INVESTIGATION OF AN INEXPENSIVE WATER METER FOR IRRIGATION SYSTEMS

by

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INTRODUCTION

There is urgent need for an inexpensive and yet an accurate method for measuring and distributing irrigation water in irrigation systems.

During the early period of irrigation, water supplies did not constitute a problem. Irrigated areas were relatively small and the natural water resources were not fully utilized. Since that time the irrigated area has increased greatly and natural water flows have become fully appropriated. Securing of additional water is becoming impossible, so the problems of water distribution and the devices for water measurement have become more and more important in recent years.

The increased utilization and value of irrigation water and the growing tendency to base annual water charges on the quantity of water used make it imperative to have an understanding of the principles and methods of water measurement. The laws governing the appropriation of water for beneficial use require the irrigator to state total quantity of water desired in acre-feet per year and proposed maximum rate of diversion either in cubic feet per second, gallons per minute, or million gallons per day. Furthermore, information concerning the relationships of water, soils, and plants which is the largest contribution of modern agricultural science cannot be utilized in irrigation practice without an accurate device for water measurement.

There were many fluid flow measuring devices and meters available on the market; though most of them were designed for industrial uses some of them were intended to be suitable for irrigation purposes. Most irrigated farms did not have a water measuring device to obtain the maximum irrigation efficiency and thus avoid waste of water or under-irrigation. There were at least three reasons why the farmer had not been receptive to purchasing a water meter:

First of all, the initial cost of water measuring devices including those of installation, were usually too high. The price of a commercial irrigation flow meter was about 300 dollars which was believed to be too high for most farmers.

Second, the water measuring devices, especially those inexpensive devices, were not very convenient to operate. Farmers did not like to measure the head of the water at some place and then refer to a chart or table to obtain the rate of flow.

Third, the open channel devices could not be used on closed pipe systems such as sprinkler irrigation systems.

PURPOSE OF THE STUDY

The purpose of this study was to develop, design, and test an inexpensive vane type irrigation meter which would be satisfactory to use on irrigation systems using pumps.

REVIEW OF LITERATURE

Kinds and Classification of Fluid Meters

There have been many articles written on fluid meters, but different writers tend to use different principles of classification and terminology. For example, the terms "positive", "total", "inferential", "differential", "constriction", "partial flow",and "proportional" have been used ambiguously or inconsistently. This has caused considerable confusion. In order to reduce this confusion and to standardize the terminology, a practical

Table 1. Classification of fluid meters

Division	Class	Type
Quantity meters	Weighing	Weigher
		Tilt traps
	Volumetric	Tank
		Reciprocating Piston
		Rotary Disk
		Nutating Disk
		Geared or Lobed Impeller (rotary)
		Bellows
		Liquid Sealed Drum
Rate meter	Head (Kinetic)	Venturi
		Flow Nozzle
		Orifice Plate
		Concentric
		Eccentic (Fixed or adjustable)
		Segemental
		Venturi Segement
		Pitot Tube
		Centrifugal
		Elbow
		Turbine Scroll Case
		Guide Vane Speed Ring
	Constant Head and Area	Funnel Meter
		Flow Prover
		Critical Flow Prover
	Area (Geometric)	Gate
		Orifice and Plug
		Cone and Disk
		Cylinder and Piston
	Head-Area	Weirs
		Flumes
	Force	Hydrometric Pendulum
		Vane
	Velocity	Propeller
		Cup Turbine
		Turbine
		Helical
	Thermal	Electric
	Special Methods	Mixtures
		Salt Velocity
		Pressure Time
		Sound Velocity

classification has been made by the American Society of Mechanical Engineers (2) and is shown in Table 1.

Devices Commonly Used to Measure Irrigation Water

According to the Water Measurement Manual (19) the following devices are used by the Bureau of Reclamation:

1. Weirs
2. Submerged orifices
3. Parshall flumes
4. Current meter gaging station
5. Commercial meters

The Water Measurement Manual also mentioned some other devices which are less commonly used on typical irrigation projects but are utilized where adaptable to special field conditions. Some of these are:

1. Float method
2. Pitot tube
3. Salt-velocity method
4. Color-velocity method
5. Calibrated gates, water wheels and valves.
6. Venturi meter
7. Flow nozzles
8. Orifice meters
9. California pipe method
10. Current meter method for pipes
11. Clausen-Pierce weir gage
12. Commercial meters

Fry and Davis (8) studied several methods of fabricating accurate and yet inexpensive rate of flow measuring devices for sprinkler irrigation pipes. The devices involved in their study were adapted to 4-inch diameter pipe made from 3/16-inch aluminum pipe and are as follows:

1. Concentric circular orifice, 2.45 inches in diameter and made from 3/16-inch aluminum plate.
2. Square-edged eccentric orifice made from 3/16-inch aluminum plate, entirely suppressed such that the effective area of the orifice was 50 percent of the cross sectional area of the pipe.
3. Square-edged eccentric orifice, similar to No. 2, with the effective area at the orifice equal to 70 percent of the cross-sectional area of the pipe.
4. Impact tube with two 1/16-inch holes drilled 0.5 diameter apart and equidistant from the center of the pipe, made from 1/4-inch copper tubing, placed perpendicular to the center line of the pipe.
5. Impact tube with one 1/16-inch hole at the center line of the pipe.
6. A modified venturi made by manually crushing the tube between two steel channels which were subsequently bolted together.
7. Square-edged eccentric orifice similar to No. 2 with an effective area at the orifice of 76 percent of the cross-sectional area of the pipe, installed in a steel press on coupler with 20 feet of straight approach.

8. Same as No. 7 with four feet of straight approach.

Among these devices square-edged orifice was recommended since it was the most accurate device studied.

Irrigation and Water Measurement Situation in Kansas

Irrigation to supplement natural soil moisture is a long established practice in Kansas. United States census records show that about 21,000 acres were being irrigated in this state by 1890. Irrigation was first practiced in the western part of the state where water resources were available to supplement the low annual precipitation. There has been a progressive increase both in the irrigated acreage and number of water sources. Most of the increase has come in the recent years. In a report edited by the Kansas Finance Council to the Kansas State Legislature called "Water in Kansas" (11) stated;

> In 1954 about 421,000 acres on 2,815 farms were irrigated in Kansas, about 14 percent was irrigated by sprinklers and the rest by ditch or other gravity systems. About 57,000 acres on 615 farms were irrigated for the first time in 1954, of which 22,000 acres were served by sprinkler systems.

Water in Kansas also reported the sources of irrigation water, acreage irrigated from each source, and the adequacy of existing irrigation water sources. These are shown in Table 2 and Table 3. It is estimated according to the county agricultural agents' annual reports that 899,755 acres were under irrigation in 1958.

Table 2. Sources of Irrigation Water and Acreage Irrigated from Each Source in Kansas.

Sources of irrigation water	Number of sources 1951	Number of sources 1954	Acres irrigated from sources in 1954
Wells	1,687	2,678	344,300
Ponds	30	81	2,600
Streams	302	396	29,600
Irrigation Ditches	129	129	44,200
Others	0	2	300
Total	2,148	3,286	421,000

Table 3. Adequacy of Existing Irrigation Water Supply Sources in Kansas.

Source	Percent of Total Acreage of Irrigated Land in 1954. Normal Year		1954	
	Adequate	Inadequate	Adequate	Inadequate
Wells	90	10	80	20
Ponds	56	44	33	67
Streams	76	24	45	55
Irrigation ditches	71	29	34	66
Other	67	33	67	33
	87	13	72	28

It is interesting to note that 82 percent of Kansas irrigated areas are irrigated from wells, and also that the most adequate source of irrigation water in Kansas is from wells.

No statistics on water measurement equipment is available but it must be realized that there are only a few of these irrigated farms which have adequate water measurement equipment.

The Principle of the Vane Meter

In the explanatory comment on the vane meters, it is stated by the American Society of Mechanical Engineers (2).

> This type meter employs a swinging vane or gate across the stream and is operated in much the same way as the hydrometic pendulum. The use of the large vane or gate provides a material obstruction in the stream and, consequently, involves a loss of head across the device. The meter, therefore, partakes to some extent the characteristics of an area meter and is really a hybrid type. The relative importance of the two effects is naturally affected by the size and the shape of the vane and the resistance of the vane against movement. The vane can be loaded by gravity only or by a spring, in the latter case, the conduit need not to be horizontal.

An elementary feature is also given as shown in Fig. 1 and it is further stated;

> A formula could be worked out for each case but would be complex. The custom, therefore, is to calibrate these meters. The normal scale reading is a complex function of flow but may be made proportional by design.

On the other hand, devices using the same principle sometimes are called impact meters. Addison (1) states;

> Impact meters depend on the dynamic thrust exserted by the liquid on a movable surface inside the pipe; the thrust is resisted by a coiled spring or other elastic element, and consequently as the flow increases the corresponding deflection of the impact surface may be transmitted to an external pointer graduated in units of the discharge.

A Sewer Aerofoil Blade Recorder which has an aerofoil shape impact surface is shown in Fig. 2.

