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THE SALT VELOCITY METHOD OF WATER MEASUREMENT

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This paper describes a new method of water measurement called the Salt Velocity Method. The authors outline the theory and development of the method, describe the apparatus and methods of computation used in laboratory and field tests, give an account of several commercial tests, and present for discussion the claims of the method for a high degree of accuracy and reliability.

INTRODUCTION

DURING the past few years the engineering societies and the technical journals have published many articles and discussions on the measurement of water power and on the design, tests, and efficiency of water wheels and settings. But very little has been published recently dealing with the measurement of water in flumes, pipes, and penstocks, and particularly with the reliability and accuracy of various methods and their applicability to the field testing of modern or recently designed water-power units.

2 The most accurate known method of measuring water is by weighing, but this method is limited to comparatively small quantities. Other methods which have been used with varying degrees of accuracy are floats, weir, current meter, pitot tube, venturi meter, color velocity, moving screen, chemical method, and the Gibson method.

3 Measuring water by means of floats in the canal is sometimes done, but conditions are seldom found where accurate results can be obtained by this method.

4 The weir, properly designed and used, will indicate the dis-

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charge within one or two per cent of the true quantity, but on account of loss of head and construction costs and the difficulties in obtaining uniform velocities of approach, the weir is usually not practical. If a weir can be calibrated by another more accurate method, as is sometimes possible in laboratories, it then becomes as accurate as the check method.

5 The current meter can be used in open channels of some power plants, preferably in the forebay and in the tailrace only when quiet water conditions prevail. If water conditions are good and the meter is properly rated and used, it should give results well within commercial requirements.

6 The pitot tube in various forms can usually be used at a reasonable cost in wood or steel penstocks. The pitometer, which consists of a pair of pitot tubes and is capable of being reversed, is an accurate and convenient form of this instrument.

7 The venturi meter is accurate, but unless the meter has already been installed, its cost would prohibit the installation for tests alone.

8 The color velocity method is only applicable to fairly long pipe lines. It appears to be very accurate, but up to date comparatively few tests have been made with this method, and as yet no means of recording graphically the passage of the color are available.

9 The moving screen, although very accurate, is applicable to permanent laboratory installations only and has been rarely used in the United States.

10 As so far developed, the chemical method with salt solution is very accurate when properly used, but it is relatively expensive.

11 The Gibson method is a very accurate method in penstocks of considerable length.

12 For many power plants, and particularly the recently designed low-head plants with short concrete penstocks of varying cross-section, all of the above methods are too expensive or too inaccurate, and none of them are universally recognized as a standard for field testing. All of them possess inherent disadvantages under the various conditions present in commercial tests. For some time a growing need has been felt for a simple and accurate method of measuring water under the above conditions and the salt velocity method has been developed to meet those conditions, as well as the conditions found in long penstocks.

Theory

13 The salt velocity method of water measurement is based on the fact that salt in solution increases the electrical conductivity of water. Salt solution is introduced near the upper end of the conduit, and the passage of the solution across one or more pairs of electrodes, at other points in the conduit, is recorded graphically

by electrical recording instruments. The passage of the salt solution between two points is accurately timed, and the volume of the penstock between the same points is accurately determined. The discharge in cubic feet per second equals the volume in cubic feet divided by the time in seconds.

Historical

14 So far as is known by the authors, no successful application of this method of measuring water has ever been made previous to 1921. Early in that year the development of this method was commenced with laboratory tests at the Worcester Polytechnic Institute. In September, 1921, the first commercial tests were made on two units of a power plant. In 1922 the authors conducted extensive investigations at the Alden Hydraulic Laboratory of the Worcester Polytechnic Institute, and at the power plant of the Laurentide Power Company, at Grand Mere, Quebec. In the fall of that year ten successful commercial tests were made. Both the laboratory investigations and the commercial tests have been continued in 1923.

Sections of Paper

15 This paper is divided into six sections, each section covering a certain period of time and a certain group of tests as follows:

I 1921 Laboratory Investigations
II 1921 Commercial Tests
III 1922 Laboratory Investigations
IV 1922 Field Investigations
V 1922 Commercial Tests
VI 1923 Laboratory Investigations

16 Each group of investigations had a common objective, i.e. the determination of the accuracy and reliability of this method of water measurement. But in each group different plants, apparatus, or methods of testing were used, and each group had its own objective independent of the common object. The six groups or sections marked six distinct steps in the development of the method to its present state.

I — 1921 LABORATORY INVESTIGATIONS

Object

17 The object of these tests was to investigate the practical possibilities of the salt velocity method. By visualizing an infinite number of floats equally distributed over the cross-section of the conduit, with each little float recording its own velocity and the whole group automatically recording a composite picture of velocities, the theoretical possibilities of this method can be readily understood.

Plant

18 The plant used for these first tests was Plant No. 1 of the Alden Hydraulic Laboratory of the Worcester Polytechnic Institute, Worcester, Mass. Fig. 1 shows the layout of this plant. The water supply is from two ponds with a combined area of 200 acres, and a constant head can be maintained for long periods. A total fall of 35 ft. is available.

19 The penstock is a riveted steel pipe about 450 ft. long. From the pond to within ten feet of the laboratory the diameter of the pipe is 40 in. In the laboratory are a 36-in. by 16-in. venturi

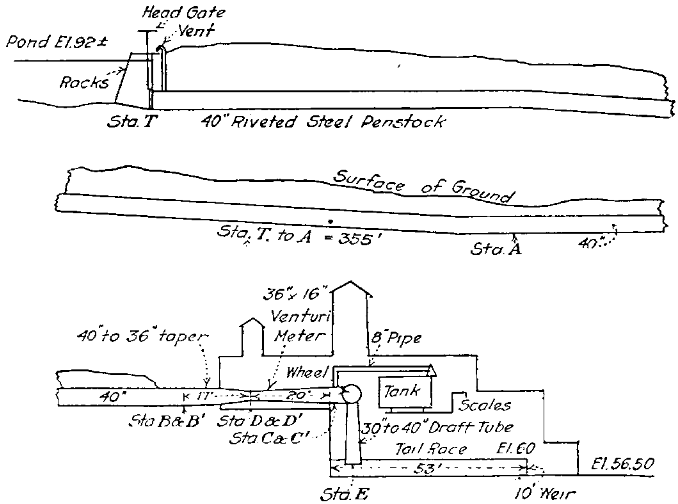

Fig. 1 Sketch of Alden Hydraulic Laboratory and Penstock, Worcester Polytechnic Institute

meter, an 18-in. horizontal water wheel with cylindrical case, and a conical vertical draft tube discharging into a tailrace at the lower end of which is a 10-ft. standard sharp-crested weir with end contractions.

Apparatus and Methods

20 In these tests, as in all subsequent tests, the apparatus in general consisted of a salt injector and electrodes in the penstock together with signaling and timing devices.

21 *Salt Introduction.* In the very first tests raw salt was introduced into the penstock, the operator punched the stop watch and then ran down the road to the laboratory where an ammeter

was connected to the electrodes, and the operator again punched the watch on deflection of the meter needle.

22 The first improvement in the introduction of salt was a closed metal box containing a charge of salt which was lowered to the mouth of the penstock by a pole. The charge of salt was released when the hinged sides of the box were raised by wires operated from a platform over the head gate. Raw salt or solution was also placed in paper bags tied to a pole, and when lowered to

FIG. 2 HEAD GATE, MOUTH OF PENSTOCK AND 2-IN. QUICK-ACTING VALVE

proper position the bags were broken by a sudden motion of the pole.

23 Later, salt was injected in a solution piped from an elevated mixing tank over the head gate. A 2-in. pipe led to a quick-acting valve, operated by a rod from the surface platform. The valve was fitted with a vertical deflecting plate and scavenging tubes and was placed facing downstream in the plane of the penstock entrance. The strength of the charge could be varied by changing the degree of saturation of the solution or by throttling at a slow-motion valve in the feed pipe. Fig. 2 shows the head gate, pipe, and valve.

24 *Electrodes.* The first pair of electrodes used were thin strips of copper, 38 in. long and 2 in. wide, spaced 2 in. apart by wooden blocks. These electrodes were placed in a horizontal position across the center of the pipe and held in place by wooden wedges. A similarly constructed electrode 6 in. long was used for traversing the pipe. This electrode was fastened to a rod passing out of the pipe through a stuffing box and could be held at any position along the diameter of the pipe. Usually during a traverse this small electrode would be held in ten different positions.

25 Later, several electrodes were made of thin copper strips $\frac{3}{4}$ in. wide and 4 in. long, spaced $\frac{3}{16}$ in. apart. These electrodes were attached to short pitometer rods, rubber-covered wires being substituted for the original pitot tubes. The rods were packed and then screwed to nipples in front of gate valves. This form of electrode could be placed in any position across the pipe, rotated to free itself from debris, or withdrawn entirely. Fig. 3 shows a 6-in. and a traversing electrode.

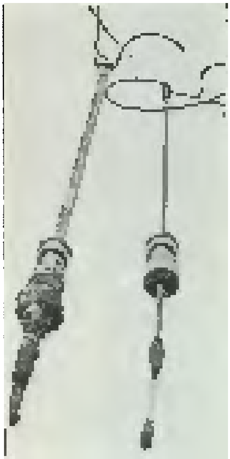

Fig. 3 Electrodes Used in Laboratory, 1921

26 *Meters.* All electrodes were connected by wires and switches to the indicating meters. In 1921 only indicating voltmeters and ammeters were used to record the current between the electrodes. Direct current at 110 volts was used on the circuits.

27 *Timing.* Soon after the first few tests had been made, a telephone line between the pond and laboratory replaced the running operator. The stop watches were then started by the operator at the laboratory on verbal signal from the pond operator, and the time was observed at various stages of the needle deflection. As a rule, two watches were used. The first watch was stopped on the initial appearance of the salt, the second watch at final appearance, and the intermediate stages were observed by metronome with the second watch running.

28 *Standard of Measurement.* The standard of measurement used in these tests was the 10-ft. weir at the lower end of the laboratory. Two hook gages in isolated stilling boxes at either side of the tailrace indicated the heads on the weir. The zero point on these gages and the level of the weir were frequently tested.

29 *Number of Tests.* Including trials, about 400 charges of salt solution (one charge called a "shot") were used in these tests, which were grouped into 30 runs of from 10 to 20 shots at each gate opening. Runs at each gate opening were repeated six to eight times.

Computations

30 During the 1921 series of laboratory tests, the computation of the discharge by the salt velocity method for comparison with the quantity indicated by the weir was made by three different methods:

1 The time was computed from the moment of salt introduction to the initial appearance of the salt at the electrodes, i.e., the beginning of the curve, and a coefficient 1.095 was computed to give the true Q. This coefficient remained constant for all gate openings and velocities.

2 The time was computed from the moment of salt introduction to the point of mean time between the initial and final appearance of the salt at the electrodes, i.e., half-way between the beginning and end of the curve, and coeffi-

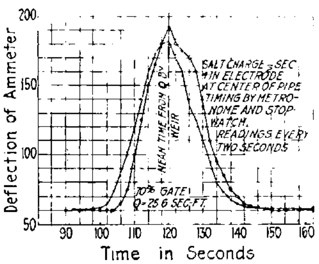

Fig. 4

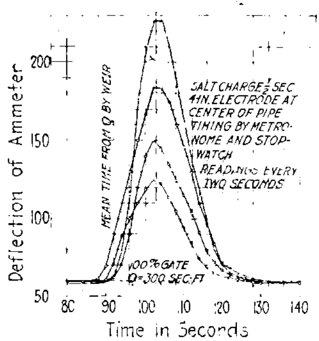

Fig. 5

Sample Curves from Tests on 40-in. Pipe, 355 Ft. Long

cients were computed to give the true Q. These coefficients varied and no constant could be established.

3 The time was computed from the moment of salt introduction to the moment of maximum density of the salt solution passing the electrodes, i.e., the point of maximum deflection of the needle or the peak of the curve, and a coefficient was computed to yield the true Q by weir. This coefficient was approximately 1.00 (averaged 0.9975).

31 The length and diameters of the section of pipe used were carefully measured and the volume of the section computed. Then

$$\frac{\text{Vol. (cu. ft.)}}{\text{Time (sec.)}} = Q \text{ (cu. ft. per sec.)}$$

32 The quantity by weir was computed by the Francis formula, namely, $Q = 3.33\ (b - 0.2h)h^{3/2}$. The heads over the weir crest varied from six inches to one foot.

Results

33 The results of computations by each of the foregoing methods are given in Tables 1 and 2. The series of tests in Table 1 were all made by injecting solid salt through the metal box. This table was taken from a thesis by Messrs. Bijur and Scanlan of the class of 1921, Worcester Polytechnic Institute.

