	22.2	
8	58.0	31.3	7.33	1.82	26.0	
9	29.1	7.45	3.68	1.94	13.1	
80	42.8	18.2	5.40	1.94	19.2	
1	49.6	24.0	6.25	1.91	22.2	
2	57.3	31.6	7.24	1.88	25.7	
986	12.5	4.2	2.62	1.91	7.4	51
7	17.9	8.35	3.75	1.85	10.6	
8	21.4	12.6	4.49	1.94	12.7	
9	26.9	18.5	5.65	1.81	16.0	
90	30.9	24.8	6.49	1.84	18.3	

(6) **Continued**

Run	**w**	**R**	**V**	**K**	N_{Re} x 10^{-3}	**T**
991	35.1	31.4	7.36	1.81	20.8	51
2	17.1	8.5	3.59	2.05	10.1	
3	24.9	16.5	5.23	1.88	14.8	
4	30.2	24.7	6.34	1.92	17.9	
5	34.5	20.5	7.24	1.82	20.4	
6	17.5	8.8	3.67	2.04	10.3	
7	24.7	16.6	5.18	1.92	14.6	
8	30.3	24.9	6.35	1.92	18.0	
9	34.1	30.6	7.15	1.87	20.2	48
1000	17.4	8.6	3.65	2.00	10.3	
1	25.2	17.1	5.29	1.90	14.9	
2	30.8	25.1	6.46	1.86	18.3	
3	34.3	30.7	7.20	1.82	20.3	
1270	64.0	0.99	1.21	2.12	10.3	42
1	110.3	2.22	2.09	1.58	17.8	
2	149.5	4.0	2.83	1.56	24.1	
3	182.5	6.0	3.45	1.57	29.3	
4	209.5	7.6	3.96	1.51	32.4	
5	83.0	1.1	1.57	1.41	13.4	
6	115.3	2.0	2.18	1.31	18.6	
7	151.0	3.26	2.86	1.24	24.4	
8	184.8	4.9	3.49	1.26	29.8	
9	200.8	6.0	3.79	1.30	32.3	
80	113.0	1.83	3.14	1.24	18.3	
1	150.5	3.43	2.85	1.31	24.5	
2	177.8	4.25	3.36	1.81	28.6	
3	202.5	5.4	3.83	1.15	32.5	
4	77.5	1.03	1.46	1.51	12.4	
5	108.8	2.03	2.05	1.51	17.5	
6	139.5	3.33	2.64	1.44	22.4	
7	158.0	4.25	2.99	1.48	25.5	
8	201.0	6.65	3.83	1.43	32.3	
807	73.5	6.05	3.28	1.75	18.2	43
8	111.0	13.8	4.94	1.75	27.4	

TABLE XVIII (Cont.)

(6) Continued

Run	w	R	V	K	N_{Re} x 10^{-3}	T
809	137.5	21.3	6.10	1.78	33.8	43
10	151.5	25.4	6.74	1.74	37.4	
1	74.0	5.65	3.30	1.62	18.3	
2	111.0	13.1	4.95	1.68	27.5	
3	138.5	20.4	6.15	1.68	34.1	
4	150.5	23.9	6.70	1.67	37.2	
819	74.0	6.3	3.30	1.81	18.3	
20	112.0	14.5	4.98	1.82	27.7	
1	138.0	22.2	6.14	1.84	34.1	
2	152.0	26.3	6.76	1.78	37.7	
3	73.5	6.2	3.28	1.80	18.3	
4	111.0	14.4	4.95	1.83	27.5	
5	152.0	25.7	6.75	1.75	37.6	

(7) Length of nipple on impact tap

Run	w	R	V	K	N_{Re} x 10^{-3}	T
169	19.5	0.47	0.87	1.96	7.5	72
171	43.0	1.63	1.92	1.39	16.4	
3	71.0	4.70	3.16	1.47	27.1	
5	103.0	9.85	4.59	1.46	39.2	
7	132.2	15.1	5.90	1.36	50.5	
8	145.5	18.0	6.48	1.34	55.5	
80	180.0	29.3	8.02	1.43	68.6	
129	20.3	0.40	0.89	1.56	7.6	72
131	42.7	1.89	1.90	1.64	16.2	
3	73.0	5.57	3.25	1.69	27.8	
6	103.0	11.0	4.6	1.63	39.3	
40	132.0	17.9	5.89	1.62	50.3	
6	156.5	25.1	6.98	1.62	59.6	
181	29.5	1.05	1.31	1.91	11.2	
4	73.0	5.75	3.26	1.69	27.9	
7	125.8	16.1	5.60	1.60	47.9	
9	151.0	23.4	6.72	1.63	57.5	