METHOD AND PROCEDURE

General Design and Construction of the Vane Meter

The vane meter was built into a ten-foot section of six-inch

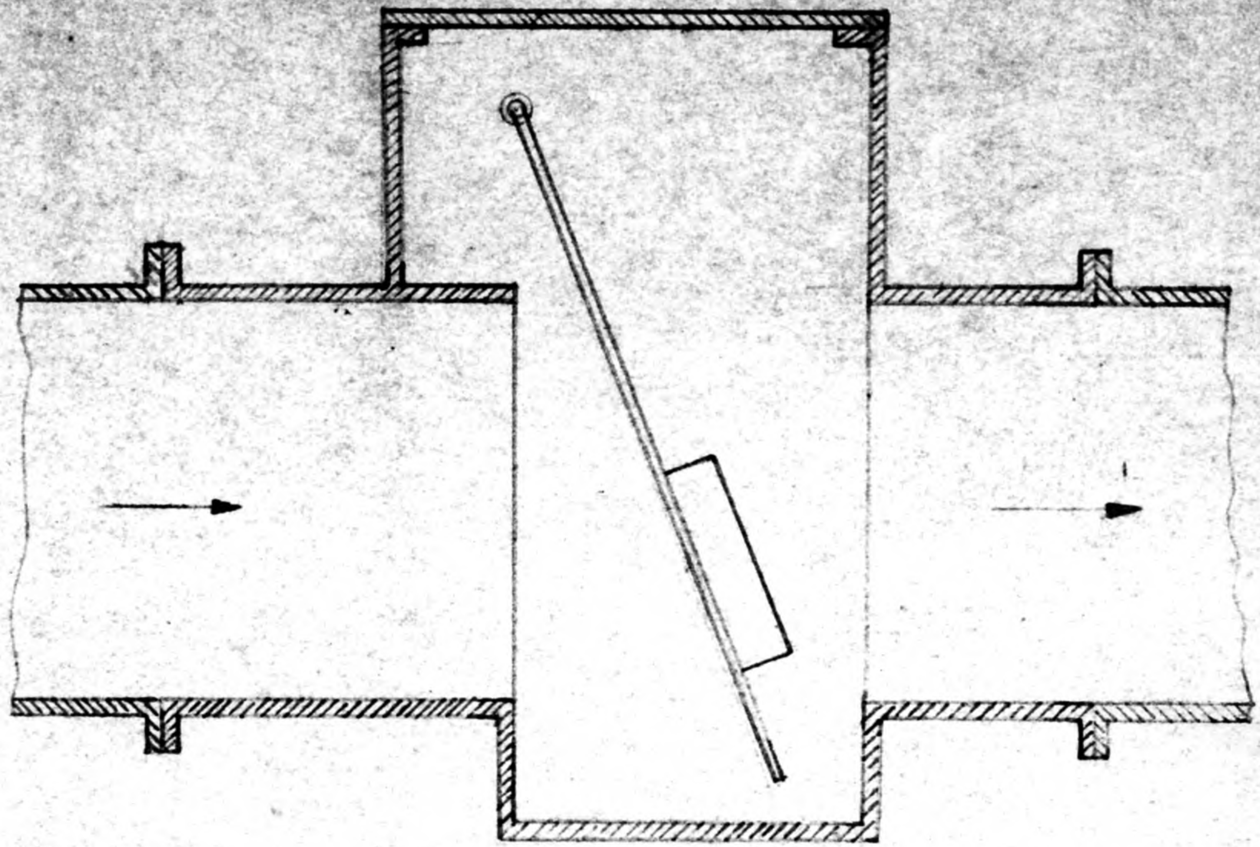


FIG I   VANE METER

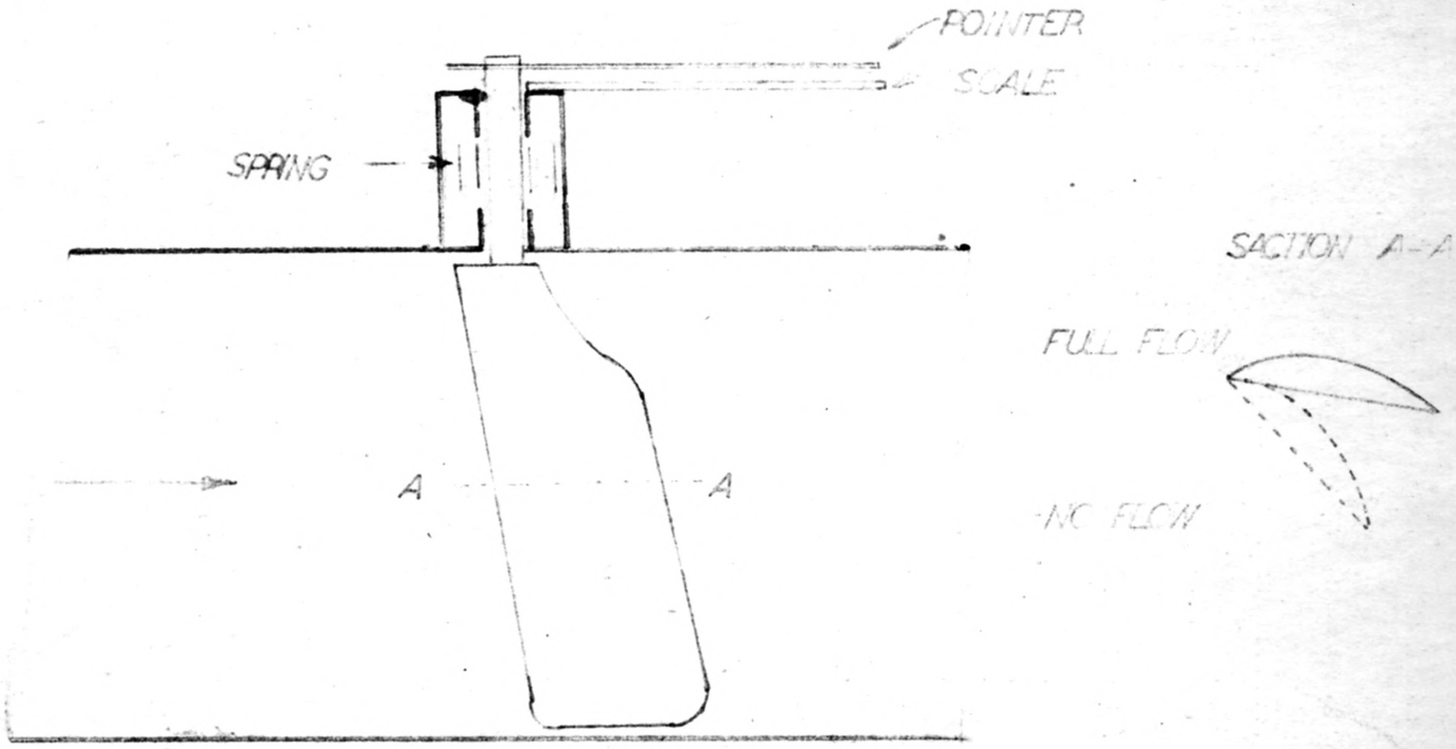


FIG 2 AEROFOIL IMPACT METER

aluminum pipe. The vane was located eight feet from the upstream end or two feet from the downstream end of the pipe.

Two 7/32-inch holes were drilled in the center line of the pipe cross-section where the vane was located. Two aluminum studs were welded over the holes. The studs had a bore of 1/4-inch and were used as supports for the vane shaft.

The vane was made from 1/8-inch aluminum plate. The upper half of the vane was 1/2 inch wide while the lower half was 1-1/2 inches wide. A 1/4-inch outside diameter stainless steel tube 11 inches long was used as the shaft to support the vane. The vane was fastened to the shaft by means of a clamp.

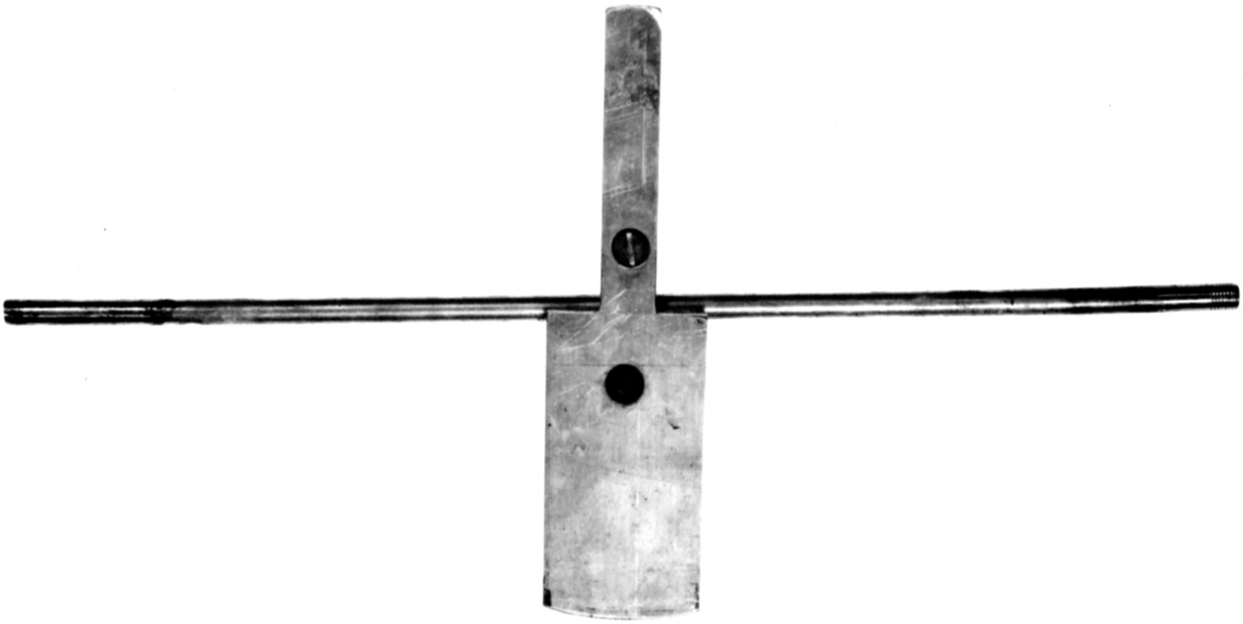
A packing gland nut was screwed onto each studs. Packing string was used to prevent the water from leaking by the clearance between the shaft and packing gland nuts. On one of the packing gland nuts, an aluminum dial plate was secured by screws. An aluminum hand was attached on one end of the shaft by means of a set screw. On the opposite end of the shaft a counterweight was screwed to a connecting rod which was 4-3/4 inches in length and was fastened on the shaft by a setscrew. The iron counterweight weighed 0.3 pound. It should be noted that the center line of the connecting rod and the counterweight must always be in the same plane with the upstream surface of the vane.