TABLE 1 RESULTS COMPUTED FROM TIME OF INITIAL APPEARANCE OF SALT AND FROM MEAN OF TOTAL APPEARANCE

Q by weir, second-feet	Q computed, 1.095 × initial time	Variations, per cent	Q computed, 0.865 × mean time	Variations, per cent	Q computed, 0.900 × mean time	Variations, per cent
6.4	6.4	0.0	7.3	+ 14.1	7.0	+ 9.4
13.6	13.4	− 1.5	13.7	+ 0.7	13.2	− 2.9
18.1	18.3	+ 1.1	18.1	0.0	17.4	− 3.9
21.4	21.4	0.0	21.4	0.0	20.6	− 3.7
26.3	26.5	+ 0.8	26.3	0.0	25.3	− 3.8
32.0	32.0	0.0	30.6	− 4.4	29.6	− 7.5
35.6	35.7	+ 0.3	32.6	− 8.4	31.4	− 11.8
21.8	21.8	0.0	23.4	+ 7.3	22.5	+ 3.2
24.9	24.9	0.0	26.6	+ 6.8	25.6	+ 2.8
29.9	29.9	0.0	31.8	+ 6.4	30.6	+ 2.3
31.6	31.3	− 1.0	Traverse			
32.0	32.0	0.0	33.3	+ 4.1	32.0	0.0

TABLE 2 RESULTS COMPUTED FROM TIME OF MAXIMUM DENSITY OF SALT

Solid Salt or Solution in Paper Bags

Gate opening, per cent	Q by weir	Coefficient = Max. time by salt / True time by weir
20	13.4	1.008
40	18.8	1.002
60	22.8	0.994
100	29.2	1.000
	Avg.	1.001

Salt Solution Through Pipe and Valve

Gate opening, per cent	Q by weir	Coefficient = Max. time by salt / True time by weir
40	18.3	0.998
40	18.2	0.989
20	14.4	0.989
40	19.6	0.999
60	23.9	0.995
80	27.3	0.999
100	28.9	1.005
80	27.6	0.998
30	17.6	0.995
50	22.3	0.998
80	27.4	1.002
30	16.9	0.990
50	21.8	0.990
70	25.6	1.000
100	30.0	1.001
	Avg.	0.997

34 Figs. 4 and 5 show curves with the meter deflection plotted on time in seconds. Fig. 6 shows a curve of true time, as determined by the weir, plotted on discharge, with the results by the salt velocity method spotted in circles and crosses. Fig. 7 shows curves illustrating the percentage of the true Q (by weir) obtained by computing the salt velocity results, using the time of initial appearance of the salt, the mean between the initial and final appearance, and the time of maximum density of the salt. During the tests the interior of the pipe was cleaned, and the results are shown both before and after cleaning.

Conclusions

35 These first laboratory tests showed conclusively that the tests could be made and repeated indefinitely with consistent results. It showed an apparently constant relation between the initial appearance of the salt at the electrodes and the time of maximum density of the salt passing the electrodes. When properly computed the discharge by the salt velocity method checked the true Q by weir within about one per cent for single runs, and much closer for a long series of runs.

36 Prior to and during these laboratory tests on salt velocity a number of tests were made by the color velocity method. A strong solution of a red aniline dye was enclosed in paper bags which were broken at the penstock entrance, and stop watches were used for timing. At the lower end of the penstock an open-ended 2-in. glass pipe was used to observe the appearance of the color. This glass was arranged with a white background. By taking the *mean* time between the initial and final appearance of the color the results checked very closely with the results by salt velocity. (See Fig. 6.)

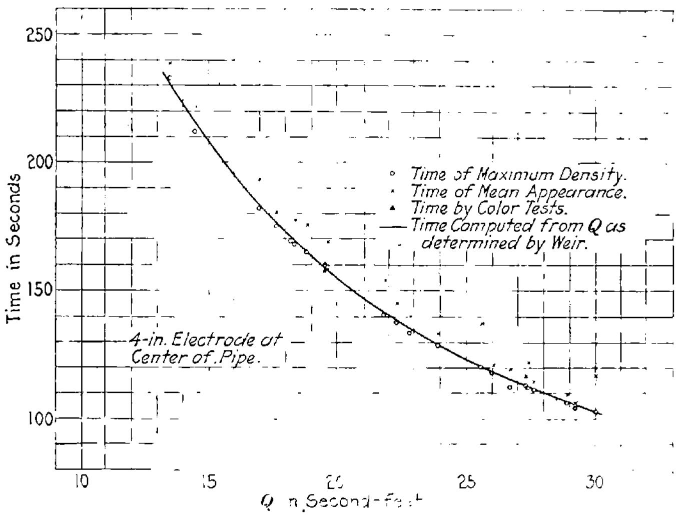

Fig. 6 Curve of Tests on 40-in. Pipe. True Time as Determined by Weir

37 The reason why the *mean* time gave accurate results by color but not by salt was because with color the eye cannot detect the color when well diluted with penstock water. If a curve of the real color appearance could be made, the portion of the curve visible to the eye would be approximately the upper third only,

and this portion of the curve is symmetrical. With salt the whole curve is visible and the two ends are usually not symmetrical.

II — 1921 COMMERCIAL TESTS

38 In September, 1921, tests were made of two hydroelectric units in New Hampshire. The object of these tests was to determine the discharge of each unit at various gate openings. Each unit tested had a penstock of 13-ft. wood-stave pipe 1400 ft. long.

Apparatus and Methods

39 *Salt Introduction.* A few tests were made by introducing raw salt in paper bags as in the first laboratory tests, but the

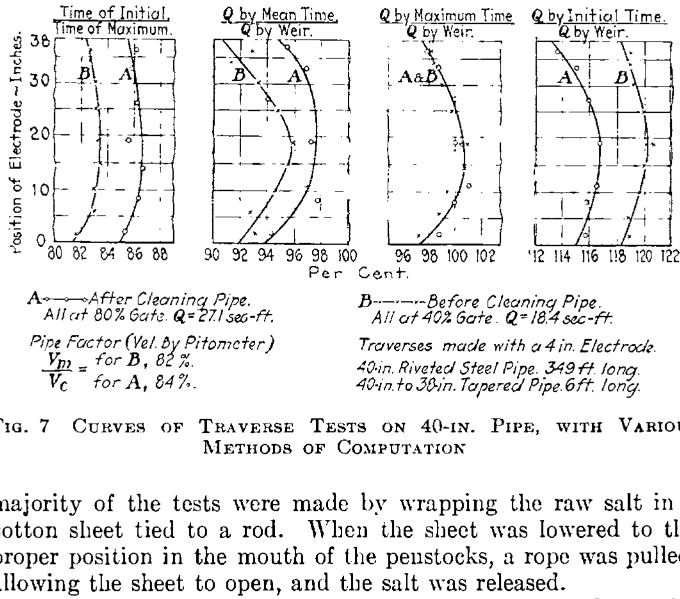

Fig. 7 Curves of Traverse Tests on 40-in. Pipe, with Various Methods of Computation

majority of the tests were made by wrapping the raw salt in a cotton sheet tied to a rod. When the sheet was lowered to the proper position in the mouth of the penstocks, a rope was pulled, allowing the sheet to open, and the salt was released.

40 *Electrodes.* The electrodes, made of thin copper plates 1 in. by 16 in. spaced $\frac{1}{4}$ in. apart, were fastened to an insulated wooden plug driven into a $1\frac{1}{4}$-in. pipe which was inserted in the penstock through a stuffing box. This electrode was located at one-third the diameter in the pipe. An indicating ammeter was used to indicate the passage of the salt across the electrode.

41 *Timing.* The operators at the salt station and at the meter were connected by telephone, and as the first operator released the salt, he signaled the second operator, who started three stop watches simultaneously.

42 By carefully watching the meter needle, one watch was stopped at the initial appearance of the salt, the second watch at

the maximum deflection of the needle, and the third watch was stopped at the completion of the passage, when the needle returned to normal position. The watches were calibrated before, during, and after the tests.

43 *Standard of Measurement.* No accurate standard of measurement was used for comparison during the tests, but after the tests two current meters were used and two tests made at the same gate opening, 70 per cent.

44 *Computations.* All times were computed from the moment

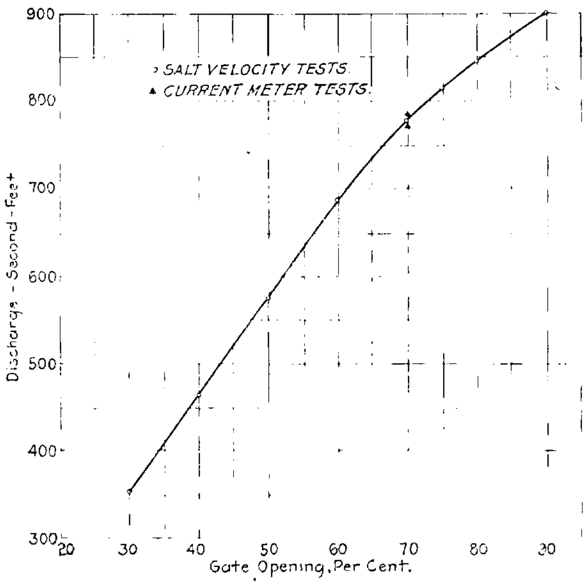

FIG. 8 CURVE OF DISCHARGE OF 13-FT. WOOD-STAVE PIPE, 1400 FT. LONG, UNDER 66 FT. HEAD

of salt introduction, i.e., from the release of the salt charge to the moment of maximum density of the salt solution passing the electrode, i.e., the maximum deflection of the meter needle.

RESULTS

45 The results of these tests were very satisfactory. The work was easily done with very simple apparatus. By reducing to a common head and plotting the discharge against gate opening, smooth curves were the result.

46 Fig. 8 shows a curve of discharge on gate opening. This curve passes through every test point. The two check tests by

current meter are shown at 70 per cent gate, and the salt velocity curve passes midway between them. These two current-meter tests varied from each other by 2 per cent.

Conclusions

47 These tests confirmed the results of the laboratory tests and showed that the salt velocity method of water measurement was applicable to power plants with long penstocks of uniform diameter.

III — 1922 LABORATORY INVESTIGATIONS

48 After learning of the development of the salt velocity method during 1921, Mr. John Riddile, Chief Engineer for the Laurentide Power Company of Grand Mere, Quebec, was convinced of the possibilities of the method for testing their units. During 1922 an extensive series of investigations was conducted for that company.

Object

49 Up to then the method had been used only on pipes of uniform diameter. This company's power house has short, rectangular, converging penstocks, and the object of this series of tests was to determine the accuracy and applicability of the salt velocity method of water measurement to that type of penstock.

Apparatus and Methods

50 *Plant.* These tests were conducted at the Worcester Polytechnic Institute Laboratory, but instead of using the 40-in. pipe all the time as in 1921, a majority of the tests were made on the pipe line below the 40-in. section, i.e., through the converging portion of the penstock, through the venturi meter, and through the wheel and draft tube. Fig. 9 shows the 36-in. by 16-in. venturi meter.

51 *Salt Introduction.* A few tests were made introducing salt at the pond with the same elevated salt-mixing tank, pipe, and quick-acting valve as were used in the 1921 tests. The remaining tests were made by introducing salt just below the lower end of the 40-in. section of penstock. This point was station B. (See Fig. 1.) The apparatus installed here consisted of an elevated 100-gal. mixing tank piped to a 15-gal. pressure tank, which in turn was piped to the penstock by $\frac{3}{4}$-in. hose and pipe. An air pipe from a pump and storage tank in the laboratory was connected to the pressure tank. Air pressure up to 60 lb. was available. Besides the air pipe and the feed pipe, the pressure tank was also fitted with screens, an inlet pipe, a waste pipe, an air vent, and a pressure gage.

52 Slow-motion valves were placed on all connections, and on

the discharge pipe a $\frac{3}{4}$-in. quick-acting valve was placed near the penstock. The brass distribution pipe was inserted into the penstock through a stuffing box. Various ways of discharging the brine from the pipe were tried: a $\frac{3}{4}$-in. open end; a $\frac{1}{4}$-in. open end; two $\frac{1}{4}$-in. holes at the center of the pipe; and 18 holes of graded sizes extending on both sides of the pipe. These holes were arranged so as to discharge vertically. This form of distribution was called a "perforated introduction." During the latter portion of these tests a $\frac{3}{4}$-in. pop valve was attached to the end of the pipe for the introduction of salt at station B. This pop valve opened and closed under pressure from the feed pipe, which was controlled by the quick-acting valve.

53 *Electrodes.* Various electrodes were used. A double-helix electrode 4 in. long was made of copper wire wound around a $\frac{3}{4}$-in.

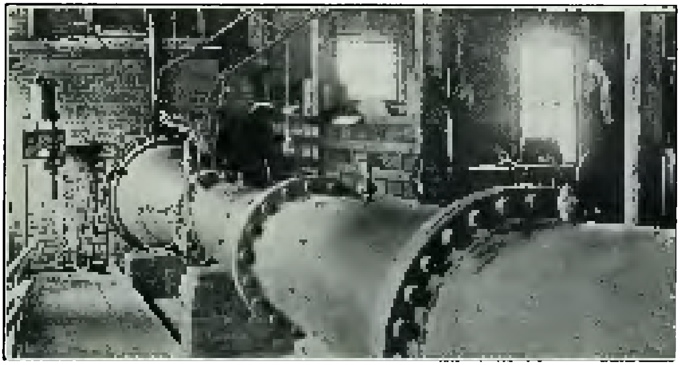

Fig. 9 36 x 16-in. Venturi Meter at Alden Laboratory

wooden plug fitted into the end of a $\frac{3}{4}$-in. pipe. Plate electrodes were made of strips of copper $\frac{1}{16}$ in. thick and 1 in. wide, and from 1 in. to 8 in. long, with spacings of from $\frac{1}{8}$ in. to $\frac{1}{4}$ in. between strips. All of these electrodes were fastened to pitometer rods and could be adjusted through stuffing boxes at any distance along the diameter of the pipe. This form of electrode is shown in Fig. 3. Other electrodes were made of 1-in. brass pipe, placed parallel, extending across the penstock and fastened to the walls by wooden insulating wedges. These pipes were spaced $\frac{3}{4}$ in. apart.

54 In connection with these pipe electrodes was an electrode called a "saddle." This was a strip of $\frac{1}{16}$-in. copper, 1 in. wide and 6 in. long, fastened to and insulated from the center of the upper brass pipe with a $\frac{1}{4}$-in. space between.

55 *Meters.* The electrodes were wired to a portable Bristol direct-current recording ammeter. This instrument had two meters with a capacity of three amperes each. Direct current at

110 volts was used. The roll of paper, or chart, for this meter was motor driven.