(7) Continued

Run	w	R	V	K	N_{Re} x 10^{-3}	T
191	30.2	1.04	1.34	1.81	11.5	72
4	72.7	5.4	3.24	1.61	27.7	
7	125.7	15.4	5.60	1.54	48.0	
9	152.0	22.1	6.76	1.54	57.9	
201	30.0	1.05	1.34	1.85	11.5	
4	72.5	5.5	3.23	1.65	27.6	
7	126.2	15.6	5.63	1.54	48.1	
10	161.2	27.1	7.19	1.63	61.5	

(8) Threading into section 2

Run	w	R	V	K	N_{Re} x 10^{-3}	T
661	73.0	6.6	3.26	1.95	11.5	72
2	110.5	15.0	4.92	1.93	41.8	
3	139.5	23.1	6.2	1.87	52.6	
4	152.0	27.0	6.75	1.84	57.4	
5	73.5	5.8	3.28	1.68	27.8	
6	112.0	13.0	4.98	1.63	42.4	
7	138.0	20.1	6.15	1.66	51.3	
8	151.0	24.3	6.71	1.68	57.0	
9	74.5	5.6	3.32	1.59	28.2	
70	109.5	12.3	4.87	1.63	41.4	
1	138.0	19.6	6.15	1.63	51.3	
2	151.0	22.6	6.71	1.63	57.0	
649	71.0	6.2	3.16	1.92	27.0	
50	110.5	14.9	4.94	1.92	42.2	
1	140.0	23.4	6.23	1.88	53.2	
2	154.5	26.9	6.87	1.79	57.9	
3	75.0	6.15	3.34	1.72	28.5	
4	110.0	13.6	4.90	1.77	41.7	
5	139.0	21.2	6.18	1.73	52.7	
6	152.5	24.9	6.78	1.69	57.8	

TABLE XVIII (Cont.)

(9) **Reaming nipple section 3**

Run	w	R	V	K	N_{Re} x 10^{-3}	T
665	73.5	5.8	3.28	1.68	18.6	44
6	112.0	13.0	4.98	1.63	28.1	
7	138.0	20.1	6.13	1.66	34.7	
8	151.0	24.3	6.71	1.68	37.9	
673	72.5	6.4	3.23	1.91	18.2	
4	109.5	14.9	4.86	1.97	27.4	
5	138.0	23.1	6.13	1.91	34.7	
6	151.0	27.1	6.72	1.87	38.0	
653	75.0	6.15	3.34	1.72	18.8	43
4	109.5	14.9	4.86	1.97	27.7	
5	139.0	21.2	6.18	1.73	34.9	
6	152.5	24.9	6.77	1.69	38.3	43
7	74.0	6.5	3.30	1.87	18.6	
8	111.0	14.8	4.95	1.89	28.0	
9	138.5	22.8	6.16	1.88	34.8	
60	151.0	27.4	6.72	1.89	38.0	

(10) **Diameter of nipple**

Run	w	R	V	K	N_{Re} x 10^{-3}	T
853	73.5	5.8	3.27	1.68	18.5	43
4	112.0	13.1	4.98	1.65	28.2	
5	139.5	20.6	6.20	1.59	35.0	
6	152.0	23.5	6.75	1.60	38.2	
771	42.5	2.1	1.89	1.82	10.7	
3	72.0	5.85	3.21	1.78	18.1	
6	126.0	17.5	5.61	1.73	31.7	
9	162.5	28.6	7.23	1.70	40.8	
1135	82.0	7.0	3.65	1.65	21.4	
7	134.3	17.9	5.97	1.57	35.0	
8	143.8	20.9	6.39	1.60	37.4	
9	159.5	25.7	7.10	1.59	41.6	
40	174.3	31.9	7.75	1.66	45.4	
1055	56.0	8.25	4.03	1.58	20.0	