The difference of force caused by the impact of the flowing water upon the lower-side vane and the upper-side vane deflected the vane, counterweight, and the hand from what would be its undisturbed position. The angle of deflection indicated by the hand is thus a measure of the water velocity and hence, also the measure of rate of discharge.

EXPLANATION OF PLATE I.

View of the vane and shaft of the vane meter.

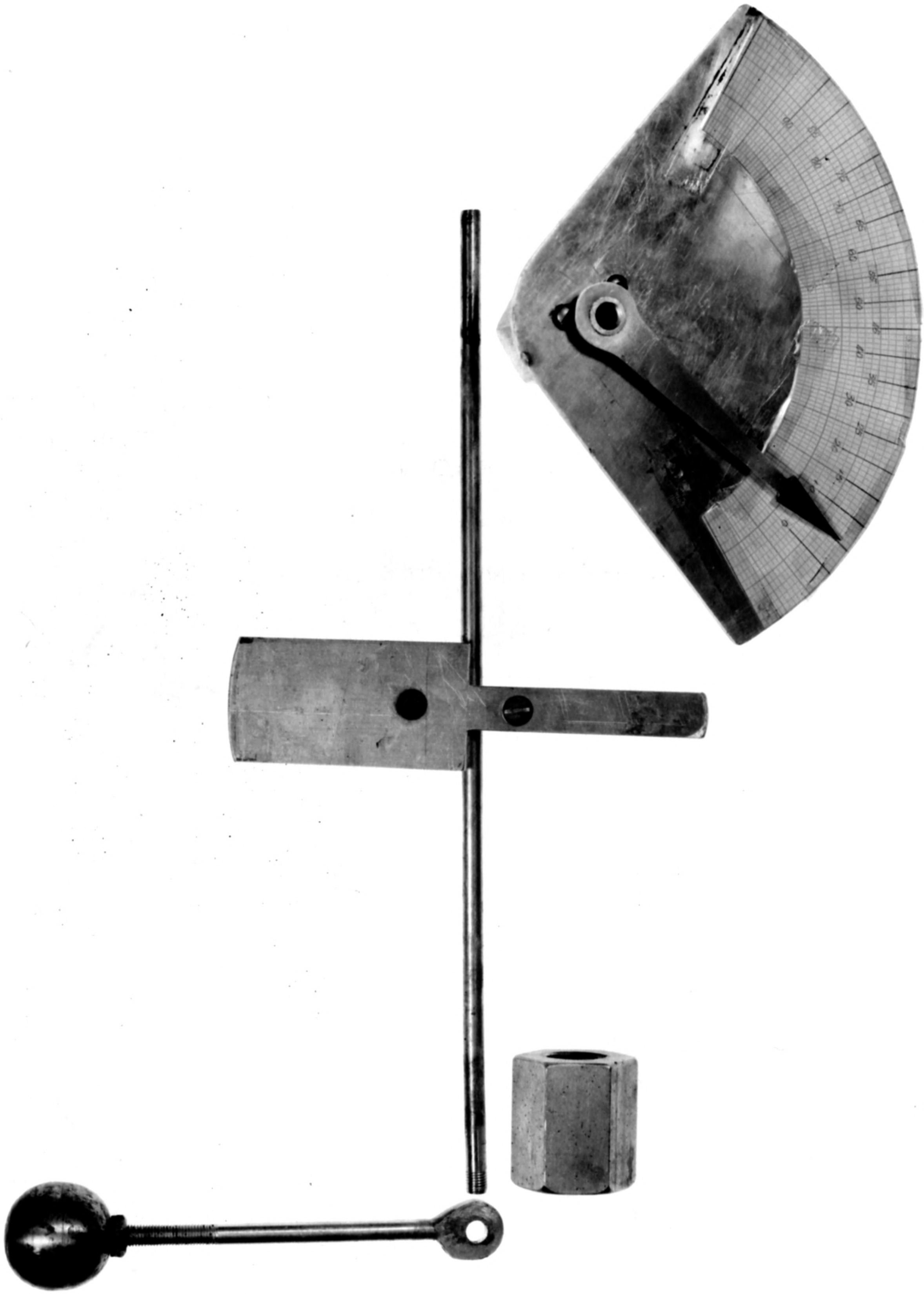
PLATE I



EXPLANATION OF PLATE II

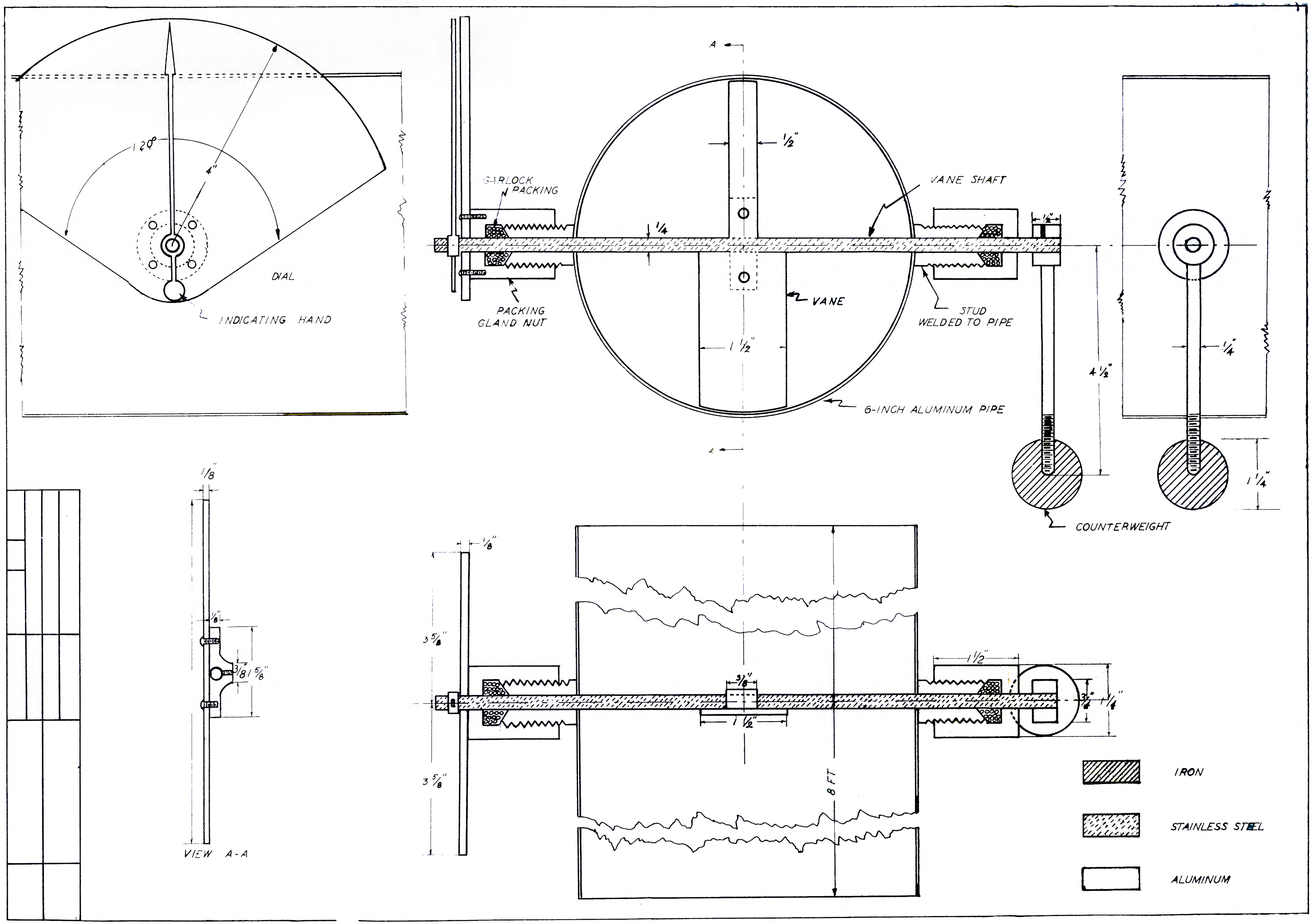
The parts of vane meter

PLATE II



EXPLANATION OF PLATE III

Full scale detailed drawing of the vane meter



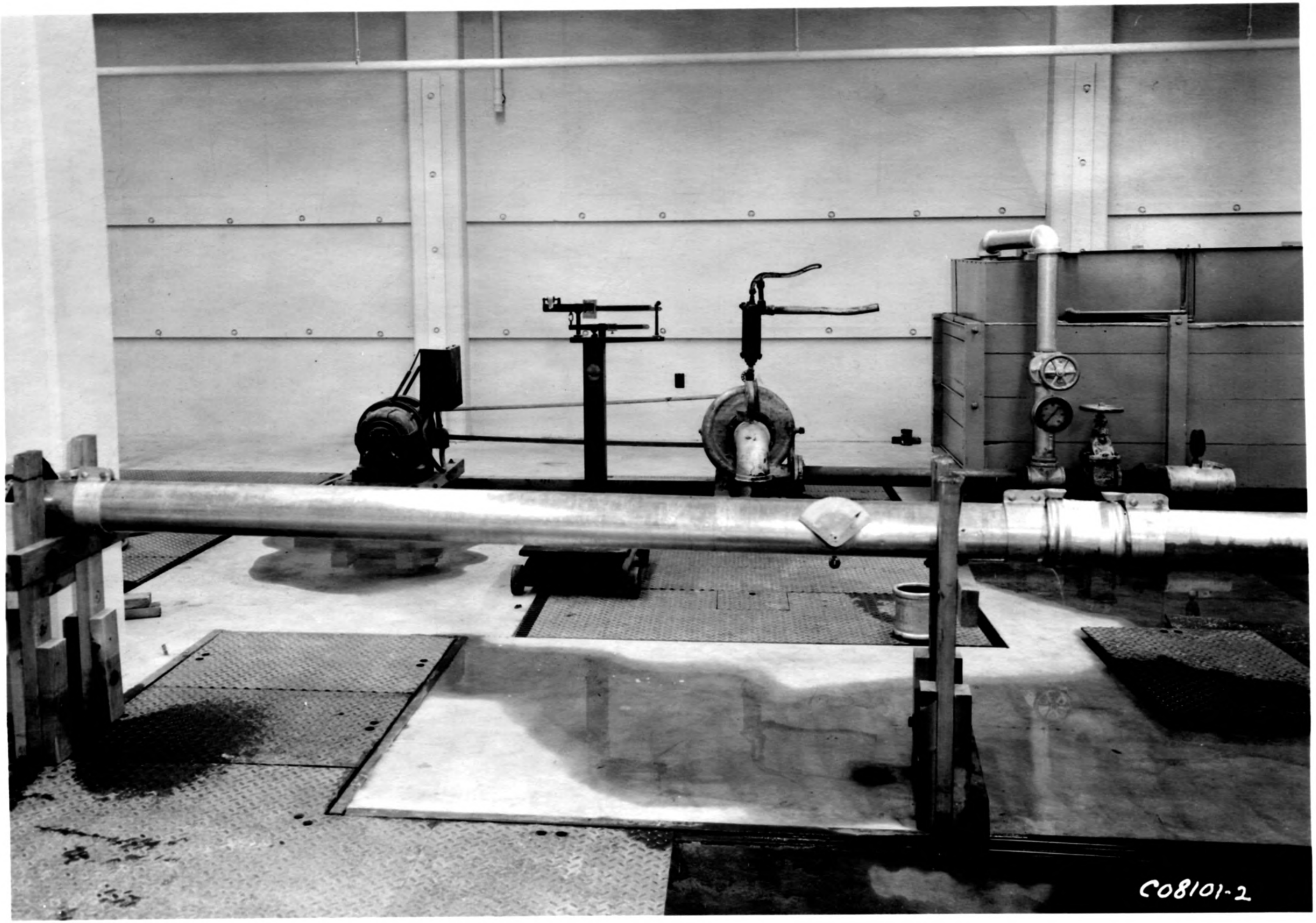
120°
4"
DIAL
INDICATING HAND
GARLOCK PACKING
PACKING GLAND NUT
A
1/2"
1/4
VANE SHAFT
VANE
1 1/2"
STUD WELDED TO PIPE
6-INCH ALUMINUM PIPE
1/2"
4 1/2"
1/4"
1 1/4"
COUNTERWEIGHT
1/8"
1/8"
3/8
1 5/8"
VIEW A-A
1/8"
3 5/8"
3 5/8"
3/8"
1 1/2"
8 FT
1 1/2"
3/4"
1 1/4"
IRON
STAINLESS STEEL
ALUMINUM

PLATE III

EXPLANATION OF PLATE IV

The 10-foot aluminum pipe with vane meter installed.

PLATE IV



Theory and Assumptions

Three assumptions were made in derivation of the following equation. First, the flow in the meter was assumed to be a simple form of turbulent flow. Second, the velocity measured from deflection of the vane would be the average velocity. Third, the effect due to the friction between the shaft and the bearings, and the disturbance caused in the flow by the shaft and the vane can be eliminated by introducing an empirical constant.

Let: Q = discharge in c.f.s.

A = cross-sectional area of the meter in square feet.

a_1 = area of lower-side vane in square feet.

a_2 = area of upper-side vane in square feet.

r = the radius of the meter in feet.

W = the mass of the weight in pounds.

w_1 = the mass of the lower-side vane in pounds.

w_2 = the mass of the upper-side vane in pounds.

L = the length from the center of gravity of the weight to the center line of the shaft in feet.

m_1 = the mass rate of the flow impact on the lower-side vane in pounds per second.

m_2 = the mass rate of the flow impact on the upper-side vane in pounds per second.

b_1 = width of the lower-side vane in feet.

b_2 = width of the upper-side vane in feet.

ρ = average density of water in pounds per square foot.

C = an empirical constant.

θ = angle of deflection in degrees.

So the horizontal force applied on the lower-side vane is

$$F_1 = C \frac{m_1}{g} V \qquad (1)$$

V is the average velocity of flow in feet per second

while that on the upper-side vane is

$$F_2 = C \frac{m_2}{g} V \qquad (2)$$

But

$$m_1 = V a_1 \rho \qquad (3)$$

$$m_2 = V a_2 \rho \qquad (4)$$