56 The passage of the brine by the different electrodes was recorded on the chart by two pens, each actuated by its own meter. The salt introduction was recorded by means of a snap switch at station T (Fig. 1), which was operated by hand simultaneously with the opening and closing of the introduction valve. At station B an automatic contact switch was placed on the handle of the introduction valve. These switches were wired to the ammeters with lamps in series for resistance, recording the time and duration of the introduction of the salt by either one of the pens, just mentioned, on the same chart.

57 *Timing.* A standard seconds-pendulum clock was wired to the ammeter, and by means of a magnet and relay recorded seconds by a separate pen (a third pen) on the same chart. For convenience in counting seconds, a break occurred every minute, at which time the pen missed two seconds records.

58 *Standard of Measurement.* The standard for the water measurement was the 10-ft. weir. The venturi meter was frequently used for check measurements.

Description of Tests

59 The general arrangement for these tests was an observer and operator at the laboratory who arranged the electrodes, operated the motor, ammeter, and switches, and took readings on the weir and venturi meter. This observer was connected by telephone to an operator at station T when salt was introduced at the pond. This second operator prepared the brine and operated the salt valve and the introduction-signal switch. When salt was introduced at station B, near the laboratory, the operators were near enough to talk. If a third operator was present, he prepared the brine, connected the air pressure, and read the gages for weir and venturi meter.

60 All tests were numbered, and the necessary notes and data were recorded on the chart. In later tests these data were recorded on data sheets, Table 3 being a sample sheet prepared for the early tests.

61 Including trials, about 1200 individual tests or charges of salt solution were used, which were grouped into 60 runs, and these in turn were segregated into 13 groups based on the stations used for the salt introduction and for electrodes. Sample charts illustrating the curves obtained from the various introduction and electrode stations are presented in Figs. 10 and 11. These curves show methods of computation, give comparison of results by salt and by weir, and will be discussed in detail later.

Computations

62 The volumes of the penstock between various stations were computed from surveys.

63 As in 1921, the study of the problem of what point on the curve to use in computing was continued. While recognizing the theoretically correct center of gravity of the curve, the exact determination of that point was still too difficult and required too much time for practical use.

64 The curves made on long sections of pipe continued to be

TABLE 3 SAMPLE DATA SHEET OF SALT VELOCITY TESTS

(Laboratory Investigations, 1922)

Length of steel pipe used {A = 275.85 ft., B = 355.20 ft.} Size, 40 in. Volume {A = 2407, B = 3096}

Run No.	Test No.	Sec. shot	Time of day	Weir	Q Venturi meter	Seconds, T to A, test	Seconds, T to A, average	Seconds, T to B, test	Seconds, T to B, average	Q, cu. ft. per sec. Weir is 100%	Remarks for all runs
	19	1	7/4/22	21.94	....	111.9		140.1		A = 21.58	Salt from tank
	20	½				111.1	111.58	140.9	141.2	−1.6%	at pond
4	21	1				112.7	Q =	141.7	Q =		
	22	2				110.8	21.58	141.7	21.92	B = 21.92	6-in. electrode
	23	2				111.4		141.4		−0.1%	at A and 12-in. in pipe
	24	1	7/4/22	22.05	....	109.1		140.0		A = 21.96	6-in. electrode
	25	2				109.8	109.56	142.0	140.22	−0.4%	at B and
5	26	2				111.7	Q =	140.4	Q =		12-in. in pipe
	27	3				109.3	21.96	138.4	22.08	B = 22.08	
	28	5				106.9		140.3		+0.1%	110-volt direct current
	29	1	7/13/22 4:30 P.M.	18.10	....	136.0		170.0		A = 17.84	
	30	2				133.0	134.20	170.9	170.92	−1.4%	
6	31	2				133.2	Q =	170.7	Q =		Salt introduced
	32	2				134.3	17.84	171.8	18.12	B = 18.12	through 2-in.
	33	3				134.3		171.2		+0.1%	pipe and 2-in. quick-acting valve
	34	1	7/15/22 5:00 P.M.	20.34	20.50	113.9		153.9		A = 20.72	
	35	1				115.7	116.08	155.8	153.38	+1.9%	
	36	2				115.8	Q =	153.4	Q =		
7	37	2				115.6	20.72	153.3	20.19	B = 20.19	
	38	2				117.4		152.0		−0.7%	
	39	2				118.1		151.9			
	40	2	7/15/22 5:40 P.M.	20.08	20.19	117.7	117.00	153.4	154.00	A = 20.57	
8	41	2				115.9	Q =	152.7	Q =	+2.4%	
	42	3				117.7	20.57	155.4	20.10	B = 20.10	
	43	3				116.7		154.5		+0.1%	

Average percentage for sheet, 5 runs, at A = + 0.2 per cent and at B = − 0.2 per cent.

symmetrical and the peaks were used with very uniform and accurate results. The curves made when salt was introduced at station B and when a short section of pipe with a varying cross-section was used were not symmetrical. For these curves a few centers of gravity were accurately determined, and for all the remainder the centers of gravity were determined by eye, with fairly uniform and accurate results. For the introduction curves, the point for timing was always taken half-way between the opening and closing of the salt introduction valve.

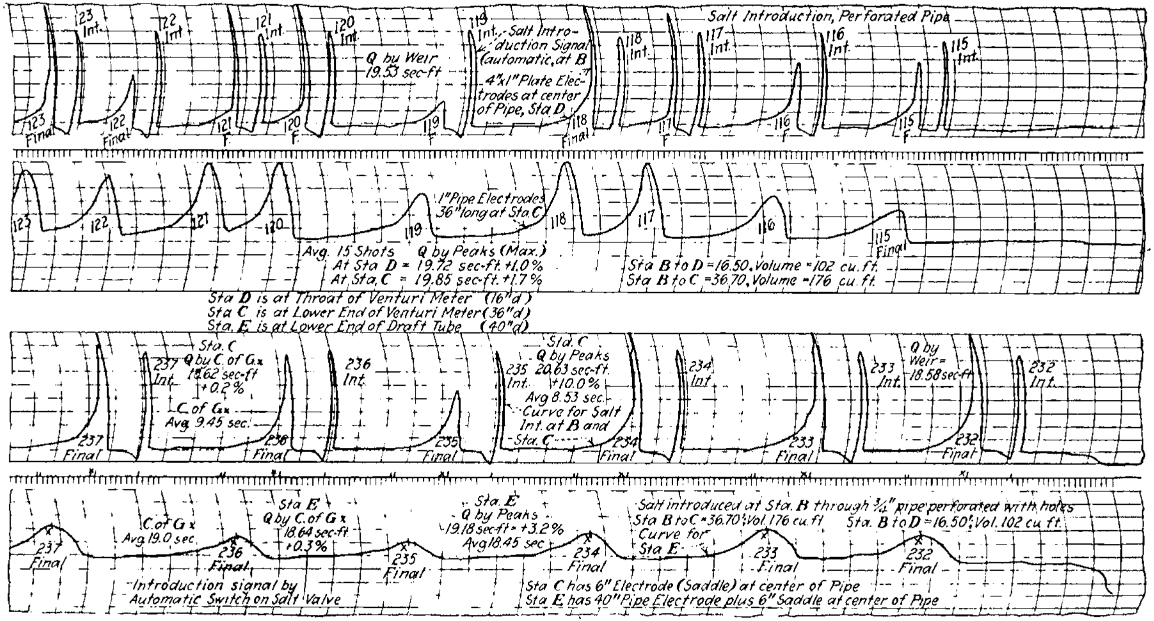

Fig. 10 Sample Curves, Tests on 40-in. Pipe with Results of Different Methods of Computation

¶ 65 Sample curves showing the amount of the variation between the maximum deflection or peaks of the curves and the center of gravity of symmetrical and distorted curves are shown in Fig. 12.

Results

66 A summary of the results of these tests is shown in Table 4.

TABLE 4 SUMMARY OF RESULTS OF SALT VELOCITY TESTS

(Investigations at Worcester, 1922. Computed to peaks of curves)

Group No.	From Station	To Station	Length	Salt at	Electrodes	Position	Runs	Shots	Per Cent + (weir=100%)	Per Cent − (weir=100%)
1	T	A	275.85	T	4" helix (wire)	center	1	2	3.50	....
2	T	A	275.85	T	6" × 1" plates	12" in	7	39	....	0.14
3	T	B	355.20	T	6" × 1" plates	12" in	7	39	0.39	....
4	T	B'	355.95	T	1" pipes, 38" L.	across	3	20	1.55	....
5	T	C	391.90	T	1" pipes, 36" L.	across	3	20	0.13	....
6	B	C	36.70	B	1" pipes, 36" L.	across	9	117	0.33	....
7	B	C	36.70	B	6" × 1" saddle	center	2	20	4.98	....
8	B	D	16.50	B	4" × 1" plates	center	4	48	0.51	....
9	B	D'	17.15	B	4" × 1" plates	center	7	102	....	0.13
10	B	E	59.15	B	1" pipes, 40" L.	across	2	19	0.92	....
11	B	E	59.15	B	6" × 1" saddle	center	5	43	3.38	....
12	B	E	59.15	B	Pipes *and* saddle		4	30	4.79	....
13	T and B to A, C', D and D'		16.50 391.15	T B	1" × 1" plates, traverse positions	10 to 12	5	325	0.42	....
						Totals	59	824		

Omitting groups 1, 7, 11, and 12 (12 runs and 95 shots) on account of electrodes at center of pipe, and averaging the remainder, shows 47 runs and 729 shots; average + 0.32 per cent.

Averages weighted for number of shots. Q by weir = 100 per cent.

A study of this summary shows that averaging 47 runs with a total of 729 shots gave a quantity for water measurements which was 0.32 of 1 per cent in excess of the quantity measured by the

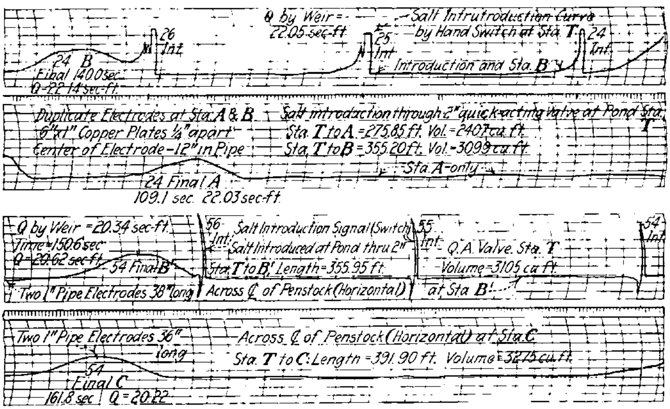

FIG. 11 SAMPLE CURVES, TESTS ON 40-IN. PIPE WITH RESULTS OF DIFFERENT METHODS OF COMPUTATION

weir. Included in these 47 runs are the results with electrodes clear across the pipe, with short electrodes one-quarter to one-third of the diameter into the pipe, with short electrodes in the center of the pipe at the venturi throat and all traverses across the pipe. The runs omitted from these 47 with accurate results are the runs with short electrodes placed at the center of the pipe at all stations except the venturi throat. The results of these latter runs varied

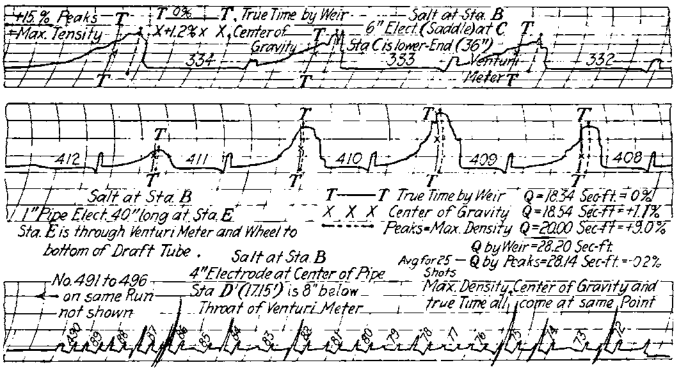

FIG. 12 SAMPLE CURVES, TESTS ON 40-IN. PIPE, SHOWING VARIATION BETWEEN PEAKS AND CENTERS OF GRAVITY OF CURVES

from the true Q by as much as 5 per cent, which is to be expected, since only the fast water at the center of the pipe was measured and all slow water was neglected. (See curves of mean velocities across the pipe which were obtained from the traverses, Figs. 13 and 14.)

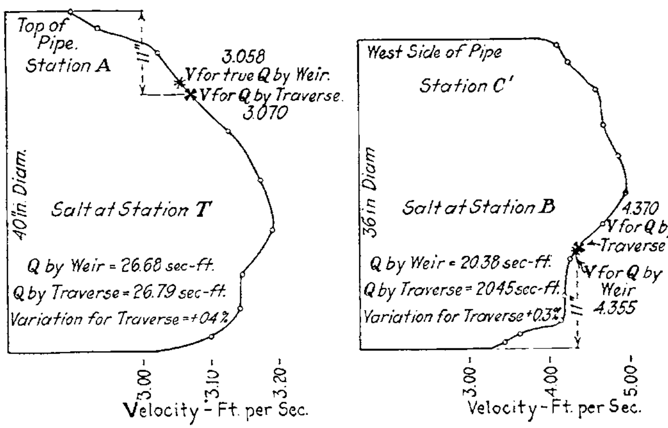

FIG. 13 TRAVERSE CURVES OF AVERAGE VELOCITY FROM SALT VALVE TO ELECTRODES, TESTS ON 40-IN. AND 36-IN. PIPE

67 These traverse curves are not curves of instantaneous velocity at those stations, but are the curves of average velocity from introduction to final electrode. These curves show the effect on Q of using an electrode at the center of the pipe at stations A and C′, and also show that using an electrode at the center at stations D and D′, the throat of the venturi meter, has no appreciable effect. The pipe factor at station D, i.e., the mean

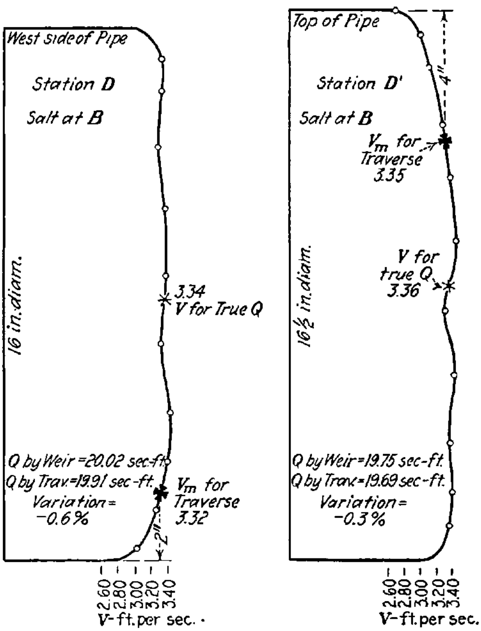

FIG. 14 TRAVERSE CURVES OF AVERAGE VELOCITY FROM SALT VALVE TO ELECTRODES, TESTS ON 40-IN. AND 36-IN. PIPE

velocity divided by the center velocity, is 0.994, while at station A the pipe factor is about 0.86 (using instantaneous velocities).