(10) **Continued**

Run	w	R	V	K	N_{Re} x 10^{-3}	T
1056	79.3	16.0	5.70	1.54	28.2	43
7	101.3	24.5	7.28	1.45	36.0	
8	112.8	29.7	8.10	1.61	40.0	
1067	55.5	8.4	3.99	1.75	19.9	
8	75.8	15.5	5.45	1.63	27.0	
9	05.5	24.0	6.87	1.58	34.2	
70	107.0	29.9	7.69	1.58	38.4	
1	51.5	7.75	3.71	1.76	18.3	
2	76.0	15.9	5.46	1.66	27.1	
3	95.0	23.8	6.84	1.59	33.9	
4	104.3	29.0	7.50	1.61	37.3	53
1084	31.3	7.54	3.96	1.50	13.2	
5	45.8	15.9	5.80	1.47	19.4	
6	53.8	21.3	6.81	1.43	22.7	
7	61.0	27.0	7.72	1.41	25.7	
8	63.0	30.3	7.98	1.48	26.7	
1080	44.0	16.5	5.56	1.67	18.6	45
1	49.0	20.9	6.24	1.67	20.9	
2	55.5	25.6	6.90	1.61	23.1	
3	59.0	29.3	7.47	1.64	25.0	
1117	17.1	8.35	3.58	2.04	9.4	45
8	28.3	20.9	5.93	1.85	15.8	
9	34.4	30.7	7.21	1.84	19.3	
20	45.0	2.4*	9.44	1.81	25.2	
1	57.3	3.97*	12.00	1.85	32.2	
2	69.5	5.76*	14.56	1.82	39.0	
3	16.7	7.85*	3.49	2.01	9.3	
4	28.0	20.90*	5.87	1.90	15.7	
5	34.7	30.90*	7.23	1.84	19.3	
6	44.8	2.38*	9.38	1.81	25.1	
7	54.3	3.44*	11.35	1.79	30.3	

* Inches of mercury-water

TABLE XVIII (Cont.)

(11) Nipple length

Run	w	R	V	K	N_{Re} x 10^{-3}	T
735	74.5	5.65	3.32	1.61	18.9	45
6	111.0	12.8	4.95	1.64	28.2	
7	139.0	20.0	6.18	1.63	35.2	
8	152.0	23.7	6.77	1.61	38.7	
9	75.0	6.45	3.34	1.80	19.0	
40	112.5	13.8	5.00	1.72	28.4	
1	141.0	21.3	6.26	1.69	35.6	
2	151.5	25.8	6.74	1.77	38.3	
747	73.5	5.35	3.27	1.55	18.6	45
8	111.0	12.0	4.94	1.54	28.2	
9	140.5	18.1	6.25	1.44	35.5	
50	151.5	21.8	6.74	1.49	38.2	
1063	48.9	7.6	3.52	1.92	17.7	53
4	70.0	15.6	5.04	1.91	25.5	
5	89.0	24.1	6.40	1.83	32.3	
6	99.3	29.6	7.14	1.82	36.0	
1089	27.3	7.6	3.45	1.99	11.5	44
90	41.5	16.9	5.25	1.92	17.5	
1	47.8	21.6	6.05	1.85	20.2	
2	53.8	26.3	6.80	1.78	22.7	
3	57.3	31.1	7.25	1.85	24.2	
4	60.5	1.69*	7.66	1.93	25.6	
5	84.1	3.13*	10.62	1.86	35.3	
6	100.0	4.32*	12.65	1.81	42.0	
7	29.3	8.0	3.71	1.81	12.4	
8	41.9	16.05	5.30	1.79	17.7	
9	49.0	21.65	6.20	1.76	20.7	
1100	55.3	26.85	7.00	1.71	23.4	
1	59.3	30.60	7.50	1.70	25.0	
2	61.0	1.57*	7.72			
3	86.3	3.07	10.91	1.73	36.3	
4	103.0	4.22	13.03	1.66	43.4	