So

$$F_1 = C \frac{V^2}{g} a_1 \rho \qquad (5)$$

$$F_2 = C \frac{V^2}{g} a_2 \rho \qquad (6)$$

when the hand indicates an angle of deflection θ the moments created by F_1, F_2, w_1, w_2 and W must be in equilibrium So

$$LW \sin\theta + w_1 g\, r/2 \sin\theta - w_2\, r/2 \sin\theta = F_1\, r/2 \cos\theta - F_2\, r/2 \cos\theta \qquad (7)$$

Therefore

$$(2W L + w_1 r - w_2 r) \sin\theta = r (F_1 - F_2) \cos\theta \qquad (8)$$

Substitute (5) and (6) into (8)

$$(2WL + w_1 r - w_2 r) \sin\theta = C r \rho \frac{V^2}{g} (a_1 - a_2) \cos\theta \qquad (9)$$

Since w_1 and w_2 are small and nearly equal, so set

$$w1 = w2$$

$$2WL + L \sin\theta = C r \rho \frac{V^2}{g} (a_1 - a_2) \cos\theta \qquad (10)$$

i.e.

$$V^2 = \frac{2 W g L \tan\theta}{C r \rho (a_1 - a_2)} \qquad (11)$$

$$V = \sqrt{\frac{2 W g L \tan\theta}{C r \rho (a_1 - a_2)}} \qquad (12)$$

But $$Q = VA$$

So $$Q = VA = \sqrt{\frac{2\ W\ g\ L\ Tan\ \theta}{C\ r\ \rho\ (a_1 - a_2)}} \times A \tag{13}$$

Since $$A = \pi\ r^2$$

and $$a_1 = b_1\ r$$

$$a_2 = b_2\ r$$

Then $$Q = \sqrt{\frac{2\pi^2\ r^2\ W\ g\ L\ Tan\ \theta}{C\ \rho\ (b_1 - b_2)}} \tag{14}$$

In this practical case

$r = 3"$

$L = 4.5"$

$W = 0.3$ lb.

$b_1 = 1.5"$

$b_2 = 0.5"$

Substitute the above values into (14)

$$Q = \sqrt{\frac{0.86\ Tan\ \theta}{C}} \tag{15}$$

Let $$K^2 = \frac{1}{C} \tag{16}$$

$$Q = 0.928\ K\ Tan\ \theta \tag{17}$$

Q is in c.f.s., if Q is expressed in G.P.M.

Then $Q = 0.928 \times 448.83\ K\ Tan\ \theta$ $\qquad Q = 416.51\ Tan\ \theta$

Method and Apparatus Used in Calibration

Water flow was obtained by means of a centrifugal pump which was driven by a 3 phase, 7 1/2 H.P. electric motor. An eight-inch gate valve, a commercial "Measure-Rite" propeller type irrigation meter, the vane meter, and then a four-inch sharp-edge orifice were connected in series with six-inch aluminum pipe. The flow then discharged into the open air horizontally. Plate V and VI show the equipment used for the test.

The eight-inch gate valve was connected directly to the discharge pipe of the pump. The "Measure-Rite" meter was connected to the gate valve and the vane meter by clamps and two sections of inner tube. The inner tubes were then strengthened by means of canvas duct. The connection between the vane meter and a seven-foot section of six-inch aluminum pipe which the four-inch orifice is attached, was accomplished by a six-inch aluminum coupling.

The "Measure-Rite" meter, according to the manufacturer, has a guaranteed accuracy of ± 2 percent. It has an indicator to indicate the rate of flow in G.P.M., and an integrator which shows the volume of flow in units of 1/1,000 acre-foot.