68 These traverses were made with an electrode 1 in. long held at the various points shown by the small circles, and when Q is computed by the equal-area method it varies from the true Q measured on the weir by less than one per cent in each case.

69 Four students of the class of 1923, Worcester Polytechnic Institute, took the salt velocity method of water measurement for their theses. Messrs. Masten and White used the salt velocity method to calibrate a 12-in. by 6-in. venturi meter and an 8-ft. suppressed weir. Messrs. Dodkin and Metcalf made 21 runs with a total of 205 shots on the 40-in. penstock. They introduced salt

at the pond, station T, and used various forms of electrodes at stations A and B. (See Fig. 1.) With the 10-ft. weir as a standard of measurement, the maximum variation of the discharges computed by the salt velocity method were + 1.10 per cent and − 0.95 per cent, with the total 21 runs averaging + 0.10 of one per cent.

Conclusions

70 These tests showed that the results are accurate and reliable for long sections of penstock, with a short electrode inserted

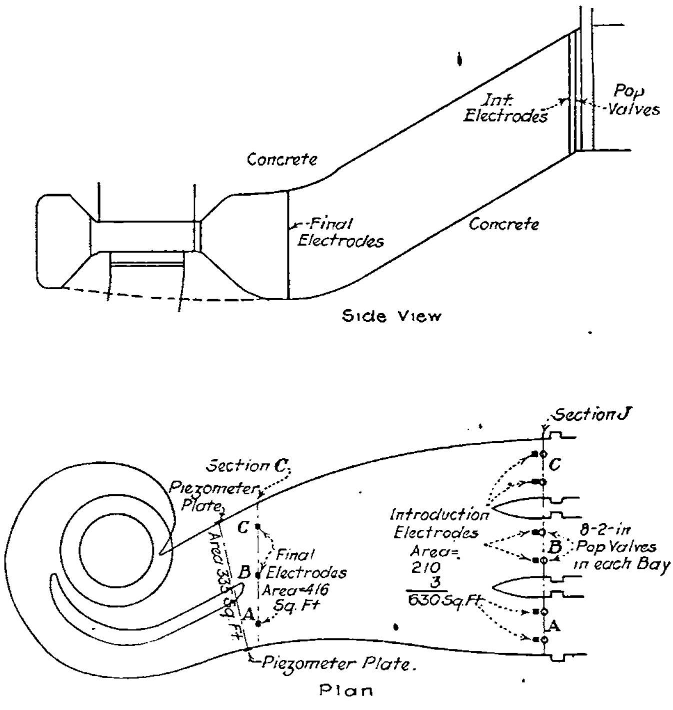

FIG. 15 SKETCH OF LAURENTIDE POWER COMPANY'S PENSTOCK

approximately 25 per cent to 30 per cent of the diameter of the pipe. This exact point can be accurately determined by the traverse. The results are also accurate and reliable for all traverses, and for converging or diverging sections of pipe with proper electrodes at proper points in the pipe.

71 Referring to the summary sheet, Table 4, this matter of results with different electrodes at the same station is shown by comparing group 6 with group 7 and group 10 with group 11.

Group 6 at station C and group 10 at station E are with pipe electrodes clear across the pipe and give variations from true Q of $+ 0.33$ of one per cent and $+ 0.92$ of one per cent, respectively, while group 7 and group 11 with 6-in. electrodes in the center of the pipe at the same stations give variations of $+ 4.98$ per cent and $+ 3.38$ per cent from the true Q by weir. Even the parallel pipe electrodes placed across the penstock favored the fast water in the center, thus accounting for the fact that nearly all variations shown on the summary sheet are plus percentages. An improved electrode to correct this feature was used in the 1923 tests at Worcester.

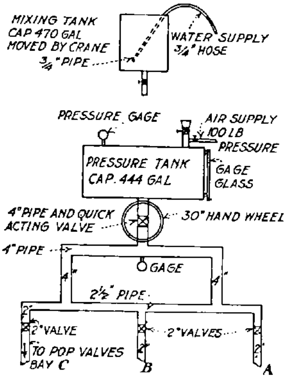

Fig. 16 Sketch of Salt Distribution System

72 The section of the Worcester penstock most nearly approaching the conditions of the Laurentide penstock was from station B to station D or D′, which section includes the upstream end of the venturi meter. This section is 39 in. in diameter at B and 16 in. and 16½ in. in diameter at D and D′, respectively. The traverse curves for D and D′ are nearly straight lines. The center water is only slightly faster than the water on the outside, and an electrode at any point in the pipe at these stations gave very accurate results.

Fig. 17 Apparatus in Gate House, Laurentide Power Company

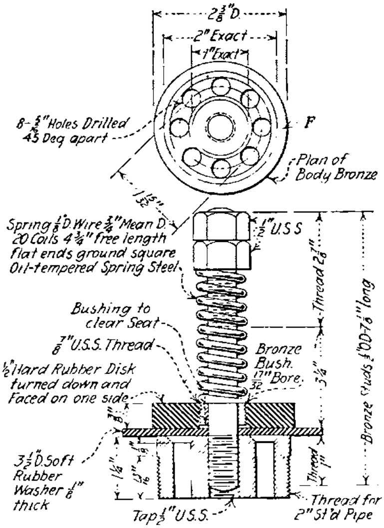

FIG. 18 DETAILS OF POP VALVE

73 The last curve of the sample curves (see Fig. 12) shows some very sharp peaks with no doubt as to their interpretation. These curves were made between stations B and D′ (venturi throat), a distance of 17 ft. The maximum deflection of the peaks and the center of gravity of the curves coincide, and they check with the true quantity as measured by the weir. The average variation for 25 shots was − 0.2 per cent.

74 These 1922 tests at Worcester were so successful and the results were so satisfactory that many doubts concerning the application of the salt velocity method of water measurement to rectangular tapering penstocks were dispelled. These tests were completed and the apparatus in the laboratory was moved to Grand Mere, Quebec, and tests were continued at the power plant of the Laurentide Power Company.

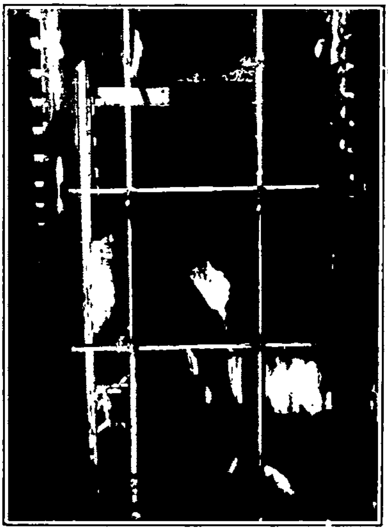

FIG. 19 POP VALVES AND ELECTRODES IN PENSTOCK

IV — 1922 FIELD INVESTIGATIONS

75 Following the laboratory investigations at Worcester in the summer of 1922, field investigations of the salt velocity method of water measurement were made at the power house of the Laurentide Power Co., Ltd., at Grand Mere, Quebec, in October and November, 1922. The object of these tests was to

determine the reliability of the salt velocity method when actually applied to short rectangular tapering penstocks in the field.

Apparatus and Methods

76 *Plant.* Unit No. 7 was used for these investigations. This consists of a 102-in. right-hand water wheel designed by the I. P. Morris Company and built by the Dominion Engineering Works, and connected by a vertical shaft to a generator built by the Canadian Westinghouse Company. The makers' rating of the wheel is 22,000 hp. under 84 ft. head and 120 r.p.m. The penstock is a sloping concrete tube about 65 ft. long, converging from a vertical rectangular cross-section of 630 sq. ft. area at the upper end, to a vertical rectangular cross-section of 335 sq. ft. area at the piezometer plates, which are located at the entrance to the scroll case of the wheel. The upper end of the penstock is divided by concrete piers into three bays of equal area. (See Fig. 15.) In making these tests, from 55 to 57 ft. of penstock (horizontal distance 48 ft.) was used with volumes varying from 27,677 to 28,819 cu. ft.

Fig. 20 Pop Valves in Action under 60 lb. Pressure

77 *Apparatus.* The apparatus used for the salt introduction was installed in the gate house and consisted of a 500-gal. open mixing tank and a 500-gal. pressure tank. The pressure tank was filled by gravity from the mixing tank, which was raised by an overhead traveling crane. A 4-in. pipe led from this pressure tank through a header and equalizer to three $2\frac{1}{2}$-in. leader pipes and three lengths of $2\frac{1}{2}$-in. fire hose, one hose passing into each bay at the upper end of the penstock. Fig. 16 is a diagram and Fig. 17 a photograph showing the arrangement of these tanks and pipes.

78 Each length of hose was connected to eight pop valves of special design located in each bay of the penstock. These 24 pop valves were arranged so as to give a uniform distribution of salt over the entire cross-section. The distribution of brine to the pop valves was controlled by a 4-in. quick-acting valve which had a 30-in. handwheel near the pressure tank. The brine was

also controlled by valves at the upper end of each leader pipe. Figs. 18 and 19 show the details of construction and location of these pop valves. Fig. 20 shows the pop valves in bay C in action while the penstock was emptied. An air pressure of 100 lb. per sq. in. was available for these tests.

FIG. 21 LOWER ELECTRODES A, B, AND C

79 At first, six pairs of small electrodes attached to the distribution pipes and placed about two inches downstream from the pop valves recorded the introduction of the salt at the upper end of the penstock. These electrodes were made of copper plates and had an area of about two square inches each. They were placed parallel to the thread of the penstock and were numbered from 27 to 32, inclusive. Electrodes Nos. 31 and 32 are shown in the photograph of the distribution pipes and pop valves in bay C. (See Fig. 19.) Later in the field tests these electrodes were moved upstream to the plane of the pop-valve faces and were placed at an angle of 45 deg., but retained the same numbers. Still later, larger electrodes were used in the original locations.

FIG. 22 ELECTRODE B

80 Other methods of recording salt introduction were a contact signal placed on the handle of the quick-acting valve and an electric signal operated by water pressure through a gage connected with the distribution pipe in bay C.

81 During the last period of these tests and during the final efficiency tests of unit No. 7, six pairs of electrodes, placed 22 in. downstream from the plane of the pop valves, were used. These electrodes, Nos. 34–39, made of 4-in. by $\frac{1}{2}$-in. steel plate, 10 ft. long, were placed parallel to the thread of the penstock.

82 Three pairs of steel electrodes, placed vertically at the lower end of the penstock and about three feet upstream from the entrance to the scroll case, recorded the passage of the salt at that section. These lower electrodes were made of 4-in. by $\frac{1}{2}$-in. steel plates spaced 1 in. apart by horn fiber insulation and with tie bolts insulated with fiber and rubber. These plates were fastened to, but insulated from, angle irons bolted to the roof and floor of the penstock. These electrodes were continuous, extending from the floor to the roof. The six plates were numbered from 1 to 6 and the three pairs lettered *A*, *B*, and *C*. (See Figs. 21 and 22.)

83 Two pairs of shorter electrodes made of steel plates 3 ft. long were placed 6 in. from the side walls of the penstock and were used during a portion of the tests. These electrodes were lettered *X* and *Y*. These locations are shown in Fig. 29.

84 Other lower electrodes were made by placing 4 x 12 x $\frac{1}{4}$-in. copper strips between the two steel electrodes at 15 points with five on each pair of electrodes, *A*, *B*, and *C*. These copper strips were not in the center of the space, but were $\frac{1}{4}$ in. from one steel and $\frac{1}{2}$ in. from the other steel. They were connected so as to form a pair of electrodes with either or both steel plates, and were numbered from 7 to 21, inclusive. These 15 short electrodes are shown in Figs. 21 and 22.

85 In later tests the fiber insulation was changed to hard rubber and finally to porcelain, and the 15 copper strips were removed, but for the last week of the tests nine of these coppers were replaced. In these last electrodes the small copper plates were placed on the outside of the steel plates instead of between them, as in the early electrodes.

86 Wires with switches connected all of the electrodes to the recording electrical instruments in the gate house. The record was made in three ways: by recording curve-drawing ammeter; by recording curve-drawing wattmeter; and by a special integrating device developed by the engineers of the Laurentide Power Company. A detailed description of this last device will be found in Section VI of this paper. A standard clock was fitted with a magnet and contact point, and was so wired through a relay that the movement of the pendulum recorded seconds on the paper chart. The time record was made by both pen and jump spark.