* Inches of mercury-water

(11) Continued

Run	w	R	V	K	N_{Re} x 10^{-3}	T
1105	16.9	8.59	3.54	2.13	10.0	49
6	26.7	20.8	5.60	2.08	15.8	
7	33.2	31.5	6.95	2.04	19.6	
8	40.5	2.23*	8.49	2.08	23.9	
9	54.8	4.06*	11.48	2.06	36.4	
10	69.7	6.40*	14.60	2.01	41.1	
1129	68.3	6.05	3.04	2.05	18.8	
30	96.8	11.7	4.31	1.97	26.8	
1	121.8	18.4	5.40	1.97	33.7	
2	158.3	30.3	7.04	1.91	43.9	49
3	164.3	1.58*	7.31	1.97	45.6	
4	174.8	1.69*	7.77	1.87	48.5	
1217	9.5	6.45	3.51	1.63	6.8	45
8	11.0	16.3	4.06	3.08	7.92	
9	15.5	23.2	5.72	2.22	11.1	
20	17.3	29.5	6.39	2.25	12.4	
1	22.9	1.77*	8.44	1.67	16.4	
2	25.9	3.04*	9.55	2.24	18.6	
3	34.5	5.39*	12.75	2.22	24.3	
4	38.1	8.25*	14.10	2.43	27.3	
5	57.5	14.70*	21.30	2.18	41.5	
6	10.3	0.67*	3.79	3.10	7.4	
7	15.6	1.36*	5.76	2.74	11.2	
8	19.9	2.15*	7.34	2.68	14.3	
9	28.8	4.42*	10.62	2.61	20.8	
30	39.8	8.23*	14.70	2.54	28.7	
1	57.0	16.23*	21.10	2.45	41.2	
2	67.5	22.70*	25.00	2.45	48.6	
3	10.6	0.70*	3.90	3.12	7.6	
4	15.1	1.33*	5.58	2.86	10.9	
5	23.9	3.30*	8.83	2.84	17.2	
6	33.5	6.62*	12.40	2.88	24.2	

* Inches of mercury-water

TABLE XVIII (Cont.)

(11) Continued

Run	w	R	V	K	N_{Re} x 10^{-3}	T
1237	45.4	11.98*	16.80	2.85	32.7	45
8	59.0	17.25*	21.80	3.43	42.5	
9	63.0	22.90*	23.30	2.85	45.5	
40	9.8	0.65*	3.63	3.30	7.1	
1	14.4	1.29*	5.33	2.04	10.4	
2	23.2	3.04*	8.55	2.79	16.7	
3	33.7	6.42*	12.5	2.75	24.3	
4	46.3	11.83*	17.1	2.73	33.4	
5	55.2	16.40*	20.4	2.65	39.7	
6	63.8	22.20*	23.6	2.68	46.0	

(12) Reaming end of nipple into section 2

Run	w	R	V	K	N_{Re} x 10^{-3}	T
515	72.0	5.8	3.21	1.76	19.8	50
7	111.0	13.4	4.95	1.71	30.4	
9	138.0	21.1	6.14	1.75	37.6	
20	153.0	24.6	6.80	1.66	41.7	
1	72.5	5.8	3.23	1.73	19.8	
2	111.0	13.3	4.93	1.70	30.2	
3	140.0	20.1	6.21	1.61	38.1	
4	152.0	23.6	6.76	1.61	41.5	
5	71.5	5.8	3.19	1.76	19.5	
6	113.5	13.3	5.05	1.62	30.9	
7	140.0	20.5	6.23	1.65	38.0	
8	151.0	23.7	6.72	1.64	41.1	

(13) Reaming end of nipple into section 5

Run	w	R	V	K	N_{Re} x 10^{-3}	T
541	73.5	5.7	3.27	1.65	20.0	50
2	110.5	12.7	4.91	1.63	30.1	
3	138.0	19.5	6.13	1.61	37.5	
4	152.0	23.5	6.75	1.60	41.3	
545	72.5	5.35	3.23	1.59	19.7	50
6	109.0	11.9	4.85	1.58	29.7	
7	140.0	17.8	6.23	1.43	38.1	
8	150.0	21.2	6.66	1.48	40.7	
9	72.5	4.85	3.23	1.44	19.7	
50	112.0	11.1	4.97	1.40	30.4	
1	138.0	16.9	6.13	1.40	37.5	
2	150.0	19.6	6.66	1.37	40.7	
3	72.5	4.7	3.23	1.40	19.7	
4	110.5	10.9	4.91	1.40	30.1	
5	138.5	16.7	6.15	1.37	37.6	
6	151.0	19.9	6.71	1.38	41.1	