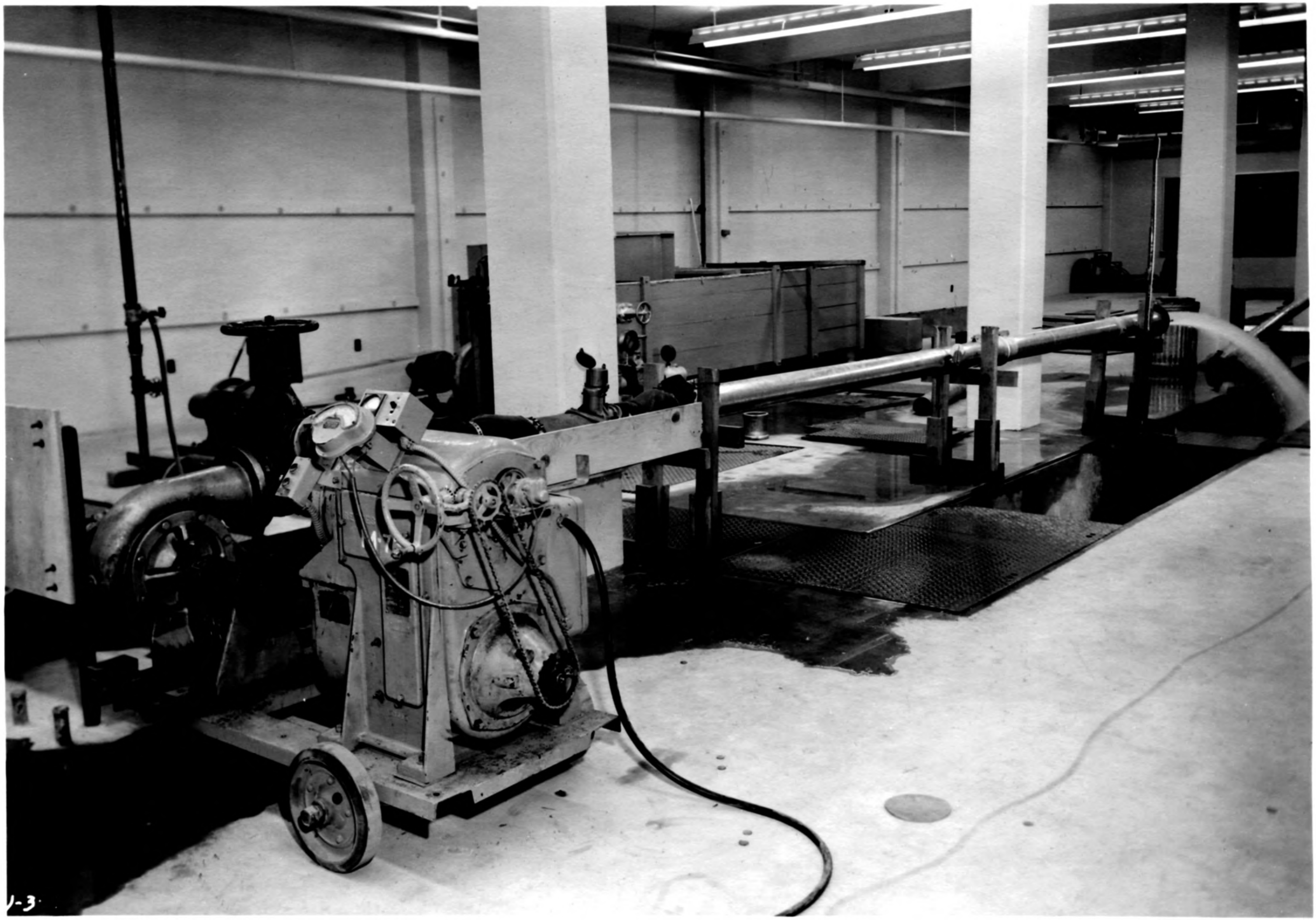
The four-inch sharp-edged orifice plate was affixed to the end of pipe with a circular disk in the center of the pipe a hole was drilled and tapped 24 inches back from the orifice plate to receive a 1/8 inch pipe fitting on which was attached rubber tube and glass tube for measuring the head on orifice.

This kind of orifice is not a very ideal device for calibration of another meter, since it is hardly warrantable to expect an error of much less then ± 2 percent throughout its range. However, there was no weighing equipment available, and the orifice plate used in this study had been calibrated by R. Schleusener, Department of Agricultural Engineering, Kansas State College, in 1950, so the accuracy was improved greatly.

EXPLANATION OF PLATE V

The centrifugal pump, the motor, the "Measure-Rite" meter the vane meter, the sharp-edged orifice and the set up for the calibrating meter.

PLATE V



EXPLANATION OF PLATE VI

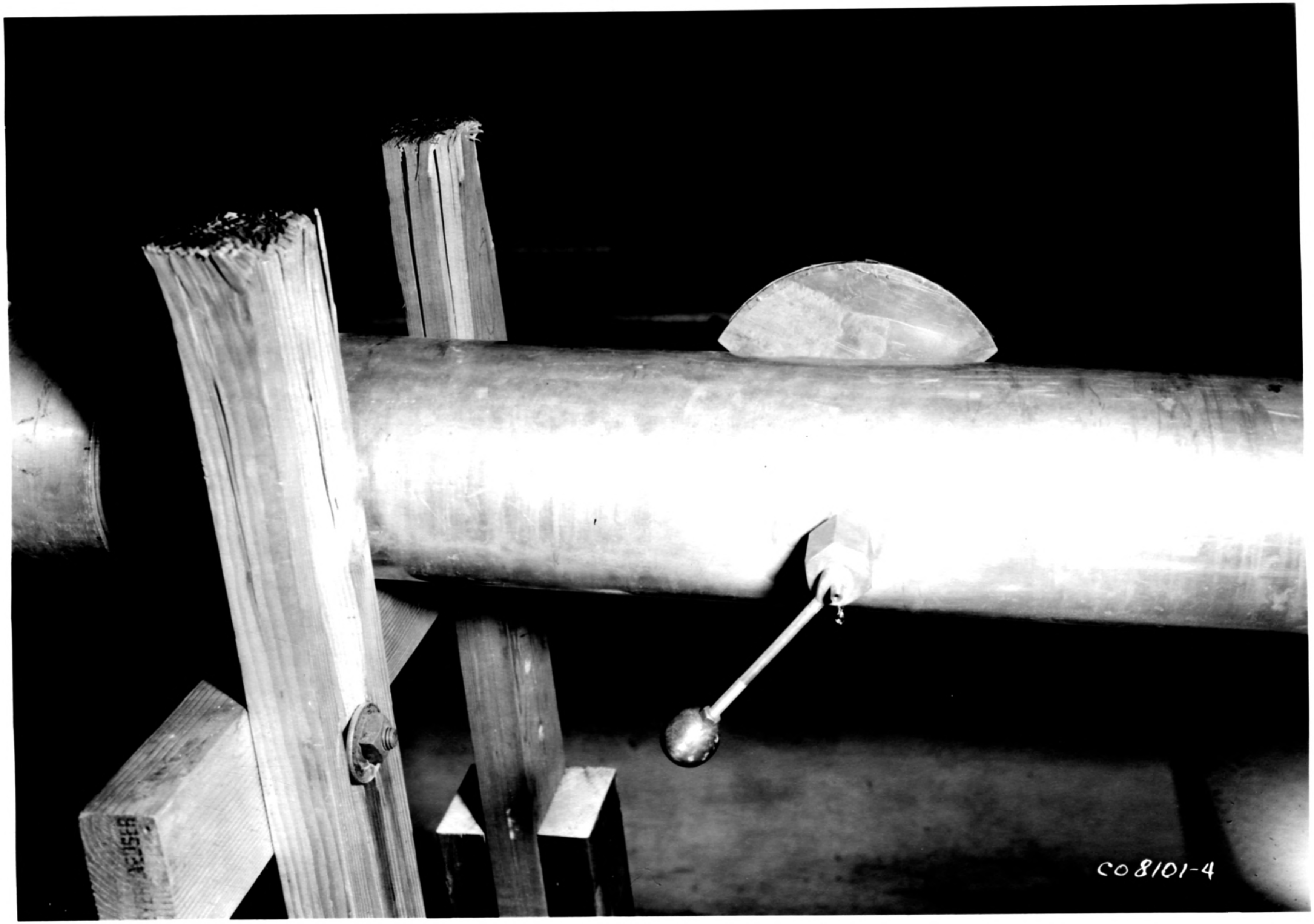
The sharp-edged orifice as used for calibrating vane meter.

PLATE VI

EXPLANATION OF PLATE VII

A view showing deflection of counter weight due to flow. Notice that the water leak by the packing gland was very slight.

PLATE VII



RESULTS OF STUDY

Data Obtained from the Calibration

There were three measuring devices used to check the rate of flow during the calibration tests. They were the sharp-edged orifice, the flow rate indicator of the "Measure-Rite" meter, and the flow rate obtained from the total volume shown by the integrator of "Measure-Rite" meter divided by the time. These three sets of data did not agree very well, but the reading from the indicator of the "Measure-Rite" meter was reasonably close to the flow rate obtained by the orifice. The flow rate obtained from the total volume divided by the time was obviously too large. It is interesting to note in Table 4 that the flow rate obtained with volume divided by time was about 7.5 percent larger than the flow rate indicated by the indicator on the "Measure-Rite" meter.

An average value of the flow rate obtained from the orifice and the rate of flow shown by the Indicator of the "Measure-Rite" meter was used whenever it was possible. Since the maximum capacity of the four-inch sharp-edged orifice was 500 G.P.M., the indicated value of "Measure-Rite" was used for flows greater then 500 G.P.M..

The data obtained for calibration are listed in Table 4 and 5.