87 During some of the speed and efficiency runs, an electric revolution counter, connected to the wheel shaft, was located on the testing tables, and through a relay and jump-spark device each revolution was recorded on the same chart. This was checked by an observer, on the counter. Fig. 23 is a wiring diagram, and Fig. 24 is a photograph of the electrical apparatus.

88 Float gages recorded the head- and tail-water elevations. A water column connected to the piezometer plates in the penstock recorded the pressure head at the entrance to the scroll case.

89 During practically all of these tests other records in connec-

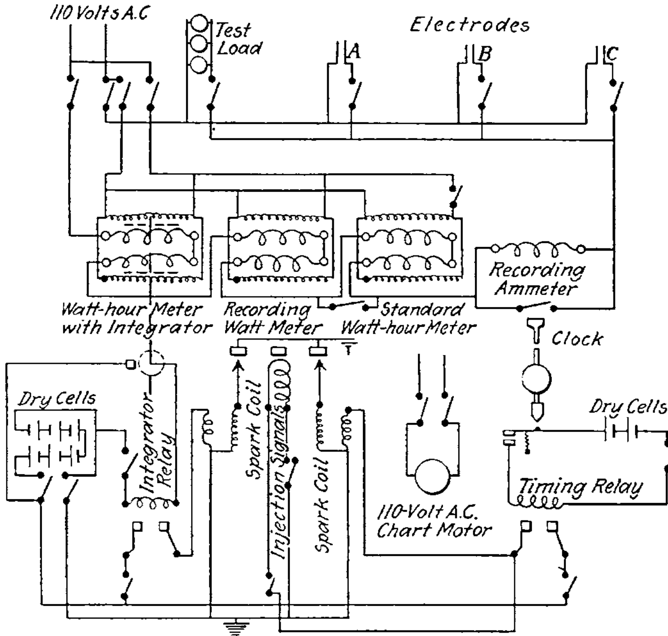

FIG. 23 WIRING DIAGRAM, LAURENTIDE POWER COMPANY TESTS

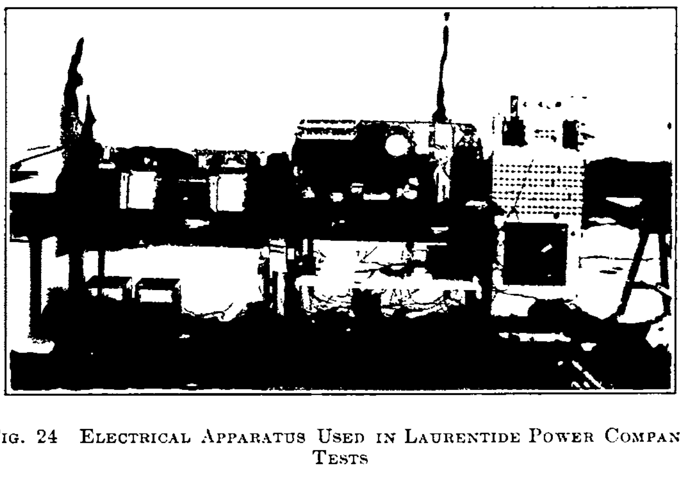

FIG. 24 ELECTRICAL APPARATUS USED IN LAURENTIDE POWER COMPANY TESTS

tion with the unit, such as load, head, and gate opening, were observed and recorded, and during the latter portion of the tests many of the runs were efficiency runs on the water wheel. The electrical load was obtained from an integrating watt-hour meter, and checked by indicating wattmeters located in the generator room of the power house.

Description of Tests

90 During all important tests, observers were stationed at the head- and tail-water gages, at the water column recording pressure

FILE 602

SHEET 1 OF 9 SHEETS

SALT VELOCITY TESTS

C. M. ALLEN, WORCESTER, MASS.

DATA OF TESTS ON Investigations (Field) UNIT NO. 7

MADE BY AT PLANT OF L.P.Co., Grand Mere.Quebec

TESTS MADE FOR Laurentide Power Co., Quebec DATE 11/10/22

LENGTH Conc.Penstock USED 57 ft. SIZE As is VOLUME 28691c.f. R.P.M. 125

Run No.	Test No.	Gate %	Time of Day	Heads			Electrodes		Seconds		Q cfps	Remarks
						Net	Int.	Final	Test	Ave.		
	1140	75	4:32:30			80.53	#27	X	9.65	9.98		110v.A.C.
	41		33:00				to 32	only	10.32			
105	42		30				inc.		9.66	Vol.-	69	
	43		45				Par.		10.30	690		
	1144	"	35:30			80.50	"	Y	11.52	11.97		
"	45		-					only	12.38			No. #45
	46		55						-	Vol.-	59	
	47		36:15						12.00	710		
	1148	"	38:40			80.45	"	A	10:45	10.26		25 V.A.C.
	49		39:00					only	10:10	Vol.-		
	50		15						10.23	8775	855	
	1151	"	40:20			80.40	"	B	12.02	12.13		
"	52		40					only	12.40	Vol.-		
	53		41:00						11.97	9465	780	
	1154	"	42:20			80.35	"	C	11.30	10.92		
"	55		40					only	10.57			
	56		43:10						11.27	Vol.-		
	57		30						10.62	9061	829	
					Total Q by Traverse						2592	
106	1158	76	46:45			80.31	#27to	A.B.C.	10.67	10.93		12V. A.C.
	59		47:10				32	X & Y	10.92	Vol.-	2524	Air in Salt
	60		30				Inc.	Par.	11.20	28691		

Fig. 25 Sample Data Sheet of Laurentide Power Company Tests

head, at the electrical instruments in the generator room, at the wheel governor, and in the operating room of the power house. The test was directed from the gate house, where observers on the salt velocity meters were connected by telephone with the observers in the power house.

91 The maintenance crew of the power house provided most of the observers, performed all the labor in connection with the installation of apparatus, and attended to the brine mixing and distribution during the tests.

92 All tests were numbered, and all tests and observations were

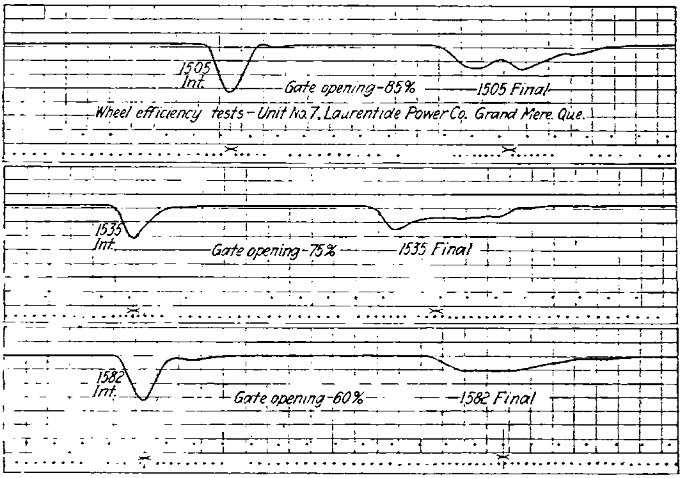

FIG. 26 SAMPLE CURVES, LAURENTIDE POWER COMPANY TESTS

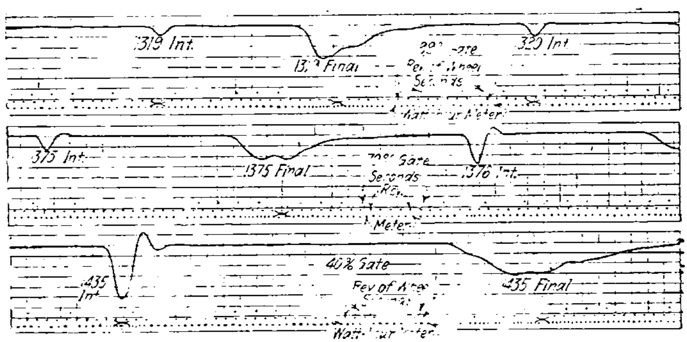

FIG. 27 SAMPLE CURVES, LAURENTIDE POWER COMPANY TESTS

recorded against the time of day. The watches of all observers were synchronized at the beginning of a test, and were checked at the end of the test. The necessary notes and data were recorded on both the moving chart and on the data sheets prepared for the purpose. Fig. 25 is a sample data sheet.

93 Including trials and all efficiency tests, about 1800 individual

tests or charges of salt solution were used. These were grouped into 220 runs of from five to twenty shots each.

94 Figs. 26 and 27 show sample curves recording the passage of salt at both the upper and lower electrodes for six different gate openings. All of these curves were made in the November tests after the various electrodes had been changed and improved.

Computations

95 The dimensions of the penstock were carefully measured by local engineers before the beginning of the tests, and the volumes between the vertical planes of the various electrodes and the pop valves were accurately computed. Then from the charts the number of seconds required for the passage of the salt between two stations was counted. The volume in cubic feet for that section,

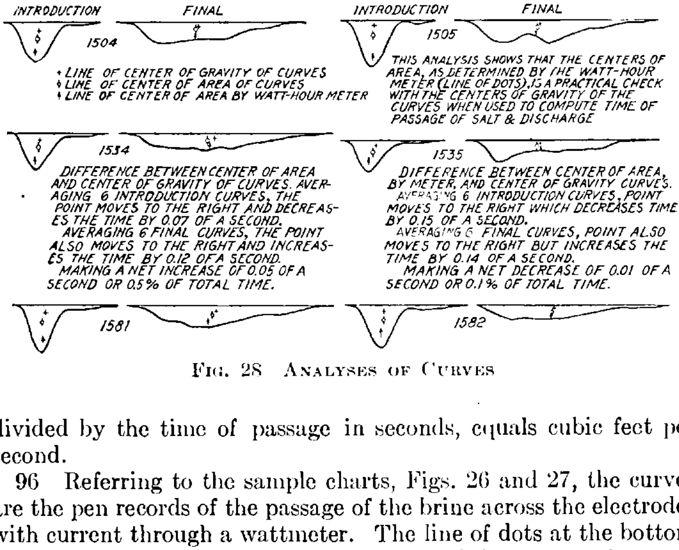

Fig. 28 Analyses of Curves

divided by the time of passage in seconds, equals cubic feet per second.

96 Referring to the sample charts, Figs. 26 and 27, the curves are the pen records of the passage of the brine across the electrodes with current through a wattmeter. The line of dots at the bottom of the charts indicates the passage of the brine across the same electrodes with current through the watt-hour meter. The middle line of dots (November 13 only) indicates the revolutions of the wheel, and the upper line of dots on all charts indicates the time in seconds.

97 As in the laboratory investigations at Worcester, considerable time was given to the problem of what point to use in computing time. Fig. 28 is an analysis of the six sample curves, for both introduction and final passage. The axes of the centers of gravity of the pen curves have been carefully determined by cardboard figures balanced on a knife edge. The axes of the centers of area of the same curves have been accurately fixed by a planimeter, and both of these axes are shown, together with the axes

of the centers of area as determined by the line of dots at the bottom of the sample curves. A study of this analysis shows that the results obtained by taking the centers of area, as indicated by the jump-spark device through the watt-hour meter on the original curves, differs by only one-tenth of one per cent from the results obtained by using the center of gravity of the pen curves made by the wattmeter.

98 Theoretically the center of gravity of the salt charge which is indicated on the chart by the center of gravity of the area enclosed by the curve is the correct point from which to compute time. In a symmetrical curve the maximum deflection, or the peak of the curve, is on the same axis as the center of area and the center of gravity of the curve, and all three will indicate the same time for the passage of the salt. The curves made by these tests

TABLE 5 COMPARISON OF RESULTS BY VARIOUS METERS ON BASIS OF SECONDS INDICATED FOR THE PASSAGE OF SALT FROM INTRODUCTION TO FINAL ELECTRODES. ALL AT 60 PER CENT GATE

Run No.	No. of tests	Meters D	E	F	Remarks
14	13	14.06	14.42	14.31	Salt in at all bays. Final at all bays
14a	8	14.36	14.55	14.50	Salt in at C only. Final at all bays
15	5	14.51	14.82	14.50	Salt in at all bays. Final at C only
Average, 3 runs		14.31	14.60	14.44	
Average, all 9 runs = 14.45					Not weighted for number of tests
Per cent plus or minus..........		− 1.0	+ 1.0	0.0	Avg. of 9 = 100 per cent.

Meters D and E were Prof. Allen's Bristol ammeters. Meter F was Laurentide Power Company's General Electric wattmeter. The "F" meter was apparently more reliable and accurate (as well as more convenient on account of watt-hour meter attachment) and was used for the majority of future tests.

were not as symmetrical as those obtained in the laboratory investigations, and the maximum deflection of the meter, that is, the peaks of the curves, would not give accurate results. But the curves were not distorted sufficiently to cause any material difference between the center of area and the center of gravity.

99 During the majority of the tests the point on the curves from which time was computed was the center of area, as indicated by the watt-hour meter record. In some of the early tests the records of the ammeters were used, and Table 5 shows the comparative results with the various meters. The computations were simpler with the wattmeter and the watt-hour meter device, and the results using the axis of center of area by that method coincided so closely with the center of gravity of the curves that any difference was ignored.