* Inches of mercury-water

(14) Threading end of nipple into section 5

Run	w	R	V	K	N_{Re} x 10^{-3}	T
677	73.5	5.8	3.27	1.68	18.4	45
8	110.0	13.1	4.89	1.71	27.4	
9	138.5	20.2	6.15	1.66	34.6	
80	151.0	23.6	6.70	1.63	37.6	
1	74.5	5.9	3.31	1.68	18.6	
2	110.0	13.2	4.89	1.72	27.4	
3	139.0	20.4	6.18	1,66	34.7	
4	150.5	23.8	6.69	1.66	37.6	
5	72.5	6.2	3.23	1.85	18.1	
6	110.5	14.2	4.91	1.83	27.6	
7	139.5	22.2	6.20	1.80	34.8	
8	152.0	26.3	6.75	1.79	37.9	
9	72.7	5.0	3.24	1.49	18.2	
90	111.0	11.8	4.93	1.50	27.7	
1	140.5	18.1	6.25	1.44	35.1	
2	150.0	21.3	6.66	1.49	37.4	
3	73.0	5.7	3.25	1.68	18.3	
4	109.5	13.1	4.87	1.73	27.3	

TABLE XVIII (Cont.)

(14) Continued

Run	w	R	V	K	N_{Re} x 10^{-3}	T
695	138.5	20.0	6.15	1.64	34.6	45
6	151.0	23.6	6.70	1.63	37.6	
7	73.0	5.8	3.25	1.70	18.3	
8	110.5	13.1	4.91	1.69	27.6	
9	139.5	20.5	6.20	1.66	34.8	
876	41.5	4.8	2.98	1.71	13.1	44
7	66.0	11.5	4.75	1.59	20.9	
8	88.5	20.1	6.36	1.55	28.0	
9	107.0	28.7	7.70	1.52	34.0	
80	42.0	5.1	3.02	1.75	13.3	
1	66.5	11.9	4.79	1.62	21.1	45
2	88.0	20.7	6.33	1.61	27.9	
3	105.5	29.2	7.57	1.59	33.4	
4	42.5	4.9	3.06	1.64	13.9	
5	66.0	11.2	4.75	1.55	21.0	
6	89.0	18.9	6.40	1.44	28.2	45
7	106.0	26.0	7.61	1.40	33.6	
8	43.5	5.4	3.13	1.72	13.8	
9	65.5	11.7	4.72	1.64	20.8	
90	88.0	20.4	6.33	1.59	27.9	
1	105.0	28.7	7.55	1.58	34.3	

(15) Brands of tees--tabulated under (6)

(16) Static tap

621	75.5	5.5	3.37	1.52	20.1	48
2	110.0	12.0	4.9	1.56	29.3	
3	139.5	19.3	6.20	1.56	37.0	
4	151.0	22.5	6.72	1.56	40.2	
629	73.0	5.5	3.25	1.62	19.5	
30	111.0	12.6	4.94	1.61	29.6	
1	138.5	20.1	6.15	1.65	36.9	
2	152.0	23.0	6.76	1.57	40.6	

(17) Threading bushing into section 6

Run	w	R	V	K	N_{Re} x 10^{-3}	T
763	76.0	5.4	3.39	1.49	19.1	44
4	111.0	11.8	4.94	1.51	28.1	
5	139.0	18.3	6.19	1.49	35.2	
6	152.0	21.9	6.76	1.49	38.6	

(18) Length of nipple, section 7

705	73.5	5.8	3.28	1.68	18.7	45
6	110.5	13.0	4.92	1.67	28.0	
7	138.0	20.3	6.15	1.69	35.0	
8	150.0	24.2	6.69	1.70	38.0	
715	76.0	6.1	3.39	1.66	19.3	
6	111.5	13.6	4.97	1.73	28.3	
7	140.5	21.1	6.25	1.68	35.6	
8	151.5	24.7	6.74	1.69	38.4	

(19) Threading section 7 into section 5

701	73.0	5.8	3.25	1.70	18.6	45
2	110.5	13.1	4.92	1.69	28.1	
3	140.5	20.7	6.25	1.65	35.6	
4	151.0	24.2	6.73	1.67	38.4	
709	74.0	6.0	3.40	1.72	19.4	
10	110.0	13.1	4.90	1.70	28.0	
1	140.0	20.4	6.23	1.64	35.2	

(20) Reaming end of section 7

712	73.0	5.9	3.25	1.74	18.5
3	111.5	13.2	4.96	1.67	28.3
4	155.5	25.4	6.9	1.62	39.3

TABLE XVIII (Cont.)