Calibration Curve and Dial Scale

Figure 3., which is the calibration curve for vane meter indicates that the curve is S-shaped. Theoretical curve is parabola.

From the calibration curve, the dial scale was easily obtained.

Table 4. Calibration data for vane meter.

Run No.	Angle of Deflection (Degree)	4" Sharp Edged Orifice: Head (Inch)	4" Sharp Edged Orifice: Discharge (G.P.M.)	"Measure-Rite" Meter: Indicator Reading (G.P.M.)	"Measure-Rite" Meter: Initial Reading (0.001Ac-ft.)	"Measure-Rite" Meter: Final Reading	"Measure-Rite" Meter: Time (Min.)	"Measure-Rite" Meter: Computed Discharge (G.P.M.)
1	3	3	100					
2	4	4	125					
3	6	6.5	165					
4	8.5	10.8	210					
5	10.5	13.8	237.5					
6	15	20.25	285					
7	16	23.7	300					
8	17	24.5	310					
9	7	8	182	190	002344.0	002347.0	5	195
10	8.5	10	205	200	2348.0	2351.2	5	209
11	10	13.25	230	220	2352.0	2355.6	5	235
12	11	15.5	250	240	2357.0	2361.0	5	260
13	19	27	325	330	2367.0	2372.4	5	352
14	26	39.8	400	400	2374.0	2380.5	5	425
15	34	57.25	477	480	2386.0	2394.0	5	520
16	44			590	2398.0	2403.8	3	630
17	48			680	2409.0	2415.8	3	740
18	55.5			800	2421.0	2428.9	3	856
19	58			900	2433.0	2441.9	3	970
20	56.5			840	2444.0	2452.3	3	905
21	46			650	2462.0	2468.4	3	695
22	36			500	2472.0	2477.0	3	544
23	30			440	2479.0	2483.4	3	479
24	22			350	2485.0	2488.4	3	369
25	38.5			520	2490.0	2495.2	3	565

Table 4 (Concl.)

Run No.	Angle of Deflection (Degree)	4" Sharp Edged Orifice		"Measure-Rite" Meter				
		Head (Inch)	Discharge (G.P.M.)	Indicator Reading (G.P.M.)	Initial Reading (0.001Ac-ft.)	Final Reading	Time (Min.)	Computed Discharge (G.P.M.)
26	50.5			720	2499.0	2506.1	3	771
27	52.5			760	2508.0	2515.5	3	815
28	56.5			840	2518.0	2526.3	3	900
29	59			920	2530.0	2539.3	3	998
30	61			1,000	2542.0	2551.9	3	1,075
31	19.5			320	2556.5	2567.1	10	346
32	27.5			400	2568.0	2581.2	10	430
33	33			480	2582.2	2598.0	10	515
34	44			600	2601.0	2620.8	10	645
35	52.5			720	2624.8	2648.4	10	770
36	55.5			800	2650.0	2676.5	10	865
37	59			880	2682.0	2711.2	10	953
38	61			960	2714.0	2746.0	10	1,042
39	46			640	2753.4	2773.9	10	668
40	48.5			680	2778.0	2800.0	10	717
41	54.5			760	2804.0	2829.1	10	818
42	60			920	2833.0	2863.3	10	986
43	62			1,000	2867.1	2900.4	10	1,085
44	24			360	2907.0	2918.9	10	388
45	29			420	2921.0	2934.7	10	446
46	36			520	2936.1	2953.1	10	555
47	39.5			560	2954.0	2972.8	10	614
48	45			620	2974.0	2994.3	10	659
49	13			240	2995.1	3003.2	10	264
50	9			200	3004.0	3010.6	10	215

Table 5. Relation between discharge, velocity, angle of deflection Tan θ, and the constant K.

Run No.	Angle of deflection (degree)	Tan θ	Discharge (G.P.M.)	Velocity (ft / sec)	V^2	K
1	3	0.05241	100	1.135	1.27	24.2
2	4	0.06993	125	1.417	2.01	28.9
3	6	0.10510	165	1.87	3.5	34.9
4	8.5	0.14945	210	2.38	5.7	38.1
5	10.5	0.18534	237.5	2.69	7.25	39
6	15	0.26795	285	3.23	10.42	39
7	16	0.28675	300	3.40	11.58	40.3
8	17	0.30573	310	3.52	12.4	41.3
9	7	0.12278	186	2.11	4.46	36.7
10	8.5	0.14945	202.5	2.32	5.28	35.2
11	9.5	0.16734	225	2.55	6.5	38.8
12	11	0.19438	245	2.88	7.7	39.7
13	19	0.34433	327.5	3.71	13.8	40.2
14	26	0.48773	400	4.54	20.6	42.5
15	34	0.67451	478.5	5.42	29.4	43.6
16	44	0.96569	590	6.7	44.8	46.4
17	48	1.11061	680	7.72	59.0	53
18	54	1.37638	800	9.08	82.5	60
19	58	1.60033	900	10.2	102.0	64
20	56.5	1.51084	840	9.55	91	60
21	46	1.03553	650	7.37	54.3	52.5
22	36	0.72564	500	5.67	32.2	44.4
23	30	0.57735	440	4.99	24.8	43
24	22	0.40443	350	3.97	15.8	39.2
25	38.5	0.79544	520	5.90	34.8	43.8
26	50	1.19175	720	8.17	66.9	56
27	52.5	1.30323	760	8.62	74.2	57
28	56.5	1.51084	840	9.55	91.0	60.2
29	59	1.66428	920	10.43	104.3	63
30	61	1.80405	1,000	11.35	128.2	71.4
31	19.5	0.35412	310	3.64	13.2	37.4
32	27.5	0.52057	400	4.54	20.6	39.7
33	33	0.64941	480	5.45	29.8	45.9
34	44	0.96569	600	6.81	46.5	48.1
35	52.5	1.30323	730	8.18	67.0	51.8
36	55.5	1.45501	800	9.10	83.7	57.2
37	59	1.66428	880	10.00	100.0	60.2
38	61	1.80405	960	10.90	119.0	66.4
39	46	1.03553	640	7.27	52.9	51.3
40	48.5	1.13029	680	7.72	59.0	52.2

Table 5. (Concl.)

Run No.	Angle of deflection (degree)	Tan θ	Discharge (G.P.M.)	Velocity (ft / sec.)	V^2	K
41	54.5	1.40195	760	8.63	74.8	53.5
42	60	1.73205	920	10.42	109.0	63.0
43	62	1.88073	1,000	11.35	128.5	68.0
44	24	0.44523	360	4.09	16.7	37.5
45	29	0.55431	420	4.78	22.8	41.6
46	36	0.72654	520	5.91	35.0	48.8
47	39.5	0.82433	560	6.36	40.5	49.4
48	45	1.00000	620	7.04	49.5	49.5
49	13	0.23087	240	2.73	7.49	32.5
50	9	0.15838	200	2.27	5.15	32.5

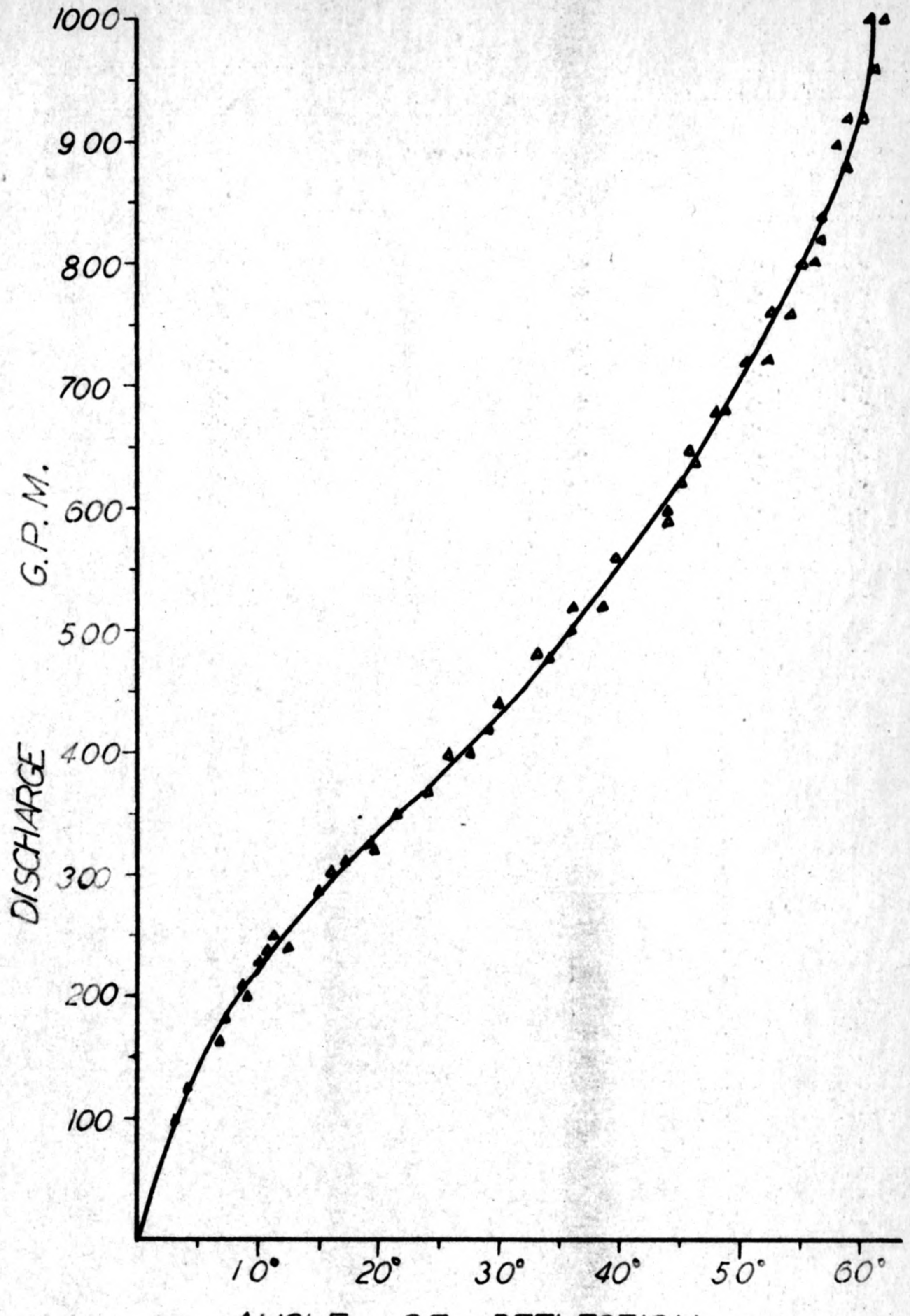


Fig. 3 The Calibration Curve of the Vane Meter.