100 Since these investigations were made, the engineers of the Laurentide Power Company have made some tests investigating the proportionality or relation between the density of the salt and the electrical conductivity of the solution. The curves in Fig. 29 show the conductivity in amperes plotted on the density of salt

solution by an arbitrary scale running up to 220. While the density of the salt solution was practically the same for all tests (specific gravity 1.18 to 1.20), the density of the solution when mixed with the penstock water and passing down the penstock changed decidedly. This is shown by the relative length of the introduction and final curves, the final curves being three times as long as the introduction curves. And when the varying velocities of the water are considered, we find that the dilution is at least six times as much, i.e., the density of the solution is only one-sixth as much at the lower end of the penstock as at the upper end. Since all of the solution actually passing the introduction electrodes was never

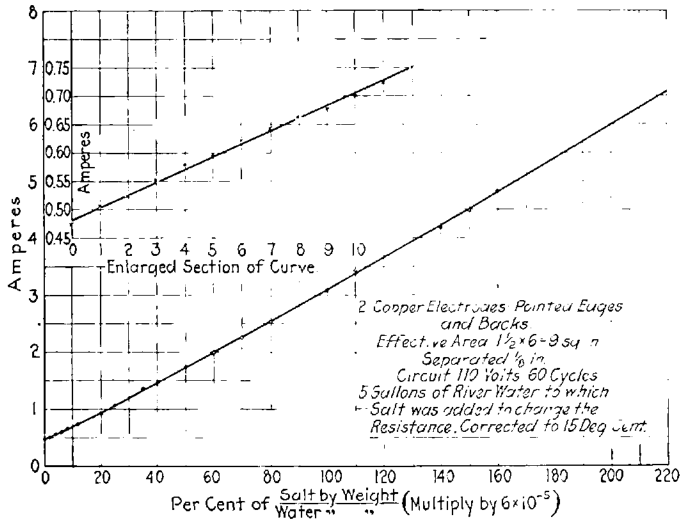

FIG. 29 CURVE OF SALT DENSITY ON CONDUCTIVITY

over ten on the scale of density, and the curve from zero to ten is practically a straight line, any error caused by varying density of salt solution at the different electrodes can be ignored.

RESULTS

101 Since these tests were mainly to determine the best apparatus and methods to be used in the efficiency tests on unit No. 7, no summary of results has been prepared. Summaries indicating the accuracy of the method are to be found in the sections on laboratory investigations. All of the result sheets shown are comparisons of results using various apparatus and methods.

102 In the summaries of laboratory investigations the accuracy of the salt velocity method in round penstocks has been shown; in other tests its accuracy in rectangular flumes and

conduits has been proved, but its accuracy in a penstock like that of unit No. 7, at Grand Mere, remained to be settled when these investigations were started in October, 1922. Since there was no standard of measurement for the discharge of unit No. 7 to compare the results with, many check runs were made. The best checks were where runs and comparisons were made between different apparatus and different methods, like checking the results with composite curves by a traverse or point measurement.

103 The general plan of these investigations was a cut-and-try process of elimination. The trials and elimination of apparatus are briefly as follows: The mixing and pressure tanks were satisfactory. Increasing the size of the filling pipe of the mixing tank saved time in filling the pressure tank, and twice the capacity of each tank would have saved more time during some runs. The distribution system of piping and pop valves was satisfactory with one exception. The fire hose, first used as leaders, was not strong enough or stiff enough, and it was replaced by iron pipe. A comparison of results with hose and pipe will be found in Table 6.

TABLE 6 COMPARISON OF DISCHARGES, USING FIRE HOSE AND USING IRON PIPE FOR LEADERS ON SALT DISTRIBUTION. AT 80 FT. HEAD

(Other conditions the same)

Run No.	No. of tests	Gate, per cent	Q cu. ft. per sec.	
150	10	80	2783	Hose
186	5	80	2713	Pipe = − 2.5 per cent
158	10	40	1382	Hose
193	5	40	1363	Pipe = − 1.4 per cent

104 Three or four types of introduction electrodes were tried. The early ones were too small and too close to the pop valves and recorded the salt from too small an area to be accurate. The last set of six long introduction electrodes were reliable and accurate. Table 7 is a comparison of results with old and new introduction electrodes. The new electrodes indicate slightly greater discharge. This is accounted for by the theory that some of the fast water went around the old introduction electrodes because they were of small area and too near the pop valves.

TABLE 7 COMPARISONS OF DISCHARGES, USING OLD AND USING NEW INTRODUCTION ELECTRODES

(Iron pipe leaders in each case. At 80 ft. head.)

Run No.	No. of tests	Gate, per cent	Q, cu. ft. per sec.	
186	5	80	2713	Old electrodes
185	5	80	2739	New electrodes = + 0.6%
183	5	40	1362	Old electrodes
193	5	40	1363	New electrodes = + 0.1%

105 Table 8 gives a comparison of results by using various combinations of final electrodes at 49.5 per cent gate opening. This table also shows the results obtained by giving each elec-

trode one-third the volume of the penstock and by an arbitrary computation of the volume for each electrode, based on dividing the penstock by lines from the centers of the piers at the upper end of the penstock to points midway between the final electrodes. No method of accurate determination of these three volumes is known, but it is quite certain that they are not equal.

TABLE 8 COMPARISONS OF DISCHARGES COMPUTED BY USING VARIOUS FINAL ELECTRODES. AT 80 FT. HEAD

Run No.	No. of tests	Gate, per cent	Q, cu. ft. per sec.	Methods of computing	Electrodes
1	6	49.5	1653	Estimated volumes, 3 threads	5 coppers paired with 1 steel at A, B, & C. (Parallel.) 3 curves to compute.
1	6	49.5	1683	Equal volumes, 3 threads	
5, 6, 7	58	49.5	1686	Equal volumes for 15 threads. (Point method.)	1 steel and 1 copper paired at 15 points. 15 curves to compute total.
8	13	49.5	1657	Estimated volumes, 3 threads	2 steels paired (no coppers) at A, B, & C. 3 curves to compute.
8	13	49.5	1649	Equal volumes, 3 threads	
13	7	49.5	1654	Total vol. of penstock used	2 steels paired and 1 steel paired with 5 coppers at A, B, & C all connected in parallel. 1 curve to compute.
Average			1664		

106 The maximum and minimum values for discharge shown in Table 8 vary by about one per cent from the average. Eliminating the values computed with threads of equal volume, the values remaining are 1653, 1654, and 1657, which are close checks.

107 Table 9 shows the volumes of the above threads and of all other volumes used between various stations and electrodes.

TABLE 9 VOLUMES USED FOR PENSTOCK. SALT VELOCITY TESTS ON UNIT NO. 7, OCT. AND NOV., 1922.

(Final electrodes at cross-section C in every case. Various signals for salt introduction.)

Introduction signal	Length horizontal, ft.	Thread	Volume of thread, cu. ft.	Total volume, cu. ft.
Handwheel and gage on pop valves	48.00	A	9093	28817
		B	10679	
		C	9045	
Old introduction electrodes, Nos. 27 to 32 inc.	47.80	A	8775	28691
		B	9465	
		C	9051	
		X	690	
		Y	710	
Using both of above signals. Average of two	47.90	A	9021	28754
		B	10662	
		C	9071	
New introduction electrodes, Nos. 34 to 39 inc.	46.19	A	Not computed	27677
		B		
		C		

108 Table 10 shows comparisons at four different gate openings between results with one composite curve and with three or five

separate curves from the final electrodes *A*, *B*, *C*, *X*, and *Y*; that is, with three or five shots to complete the measurement. These comparisons show very little variation between traverses and

TABLE 10 COMPARISON OF DISCHARGES TAKING FINAL ELECTRODES AS A TRAVERSE, *A*, *B*, *C*, *X*, AND *Y*, SEPARATELY (3 OR 5 CURVES) AND AS A COMPOSITE, 3 OR 5 ELECTRODES CONNECTED IN PARALLEL. (1 CURVE.) AT 80 FT. HEAD

Run No.	No. of tests	Gate, per cent	Q. cu. ft. per sec.			
1	6	49.5	1653	Avg. 1655	Traverse	= 100%
8	13	49.5	1657	*A*, *B* & *C*	Traverse	
13	7	49.5	1654	*A*, *B* & *C*	Composite	= −0.1%
105	25	75	2585	*A*, *B*, *C*, *X*, & *Y*	Traverse	= 100%
106	3	75	2618	*A*, *B*, *C*, *X*, & *Y*	Composite	= +1.3%
187, 188, 189	14	80	2722	*A*, *B*, & *C*	Traverse	= 100%
185	5	80	2730	*A*, *B*, & *C*	Composite	= +0.3%
190, 191, 192	17	40	1370	*A*, *B*, & *C*	Traverse	= 100%
193	5	40	1363	*A*, *B*, & *C*	Composite	= −0.5%
				Average −	Composite	= +0.25%

composites, the average for the four gate openings indicating that the discharge by composite is one-quarter of one per cent in excess of the discharge indicated by the traverse.

109 In connection with these traverses, the direction and veloc-

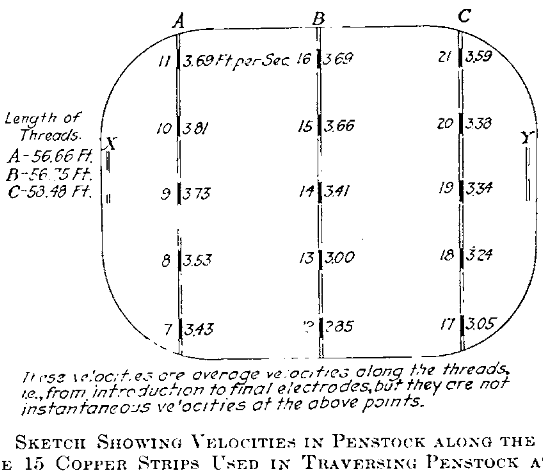

FIG. 30 SKETCH SHOWING VELOCITIES IN PENSTOCK ALONG THE THREADS OF THE 15 COPPER STRIPS USED IN TRAVERSING PENSTOCK AT CROSS-SECTION C

ity of flow in the different parts of the penstock were studied. Fig. 30 shows the location of all electrodes used in making these traverses, together with the velocities in feet per second at each electrode for one gate opening. Fig. 31 shows the curves of these velocities in the penstock. These velocities are not instantaneous velocities, but are average velocities between the introduction electrodes and the final electrodes. These curves are plotted for both horizontal and vertical cross-sections of the penstock and indicate clearly that the fastest water is at the top and at the left, or *A*, side of the penstock.

110 The dispersion of the salt is indicated in Fig. 32. This shows the results of introducing salt at one bay only and taking the final curve from each electrode separately. Five shots were

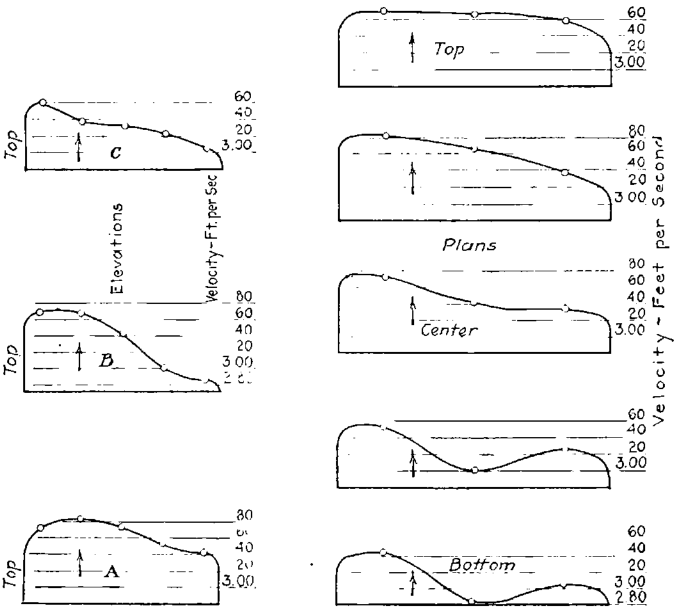

FIG. 31 TRAVERSE CURVES, LAURENTIDE POWER COMPANY TESTS

taken with salt introduced at each bay. The extent of this dispersion or distribution is greater at the smaller gate opening when the velocity of the water is slower. At 50 per cent gate opening, when salt was introduced at *B*, the center bay, its effect showed at all the final electrodes except *Y*. This is consistent with the traverse curves showing faster water on the *X*-side than on the *Y*-side.

111 As one phase of this investigation, speed runs were made. The generator load was delivered to electric boilers, making a wide range of speed possible. The curves of discharge on r.p.m. for various gate openings are shown in Fig. 33. These speed curves are very consistent with the speed curves derived from the

Holyoke tests of the I. P. Morris Company's model runner. It was possible to pick up slight differences in discharge on change of speed, these differences being as low as three second-feet with total discharges running up to 3000 sec-ft. The bumps in the curves at 65 per cent and 75 per cent gate opening are duplicates of those shown by the Holyoke tests. The results of these speed runs gave added confidence to this method of water measurement, and the resulting speed curves were used in reducing values for the efficiency report on unit No. 7.

112 Early in October the velocity of the water near the roof and floor walls of the penstock was determined by the fifteen

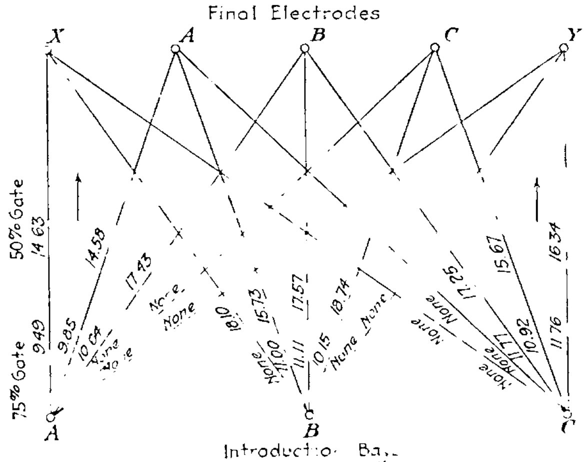

FIG. 32 SKETCH SHOWING DISPERSION OF SALT

(Seconds required for passage of salt from introduction electrodes in one bay only to various final electrodes at two gate openings.)