(21) Vertical arrangement

Run	w	R	V	K	N_{Re} x 10^{-3}	T
780	42.0	2.1	1.87	1.83	10.6	43
2	73.0	6.0	3.26	1.75	18.5	
4	116.0	13.5	5.16	1.58	29.4	
6	139.0	20.8	6.20	1.69	38.5	
8	163.5	23.1	7.28	1.69	41.6	
9	111.5	13.3	4.96	1.69	28.2	
91	139.5	20.5	6.21	1.66	35.3	
2	150.5	24.4	6.70	1.70	38.1	
3	162.5	28.3	7.23	1.69	41.2	
4	74.0	5.8	3.30	1.66	18.8	
5	113.5	13.4	5.05	1.63	28.7	
6	138.5	20.5	6.16	1.68	35.1	
7	152.0	24.2	6.76	1.65	38.6	
8	161.5	27.9	7.19	1.68	40.9	

(22) Flow into the tee branch, Section 1, threading

Run	w	R	V	K	N_{Re} x 10^{-3}	T
1141	73.4	5.5	3.26	1.61	18.3	42
2	95.0	10.0	4.23	1.75	23.7	
3	120.0	14.4	5.34	1.58	30.0	
4	136.3	18.6	6.06	1.56	34.1	
5	148.8	21.6	6.60	1.55	37.1	
6	179.3	31.8	7.97	1.56	44.8	
7	72.0	5.3	3.26	1.62	18.0	
8	108.5	12.2	4.82	1.63	27.1	
9	134.5	17.8	5.98	1.55	33.6	
50	148.0	21.4	6.48	1.54	37.1	
1	174.0	30.2	7.74	1.57	43.5	
2	69.8	5.65	3.11	1.82	17.5	
3	107.8	10.8	4.78	1.48	26.8	
4	125.5	16.3	5.69	1.57	32.0	
5	149.0	22.2	6.62	1.56	37.2	
6	174.0	20.0	7.74	1.57	43.5	

(23) Brands of tees

Run	w	R	V	K	N_{Re} x 10^{-3}	T
1177	73.5	5.7	3.27	1.66	18.3	43
8	112.3	12.5	4.99	1.56	28.0	
9	123.8	18.1	5.95	1.59	33.4	
80	152.0	23.0	6.76	1.57	38.0	
1	177.0	30.1	7.86	1.52	44.1	
1207	87.8	6.9	3.91	1.42	22.5	
8	116.5	12.1	5.19	1.40	29.9	
9	144.5	17.9	6.43	1.34	37.0	
10	165.5	24.0	7.38	1.37	42.5	
1	184.0	29.4	8.19	1.37	47.3	
2	81.3	6.1	3.62	1.44	20.9	
3	111.8	11.9	4.97	1.50	28.7	
4	140.8	18.1	6.25	1.44	36.1	
5	162.0	24.3	7.20	1.46	41.5	
6	179.5	30.4	7.99	1.49	46.1	

(24) Threading, section 3 into section 2

Run	w	R	V	K	N_{Re} x 10^{-3}	T
1157	73.0	5.1	3.25	1.51	18.3	42
8	102.0	10.4	4.53	1.58	25.5	
9	125.0	15.7	5.66	1.53	31.8	
60	150.0	21.9	6.67	1.54	37.5	
1	174.8	29.9	7.75	1.56	43.5	
2	71.5	5.5	3.18	1.70	17.9	
3	102.5	10.7	4.56	1.60	25.7	
4	127.0	15.9	5.65	1.56	31.8	
5	148.0	21.8	6.58	1.57	37.5	
6	175.5	29.5	7.80	1.52	43.8	

(25) Impact tap, section 3

Run	w	R	V	K	N_{Re} x 10^{-3}	T
1202	79.5	5.8	3.54	1.44	20.4	45
3	116.8	12.2	5.19	1.41	29.9	

TABLE XVIII (Cont.)

(25) Continued

Run	w	R	V	K	N_{Re} x 10^{-3}	T
1204	143.0	18.0	6.34	1.39	36.7	45
5	167.5	24.4	7.45	1.36	43.0	
6	184.0	30.3	8.19	1.41	47.2	

(26) Section 4, threading

Run	w	R	V	K	N_{Re} x 10^{-3}	T
1167	70.8	5.9	3.16	1.86	17.8	43
8	107.3	11.9	4.78	1.61	26.8	
9	139.5	19.2	6.20	1.56	35.0	
70	159.8	23.6	7.10	1.46	40.0	
1	178.3	29.5	7.93	1.46	44.6	
2	73.5	5.7	3.27	1.66	18.4	
3	108.0	12.1	4.81	1.63	27.1	
4	131.5	17.7	5.85	1.61	33.0	
5	153.5	24.2	6.83	1.62	38.5	
6	171.5	29.3	7.64	1.57	43.0	