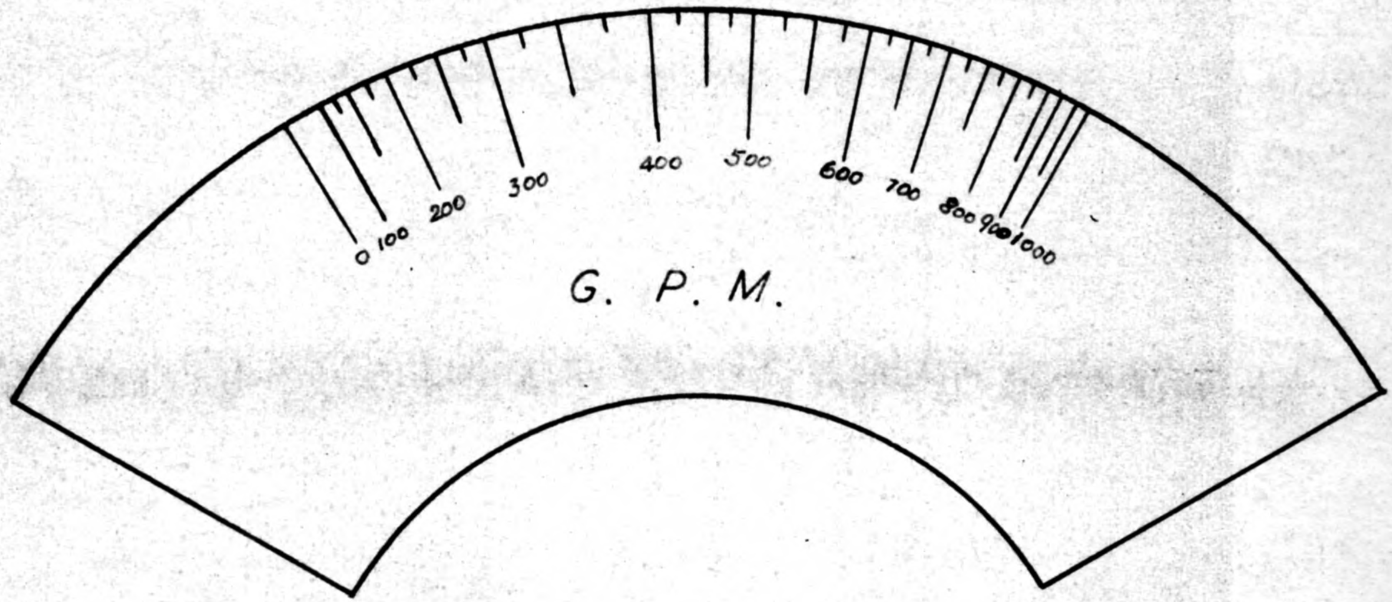


Fig. 4 Dial scale of the vane meter

Fig. 4., shows the dial scale, which covers a total angle of 61 degrees for measured flow from zero to 1,000 G.P.M., the smallest division on scale is 25 G.P.M.. It was found that the scale is not linear due to the S-shaped calibration curve.

Correlation Between Discharge and the Tangent of the Angle of Deflection

From the calibration curve, it was apparent that the correlation between discharge and the angle of deflection would not be linear. The S-shaped calibration curve suggested that the correlation equation was at least of third order, and possibly higher.

A high order correlation equation with 50 pairs of observation data was too laborious to work out by least-square method unless a computer was used. So the data were plotted on logarithmic paper by using Tan θ as abscissa and discharge in G.P.M., as the ordinate. The plotted points in Fig. 5. still show a slight trace of S-shape curve but it was considered close enough to assume a straight line.

An experimental equation was thus obtained;

$$\text{Tan}\ \theta = 0.000304\ Q^{1.6} \qquad (Q \text{ in G.P.M.})$$

Reproduce ability and Range of Measuring Flow

The 50 pairs of observation data were obtained in two sets of tests. The second test was one week later than the first one, and between these two tests the garlock string packing used in the packing gland nuts were changed due to excessive leakage but the results obtained from these tests were checked. It was noted that as long as the indicating hand indicated

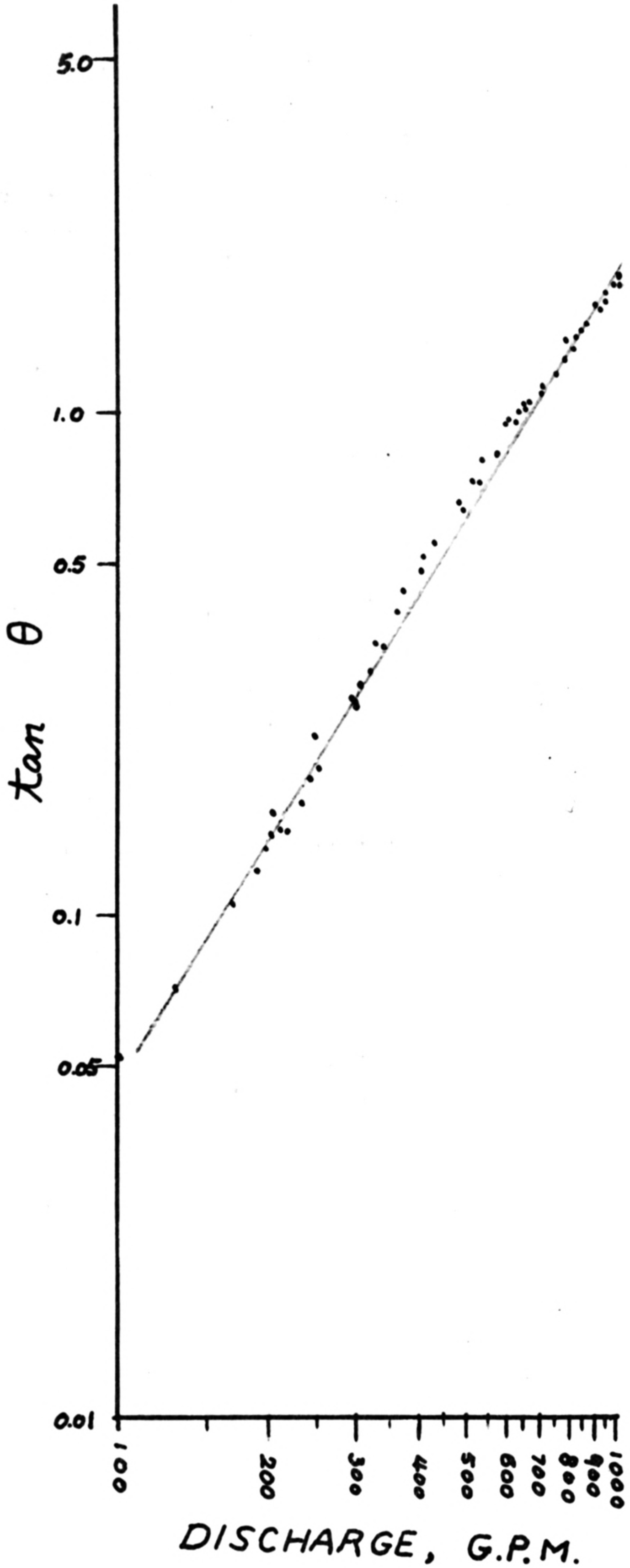


Fig. 5 Correlation between discharge and tangent of the angle of deflection.

at zero point when there was no flow reproduce ability would not be a great problem.

The range of indicated flow rate on the dial was from zero to 1,000 G.P.M.. However, the pipe did not flow full for tests less than 100 G.P.M., and the scale divisions became too close when the flow rate exceeded 850 G.P.M.. So the working range of this vane meter is between 100 G.P.M. to 850 G.P.M..

From practical experience, it has been observed that a six-inch pipe is seldom used for discharges greater than 700 G.P.M. and was never designed to be used for flows under 300 G.P.M.. So the range of this vane meter appears to be very practical.

For greater or smaller flow, this vane type meter could be designed and constructed for 4-, 8-, and 10-inch pipes.

Pulsation

The pulsation in this vane meter was not as large as that of the manometer of the sharp-edged orifice especially at the high rates of flow. However, it still made the reading of the angle of deflection difficult and is one source of error.