12-in. copper electrodes attached to the long steel plates at *A*, *B*, and *C*, but the velocity near the side walls was not accurately determined. Early in the investigations, two short electrodes, *X* and *Y*, close to the side of the walls of the penstock were placed in the same plane as the three pairs long electrodes *A*, *B* and *C*, which had been installed from the beginning. Table 11 compares tests with and without *X* and *Y*.

TABLE 11 COMPARISONS SHOWING EFFECT OF NEW SIDE ELECTRODES *X* AND *Y* USED WITH ELECTRODES *A*, *B*, AND *C*, AT 80 FT. HEAD

Run No.	No. of tests	Gate, per cent	Q, cu. ft. per sec.	—Final Electrodes—	
26	10	75	2643	*A*, *B*, *C*, *X*, and *Y* parallel	
101	24	"	2647	" " " " " " "	
103	3	"	2631	" " " " " " "	
106	3	"	2620	" " " " " " "	
107	5	"	2639	" " " " " " "	
Average.			2642	" " " " " " "	Weighted for shots
108	5	"	2634	*A*, *B*, and *C* only parallel	− 0.3%

113 These comparisons indicate that the adding of X and Y did not affect the indicated discharge because the velocity at X was only slightly faster than the velocity at A, while the velocity at Y was slightly lower than that at C. The average of five runs

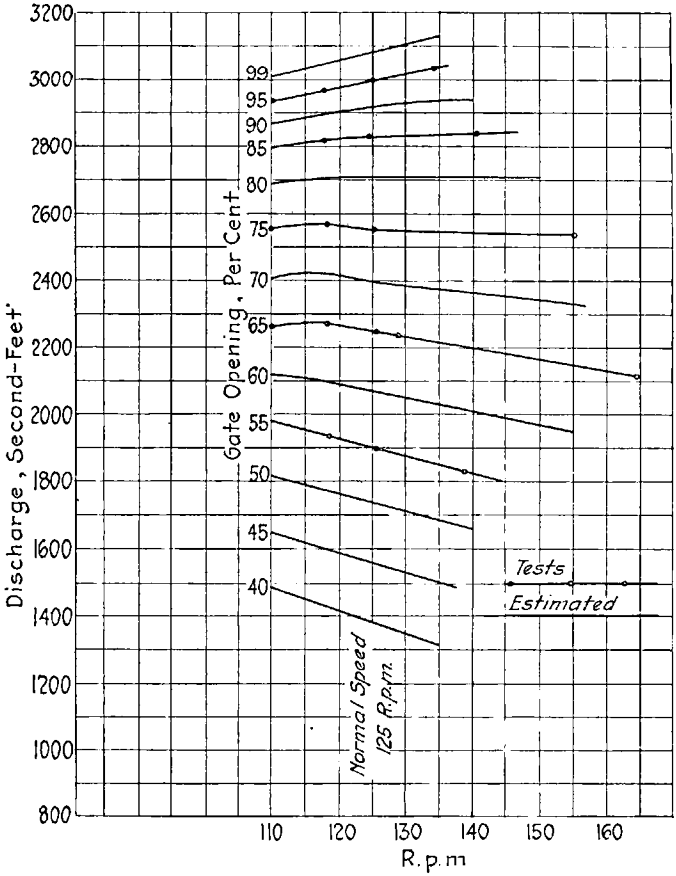

FIG. 33 CURVES OF DISCHARGE AT VARIOUS SPEEDS AT 80 FT. HEAD

shows 2642 sec-ft. with the five electrodes and 2634 sec-ft. with three electrodes.

114 Table 12 is a comparison of the time required for the passage of salt from the introduction electrodes to X and to A, as well as to Y and to C. The time to X was 1.2 per cent faster than the time to A, the nearest long electrode, while the time to Y was 3 per cent slower than the time to C. Averaging, we find that the time to X and Y together was less than 1 per cent slower than to A and C together. Since the areas and the volumes assigned

to the electrodes A and C are twelve times the areas and volumes assigned to X and Y, the effect of X and Y on the total discharge computed from either traverse or a composite curve is less than

TABLE 12 COMPARISON OF TIME REQUIRED FOR PASSAGE OF SALT FROM INTRODUCTION ELECTRODES TO FINAL ELECTRODES A AND C AND TO X AND Y

Gate, per cent	Seconds to X	Seconds to A	Gate, per cent	Seconds to Y	Seconds to C
50	14.63	14.58	50	16.34	15.67
60	13.20	13.55	60	15.80	15.61
65	11.09	11.63	65	13.80	13.11
67.5	11.64	11.02	67.5	13.03	13.03
75	9.98	10.26	75	11.97	10.92
80	9.49	9.85	80	11.76	10.92
Totals........	70.03	70.89	Totals........	82.70	79.26

Seconds for X = − 1.2% Seconds for Y = + 3.0%

Average seconds for X and Y = + 0.9%

one-tenth of one per cent, which checks the comparison in Table 8. After this was determined the short electrodes X and Y were abandoned.

Conclusions

115 The greatest value of these investigations was the demonstration, under field conditions, that the tests by the salt velocity method as applied to the setting at Grand Mere could be repeated and checked indefinitely, and that the tests could be repeated with varying apparatus and equipment and with various methods of computation, and still check. These tests tried out and eliminated several sources of error, and showed that the final apparatus and methods used in the efficiency tests were an improvement over the original apparatus first installed.

116 With all the various apparatus and methods used, the maximum variations shown in the comparisons were + 1.3 per cent and − 2.5 per cent, with an average variation of one-tenth of one per cent for the whole. With improved apparatus the maximum variations were reduced. For all comparisons made between tests at different times the discharge values were reduced to a common head.

V — 1922 COMMERCIAL TESTS

117 During the fall of 1922, ten successful commercial tests were made using the salt velocity method. On all of the tests the object was the measurement of the discharge through the penstock of a power plant. On seven of the tests the discharge values were used in computing the efficiency of the units, on two tests the discharge values were used to calibrate meters, and in the tenth test the values were used for determining the efficiency of the unit and also for calibrating a Johnson valve to be used as a venturi meter.

Apparatus and Methods

118 The plants under test were all hydroelectric power plants. The sizes of penstocks used were:

Two tests —	Riveted steel	11 ft. diameter, 1000 ft. long.
Two tests —	" "	12 " " 500 " "
Two tests —	" "	13 " " 1500 " "
One test —	Reinforced concrete	20 " " 500 " "
Three tests —	Concrete.	Rectangular tapered, 10 to 70 ft. long.

119 The tanks used varied from 150 to 1200 gal. in capacity and the salt pipes from 2 to 4 in. in diameter. Fig. 34 shows one of the large installations.

120 *Salt Introduction.* In all cases the salt solution was controlled by a quick-acting valve in the supply pipe leading from

Fig. 34 Salt Tanks and Distribution Pipes for Test of 50,000-hp. Unit

the pressure tank, and was introduced into the penstock through pop valves. In the steel pipes one $2\frac{1}{2}$-in. pop placed at the center of the penstock entrance was used. In the concrete penstocks multiple pops of various sizes were used, as many as 24 being installed for one penstock.

121 *Electrodes.* The electrodes were of various forms and sizes, and both steel and copper were used. For insulation of these electrodes horn and fiber, hard and soft rubber, and porcelain were used, and on the later forms waterproof shellac was freely used on all contact surfaces. The spacings between pairs of electrodes varied from $\frac{1}{16}$ in. to 4 in. In most cases two plates were used for each set, but in the others three parallel plates were used to get more surface and a greater deflection of the meter needle. Fig. 35 shows a design using three copper plates.

122 For the circular penstocks one set of electrodes was used

for finals at the lower end, but on the rectangular penstocks multiple sets were used to cover the cross-section. In one case a complicated system of electrodes was used. By a combination

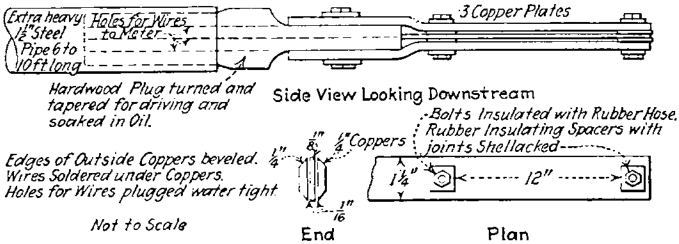

FIG. 35 SKETCH OF 3-PLY ELECTRODE

of long steel and short copper plates 35 electrodes were placed in one plant to cover a cross-section of 335 sq. ft. area. Figs. 36 and 37 show two forms of electrodes used on a test of unit No. 6

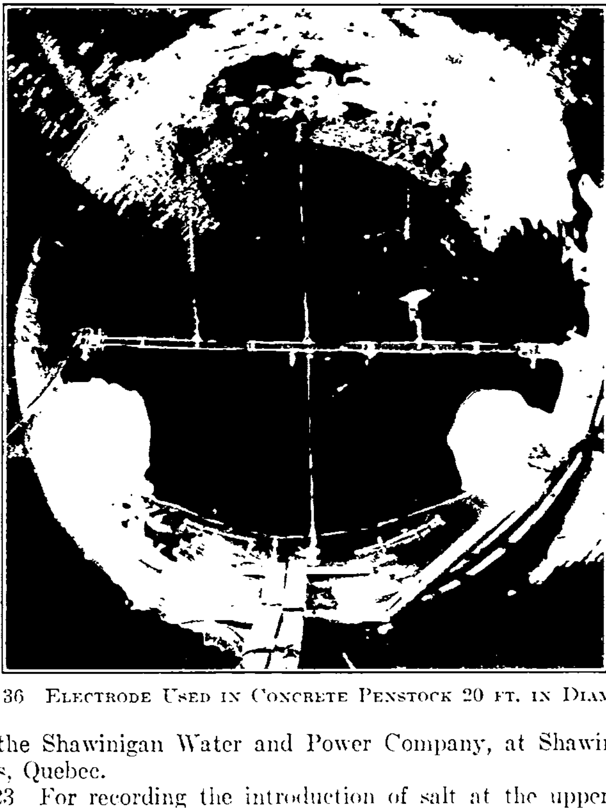

FIG. 36 ELECTRODE USED IN CONCRETE PENSTOCK 20 FT. IN DIAMETER

for the Shawinigan Water and Power Company, at Shawinigan Falls, Quebec.

123 For recording the introduction of salt at the upper end of the penstock, both switches and electrodes were used. On

all the long pipes a contact switch was installed on the handle of the quick-acting valve, but on all the short penstocks upper electrodes were placed close to the pop valves. In several cases the upper electrodes were fastened to the pop valves.

124 *Meters.* All introduction signals and all electrodes were wired to the recording meters. These meters were the same instruments as were used in the 1922 field investigations. Alternating current at 110 volts was used in these circuits, but at times portable transformers were used to change the voltage and current

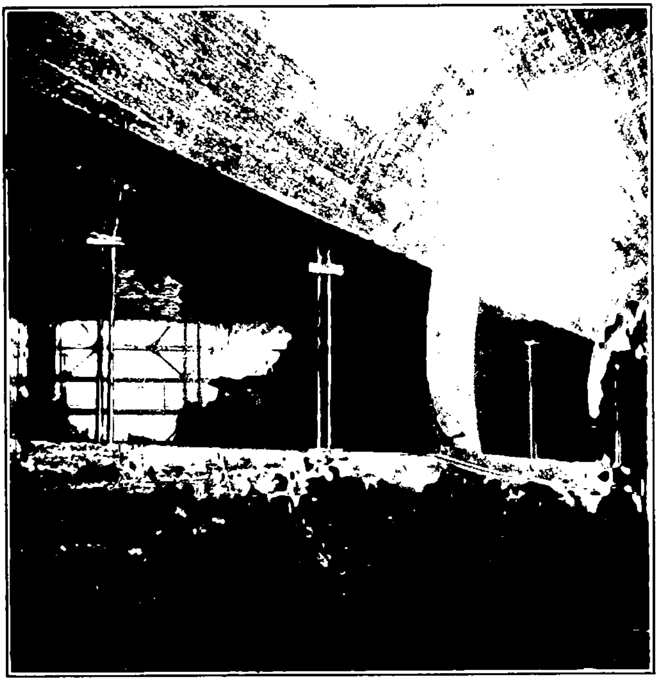

Fig. 37 Electrodes Used in Gathering Tubes

in regulating the deflection of the meter needle and the height of the curves.

125 *Timing.* On some of these tests a standard seconds-pendulum clock was wired to the recording meters, and by means of batteries, a relay, and a spark coil, jump-spark dots recorded seconds on the chart. For the remainder of these tests no clock was available and a seconds pendulum with a magnetic weight was used. This pendulum was made in the field, and during the first test did not beat exact seconds, making a time calibration necessary. For all the later tests the pendulum was adjusted to beat exact seconds and was frequently checked.

126 *Standards of Measurement.* No standards of water measurement were employed on these tests and no other methods used except when a meter was being calibrated. At one plant the same unit was tested by the Gibson method, and the final curves by the two methods checked exactly along the range of high efficiency and only varied slightly at the lower gate openings.

127 *Computations.* Prior to a test the volume of a penstock was always accurately determined from plans and checked by field survey.

128 When the salt introduction was recorded by a signal switch on the quick-acting valve, time was computed from a point midway between the opening and closing of that valve. For all curves indicating the salt passing the electrodes, the time was computed to the center of gravity of the curve or to the center of area as indicated by the line of jump-spark dots through the watt-hour meter. From 5 to 10 shots or charges of salt solution were used for each run, and the average of all the shots during a run was used in computing the discharge.

Results and Conclusions

129 The results of the tests on the long, round penstock were consistent and confirmed the accuracy and reliability of the method applied to such penstocks. They also justified the various apparatuses and methods of computation used on the rectangular, tapering penstocks, but they did not shed any additional light on the accuracy of the method as applied to that type of penstock.