(27) Vertical arrangement

Run	w	R	V	K	N_{Re} x 10^{-3}	T
1192	80.0	6.0	3.56	1.49	20.6	45
3	112.0	12.2	4.98	1.53	28.8	
4	135.5	17.5	6.03	1.50	34.8	
5	155.8	23.6	6.92	1.54	39.8	
6	182.5	31.5	8.12	1.50	46.9	
7	77.0	5.9	3.43	1.56	19.6	
8	111.3	11.8	4.95	1.51	28.6	
9	136.0	17.6	6.05	1.50	34.9	
1200	157.5	24.1	7.00	1.53	40.4	
1	177.0	29.8	7.86	1.51	45.5	

(28) Close nipple system

Run	w	R	V	K	N_{Re} x 10^{-3}	T
1299	75.0	4.0	3.34	1.10	19.3	45
1300	106.0	7.7	4.72	1.08	27.3	
1	129.0	11.7	5.74	1.11	33.2	
2	158.3	18.3	7.05	1.14	40.8	

(28) Continued

Run	w	R	V	K	N_{Re} x 10^{-3}	T
1303	195.0	26.7	8.67	1.10	50.1	45
4	74.5	4.3	3.32	1.21	19.2	
5	106.5	8.5	4.73	1.18	27.3	
6	140.0	14.3	6.23	1.15	36.0	
7	161.0	19.4	7.16	1.18	41.5	
8	194.5	27.7	8.65	1.15	50.0	
9	81.3	4.5	3.62	1.07	20.9	
10	107.5	8.0	4.78	1.09	27.6	
1	142.5	14.1	6.34	1.10	36.8	
2	162.3	18.9	7.22	1.13	41.8	
3	193.8	26.2	8.62	1.10	49.8	
4	74.8	4.6	3.33	1.29	19.2	
5	107.3	9.4	4.77	1.29	27.6	
6	134.0	14.4	5.96	1.27	34.5	
7	159.0	19.8	7.07	1.24	40.8	
8	194.0	29.6	8.63	1.24	49.8	
9	76.8	4.5	3.42	1.20	19.8	
20	126.3	12.0	5.63	1.19	32.5	
1	144.8	15.4	6.44	1.16	37.2	
2	160.5	19.7	7.14	1.21	41.3	
3	194.0	28.0	8.63	1.17	49.8	
4	82.0	5.1	3.65	1.18	21.1	
5	109.0	9.0	4.85	1.19	28.0	
6	133.5	13.0	5.94	1.15	34.4	
7	154.8	18.3	6.89	1.21	39.8	
8	195.5	27.8	8.70	1.15	50.3	
9	90.5	6.0	4.03	1.14	23.2	
30	130.0	11.8	5.78	1.37	33.4	
1	153.5	16.3	6.82	1.09	39.4	
2	171.5	19.8	7.63	1.06	44.1	
3	192.5	25.4	8.56	1.08	49.5	
4	88.0	5.8	3.92	1.18	22.7	
5	127.5	12.2	5.67	1.18	32.8	
6	148.5	16.3	6.60	1.16	38.2	
7	164.5	19.7	7.32	1.14	42.3	46
8	194.0	27.4	8.64	1.14	49.9	

TABLE XVIII (Cont.)

(28) Continued

Run	w	R	V	K	N_{Re} x 10^{-3}	T
1339	92.0	6.1	4.10	1.13	23.7	46
40	122.0	12.3	5.43	1.30	31.4	
1	155.5	17.3	6.91	1.13	40.0	
2	172.5	21.3	7.66	1.13	44.3	
3	193.0	27.4	8.58	1.16	49.6	
4	94.5	6.9	4.21	1.21	24.4	
5	129.0	12.6	5.74	1.19	33.2	
6	156.0	18.8	6.94	1.22	40.1	
7	193.5	28.2	8.60	1.19	49.7	

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ADDRESSES OF MANUFACTURERS

1. Crane Company, 836 S. Michigan Avenue, Chicago 5, Illinois.

2. Detroit Brass and Malleable Iron Works, 100 S. Campbell, Detroit 9, Michigan.

3. Stockham Pipe Fittings Company, 4000 10th Avenue North, Birmingham Alabama.

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NAME OF AUTHOR: Spencer Harlan Landes

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