For velocity-type flow meters or head type flow meters one should not take the average of two extreme points of pulsation because it always tends to over estimate the flow due to its square root relation of head and flow rate. For this vane meter, since the calibration curve was S-shaped, it may over estimate or under estimate the flow at different flow rates on the calibration curve.

During the calibration, a third point between two extremes was found, where the indicating hand stayed longer than any other points. This point was found to be the mean value.

The maximum pulsation was found from 375 to 500 G.P.M.. The corresponding range of angle of deflection is between 35 to 45 degrees.

It was observed that the degree of pulsation was different for different pumps. Two centrifugal pumps were used in the calibration. The older pump had considerably more pulsation than the new one.

It is apparent that the vane meter, like the head meters, could not be used in conjunction with reciprocating pumps due to excessive pulsation. Fortunately, reciprocating pumps are seldom used in irrigation.

Static Error and Accuracy

The largest error which occurred from the calibration was 30 G.P.M. for a range of 1,000 G.P.M.. It has an accuracy of ± 3 percent. But this accuracy contained the error of the "Measure-Rite" meter, which the manufacturer claims to have an accuracy of ± 2 percent. According to the rule of combined accuracy, if

a = accuracy of instrument A.

b = accuracy of instrument B.

c = combined accuracy of instrument A and instrument B in series. Then

$$c = \sqrt{a^2 + b^2}$$

So if x = Accuracy of the vane meter.

$$3^2 = 2^2 + x^2$$

$$9 = 4 + x^2$$

$$x^2 = 5$$

$$x = 2.24$$

This means that the vane type meter has an accuracy of ± 2.24 percent which is reasonably good. Since the accuracy of the "Measure-Rite" was not as good as it was claimed to be, the actual accuracy of vane meter was even better than ± 2.24 percent.

Precautions

Attention must be paid to the following precautions in operating the vane meter so as to assure high accuracy of the vane meter:

1. The whole unit of vane meter should be in level position.
2. The center line of the shaft must be level.
3. The hand should indicate the zero reading when there is no flow.
4. The center line of the weight and the connecting rod should always be in the same plane with the upstream surface of the vane.
5. The vane should be in the center of the pipe.
6. Read the third point between two extremes of pulsation where the hand stays longer than any other points.

Precautions 1, 2, 4, and 5, are for installation while precautions 3 and 6 are for operation.

CONCLUSIONS

This vane meter, based on its performance in the tests, appears to be a promising device for measuring irrigation water. The results of this study support the following distinct advantages over other types of flow measuring devices commonly used to measure irrigation water:

Table 6. Irrigation Table. Rate of Water Application.

Discharge		Number of Acres Covered in Twelve-Hour Pumping Period — Depth of Irrigation Water							
G.P.M.	c.f.s.	1"	2"	3"	4"	6"	8"	10"	12"
100	0.2228	2.66	1.325	0.883	0.6625	0.442	0.3313	0.265	0.221
150	0.3345	3.98	1.991	1.328	0.995	0.664	0.4975	0.398	0.332
200	0.445	5.32	2.65	1.766	1.325	0.84	0.6626	0.530	0.442
250	0.557	6.64	3.316	2.212	1.6575	1.106	0.8288	0.663	0.553
300	0.668	7.96	3.98	2.655	1.990	1.327	0.995	0.796	0.663
350	0.7795	9.30	4.641	3.094	2.330	1.548	1.160	0.93	0.774
400	0.892	10.61	5.305	3.525	2.652	1.770	1.328	1.061	0.884
450	1.002	11.95	5.966	3.977	2.983	1.990	1.491	1.193	0.995
500	1.113	13.28	6.630	4.421	3.315	2.211	1.658	1.326	1.105
550	1.225	14.60	7.296	4.866	3.648	2.433	1.824	1.459	1.216
600	1.336	15.92	7.96	5.31	3.98	2.654	1.990	1.592	1.326
650	1.4475	17.26	8.621	5.749	4.320	2.875	2.155	1.726	1.437
700	1.560	18.58	9.280	6.180	4.640	3.095	2.321	1.858	1.548
750	1.6705	19.90	9.946	6.619	4.982	3.318	2.488	1.991	1.658
800	1.782	21.22	10.61	7.05	5.304	3.539	2.656	2.121	1.768
850	1.893	22.56	11.271	7.50	5.635	3.760	2.819	2.254	1.879

1. Inexpensive. The greatest advantage of this vane meter is its low cost. If it is put on the market the whole unit containing 10 feet of six-inch aluminum pipe will cost less than 30 dollars. No other cost is needed in installation, and the only maintenance needed is to change the packing strings when the leaking between the shaft and packing nuts becomes excessive, so the maintenance cost is very small.

2. Convenient to use. The flow rate can be read directly from the dial. From Table 6. the farmer can decide the flow rate needed to cover his field for a certain depth of irrigation water in a twelve-hour pumping period.

3. Accurate. From the experiments, this vane meter has a ± 2.24 percent accuracy which can be compared with that of high-priced commercial irrigation meters. Its accuracy is higher than that of the other devices commonly used to measure irrigation water. For example, a standard weir has an accuracy of ± 5 percent. If absolute method (weighing) is used in calibration a higher than ± 2.24 percent accuracy can be obtained.

4. All around usage. This vane meter can be used in sprinkler irrigation systems or systems using gated pipe or open ditch provided the meter is flowing full.

5. Durable. All the parts of this vane meter are made of solid metal and will not wear appreciably in service.

These advantages lead to a conclusion that this vane meter can be easily popularized, and the popularization of this vane meter will be an aid in making better use of irrigation and increasing the irrigation efficiency.

Since 82 percent of irrigation water in Kansas comes from wells and the remainder is pumped from rivers, lakes, and ponds; and the tendency toward more sprinkler irrigation, the vane meter may have more use in Kansas than in other places in United States.

SUGGESTION FOR FURTHER STUDY

The vane type meter which was designed and constructed for this study is not near perfection; however, many improvements can be made to make it a practical flow meter. The following suggestions may be helpful for considering further study:

1. The 10-foot length of pipe used with this vane meter is too long to handle conveniently, especially if it were to be delivered from a factory to the farmers. So it is suggested that the length of whole unit be reduced to five feet in order that it can be conveniently carried in a vehicle. In doing so some accuracy may be sacrificed.

2. Instead of the indicating hand being driven directly by the shaft, the hand may be coupled to the vane shaft by two gears with a ratio of 5:1, so that when the vane and the shaft turn an angle of 60 degrees the hand turns an angle of 300 degrees. The larger scale would then be easier to read. Increased fluctuation from pulsation is likely to be a disadvantage.

3. A cam could be used to transform the unlinear scale to a linear scale.

4. Instead of the present counterweight, a spring might be used as the balancing force so that the meter will not need to be in the absolute level position.

5. Use a spring as balancing force on one end of vane shaft, and on the other end use a magnet to turn a magnetic indicating hand which is

located outside of pipe. This arrangement would enclose all the moving parts on the pipe and would make the meter absolutely water-tight, and reduce losses from friction.

6. Design and build vane meters for 4-inch, 8-inch, and 10-inch pipes and calibrate by weighing the water flow.

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INVESTIGATION OF AN INEXPENSIVE WATER METER
FOR IRRIGATION SYSTEMS

by

YII-SOONG TSAO

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There is urgent need for an inexpensive and yet an accurate method for measuring and distributing irrigation water in irrigation systems. A water measuring device is necessary in modern agriculture to assure optimum efficiency of irrigation and to avoid excessive waste or under-irrigation.

Although there are many kinds of fluid flow measuring devices and meters on the market, most of them are designed for industrial uses. Some commercial meters are said to be designed for irrigation but they are not as accurate as claimed by the manufacturer; and due to the high expense involved, most farmers object to purchasing them.

It was the purpose of this study to develop, design, construct, and test an inexpensive device for measuring irrigation water. A vane meter was designed for this purpose, since it appears to be adaptable for flow measurement in irrigation systems.

The construction of this vane meter was rather simple. It contains a vane, a shaft, a counterweight, and a dial with an indicating hand. The entire unit was built into a ten-foot section of six-inch aluminum pipe.

The difference of force caused by the impact of the flowing water upon the lower-side of the vane (which has a larger area than the upper-side vane) and the upper-side of vane deflects the vane, counterweight, and the indicating hand from what would be its undisturbed position. The angle of deflection indicated by the hand was thus a measure of the water velocity, and hence, a measure of the rate of discharge.

After the vane water meter was built, it was calibrated with a four-inch square-edged orifice on six-inch aluminum pipe and a commercial "Measure-Rite" irrigation meter in a range from 100 G.P.M. to 1,000 G.P.M..

The results of the calibration showed that the relation between the angle of deflection and discharge was a complex S-shaped curve which is different from that obtained from the theory. For practical purposes, the results were considered satisfactory. It was concluded that the vane type meter is a very promising device for measuring irrigation water.

Several distinct advantages were found as follows:

1. Inexpensive: It can be put into the market at a price probably less than 30 dollars. No installation cost and very little maintenance is needed.

2. Convenient to use: The rate of flow is shown directly on the dial.

3. High accuracy: From the experiments it was learned that a vane meter of this type has an accuracy of ± 2.24 percent which is considered at least as good as a high-priced irrigation meter.

4. Can be used in sprinkler irrigation systems.

5. Durable.

It was concluded that this vane meter is the type of water meter which every farmer could afford and operate and still meet the requirements of a good irrigation water meter. Therefore, this vane meter can be easily popularized.

There are many improvements needed on the present design in order to make it completely satisfactory for indicating rate of flow of irrigation water.