130 However, one of these tests on a large unit in Canada did confirm the accuracy of the salt velocity method on rectangular converging tubes. The penstock for this unit was 500 ft. long with a uniform diameter of 20 ft., and was fed by four rectangular converging tubes and one elliptical diverging tube. During these tests it was possible, at five different gate openings, to compare the discharge measured in these five tubes with the same discharge measured in the main penstock of uniform cross-section. The greatest variation was 0.7 per cent, and the average of all discharges checked exactly. These four rectangular converging tubes were typical of the penstocks at Grand Mere, and this checking of results gave added assurance to the accuracy of the tests on rectangular tapering penstocks.

VI — 1923 LABORATORY INVESTIGATIONS

131 Following the field investigations at Grand Mere, Quebec, which were completed in November 1922, another set of laboratory investigations was made at Worcester, in January, February, and March, 1923. The main object of these investigations was to determine the degree of accuracy of the salt velocity method against the weighing tank, and particularly the accuracy of the

apparatus and methods of computation used during the field and efficiency tests of 1922.

Apparatus and Methods

132 *Plant.* An 8-in. steel pipe, reduced to 6 in. and 4 in., and branching from the main penstock of the Alden Hydraulic

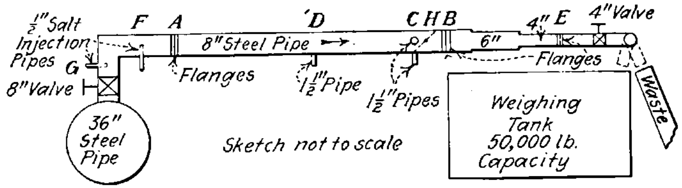

Fig. 38 Sketch of 8-in. Steel Pipe, Worcester Polytechnic Institute Laboratory

Laboratory, was used for these later investigations. Fig. 38 shows this pipe and the stations used in these tests.

133 *Apparatus.* The brine was mixed in a 50-gal. open mixing tank, and a hand force pump was used for the salt injection through ½-in. pipes. These pipes entered the 8-in. pipe at two

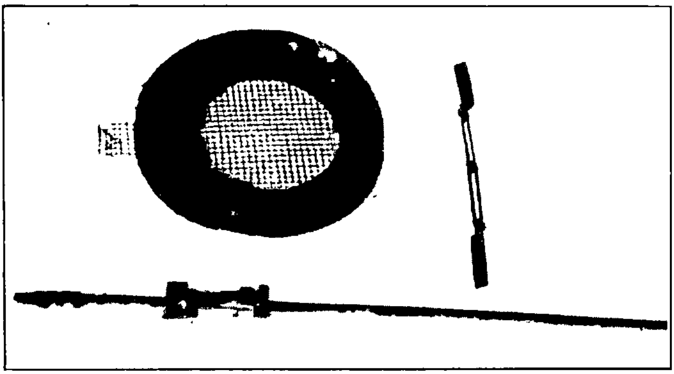

Fig. 39 Electrodes Used in Laboratory, 1923

stations, F and G. F was 3 ft. downstream from a 90 deg. bend in the 8-in pipe, and G was 1 ft. upstream from the same bend. Both of these injection pipes were controlled by valves, and pop valves, open ends, and perforated pipes were used for the salt distribution.

134 Various electrodes were used. Two wire screens (¼-in. mesh), spaced from ⅛ in. to ½ in. apart, were used at stations A, B, and E. A traversing electrode was made of ¾-in. by $\frac{1}{16}$-in. copper plates, with ⅜ in. of the plates exposed. Four of these plates,

spaced $\frac{1}{16}$ in. apart, were placed parallel to each other. This electrode attached to a pitometer rod was used at station C.

135 The so-called "flat" electrodes were made of two $\frac{3}{4}$-in. by $\frac{1}{16}$-in. copper plates 8 in. long, placed parallel and spaced $\frac{1}{8}$ in. apart. These electrodes were used at stations A, C, and D. When used at station A these plates were fastened between the pipe flanges, and when used at C and D they were fastened to pitometer rods and inserted through stuffing boxes.

136 The so-called "improved" electrodes were made of the same plates as the flat electrodes, but with different spacing. The $\frac{1}{8}$-in. spaces at the ends remained unchanged, but the center spacing was increased to $\frac{1}{2}$ in. and to $\frac{3}{4}$ in. These electrodes were used at stations A, C, and D. Photographs of four electrodes are shown in Figs. 39 and 40.

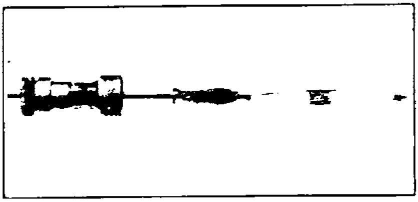

FIG. 40 IMPROVED ELECTRODE USED IN LABORATORY, 1923

137 In order to simulate the conditions in the unit No. 7 penstock at Grand Mere, where the perpendicular final electrodes were at an angle with the direction of the water flow, one improved electrode was made of longer plates (11 in.), which was used at station H. Station H was 4 in. below station C and is the center of this longer electrode when inserted at station C and bent downstream at an angle of 45 deg.

138 Various combinations of all these electrodes were used during the tests.

139 The electrodes were wired to a Bristol alternating-current recording ammeter of five amperes capacity. Current at 110 volts was used, and the chart was motor-driven, either by electric or by phonograph motor. The electrodes were also connected to a recording wattmeter, and a polyphase watt-hour meter. This watt-hour meter was a part of a device developed by Mr. Thibeault of the Laurentide Power Company and called an "integrator." Since 110-volt, 60-cycle, alternating current was used in the salt electrode circuits, it was necessary to use alternating-current instruments. The wattmeter and the watt-hour meter were of the commercial polyphase type (although single-phase current was used) with the two potential elements in parallel and the two current elements in series to double the torque and augment the quickness of the instruments to respond to changes in the load. The recording ammeter and recording wattmeter were of the ordinary type and need no special mention, but the action of the integrator requires detailed description.

140 The object of this integrator is to determine by exact, simple, easily workable, and graphical means the instant when

one-half of the salt-solution charge has passed the electrode. A commercial watt-hour meter is connected with its current coil in series with the electrodes and with its potential coil energized by a constant voltage. On the rotating shaft of the meter is mounted a simple circuit interrupter giving 24 interruptions per revolution to its circuit, which is a local direct-current circuit through the actuating coil of a simple contact-*opening* relay. These contacts in turn energize the low-tension side of a spark coil of which the high-tension leads are connected to a spark gap. A spark punctures the recording-wattmeter chart at every interruption of the interrupter circuit.

141 The spacing between punctures will vary inversely as the speed of the watt-hour meter disk, and consequently inversely as the conductivity of the liquid between the electrodes. While water only is passing the spacing should be uniform; but while the salt solution charge is passing the spacings become smaller. This corresponds to the curve of the recording instrument, the ordinates of which are low and uniform under the former condition and higher under the latter.

142 The recording wattmeter gives a measure of the amount of salt in the charge (assuming constant velocity and a straight-line relationship between salt density and conductivity) in the area of that part of the curve lying above the horizontal line representing the conditions when no salt is passing.

143 A measure of the salt passing is also recorded by the integrator. The horizontal line on the chart, indicating a uniform condition of conductivity of normal water, is here replaced by its exact equivalent in a series of uniformly spaced punctures. Conductivity in excess of this value occurring during the passage of salt demonstrates itself proportionally by the increase in frequency of the punctures.

144 Referring to a chart containing a complete record of the passage of a salt charge by the integrator, Fig. 26 or 27, the time when the solution started to pass and the time it left the electrodes are noted by observing when the spacing of the lower line of punctures changes. Measuring the distance between these two (initial and final) points and dividing by the length of the normal spacing determines how many punctures would have occurred if no salt had passed. By counting the actual number of punctures occurring during the period of salt passage just selected and subtracting from this number the number derived as above, representing the number of punctures due under normal conditions of flow of water with no salt added, the number of excess punctures is determined.

145 The resultant figure of excess is thus proportional to the amount of salt in the charge. One-half this figure of excess is also proportional to one-half the quantity of salt in the charge. Therefore, if that point on the chart is found where the actual number of puncture spacings minus the number due to the water before

dosing with salt, equals one-half the excess of the total passage, the moment is established when one-half of the salt charge has passed. To facilitate the determination on the chart of this point, a simple portable scale was adopted which greatly reduced the amount of work required.

146 To provide a time scale on the charts of the recorders of all types, the same device of puncturing the sheet with a jump spark was employed, the spark being controlled by a relay actuated in turn by a contact-making clock that marks one-second intervals on the chart. A wiring diagram is shown in Fig. 23.

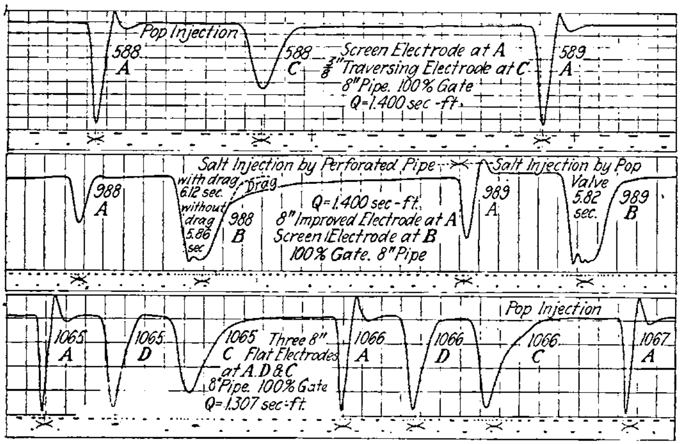

FIG. 41 SAMPLE CURVES OF TESTS ON 8-IN. STEEL PIPE

147 The standard for the water measurement during these tests was a copper-lined weighing tank of 50,000 lb. capacity. The scales were frequently checked with standard weights and were very accurate. They were also very sensitive, a difference of $\frac{1}{4}$ lb. showing on the balance arm.

DESCRIPTION OF TESTS

148 All of the apparatus and all observers for these tests were in one room. One observer operated the salt pump. Another operated the switches and the recording meters and directed the tests. A third man operated the weighing tank and kept the data noted. During a part of the time a fourth observer was used in computing curves and changing pipe and electrode connections.

149 All tests were numbered and recorded against the time of day, and the necessary notes were kept on both the meter charts and the data sheets. Sample curves are shown in Figs. 41 and 42.

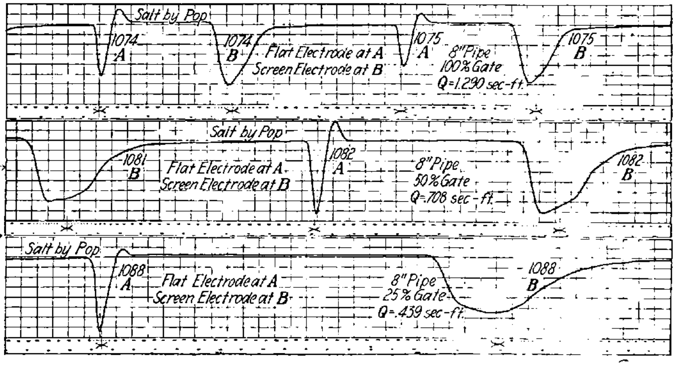

FIG. 42 SAMPLE CURVES OF TESTS ON 8-IN. STEEL PIPE

FILE 603

SHEET 1 OF 14 SHEETS

SALT VELOCITY TESTS

C. M. ALLEN, WORCESTER, MASS.

DATA OF TESTS ON Investigations (1923) UNIT NO. -

MADE BY AT PLANT OF W. P. I. LAB. Worcester

TESTS MADE FOR Laurentide Power Co., Ltd. Quebec DATE 2/4/23

LENGTH. Steel Pipe USED A-D 9.77 A-C 20.91 A-B 22.53 SIZE 8"+ VOLUME 3.526 7.548 8.130 R. P. M. -

Run	Test No.	Gate %	Time of Day P.M.	Meter Wt.	lbs. per min.	s.f.	Electrodes Int.	Final	Seconds Test	Ave.	Q c.f.p.s.	Remarks
	1054		2:34	862					D	C		
	1064	100					Flat	2 Flats	2.63	5.68	A-D	2 Flats
	5		6	29355	4893	1.307	A	D & C	2.57	5.57	1.367	A, D & C
128	6						Vol.	Vol.	2.52	5.60	+4.6%	
	7						D=	C=	2.50	5.58	A-C	Pop
	1068		2:40	30217			3.526	7.548	2.58	5.65	1.345	
								Ave.	2.58	5.61	+2.9%	
									B			
	1069	100	2:48	1589			Flat	Screen	6.42			Flat &
	70						A	B	6:17			Screen
	1								6.22			A & B
	2							Vol.=	6.32			Pop
129	3		4	19533	4883	1.304		8.130	6.26	6.26	1.299	
	4								6.27			
	5								6.27		-0.4%	
	6								6.18			
	7								6.24			
	1078		2:52	21122					6.28			
	1079	50	2:56	21113			Same		11.52			"
	80								11.47			
130	1		5	13259	2652	.708	V.=	8.130	11.47	11.51	.707	
	2								11.49			
	1083		3:01	34372					11.59		-0.1%	
	1084	25	3:08	1232			Same		18.75			"
	5								18.38			
131	6					.439	V.=	8.130	18.30	18.44	.441	
	7								18.38		+0.5%	
	1088								18.39			
			14	22968	1641				D	C		
	1089	25					Flat	Flats	8.18	16.50	A-D	3 Flats
	90						A	D & C	7.55	16.57	.454	A, D & C
132	1					.439	Vol.	Vol.	7.70	16.30	+3.4%	
	2						D =	C =	7.79	16.75	A-C	Pop
	3						3.526	7.548	7.55	16.77	.455	
	1103		3:22	24200				Ave.	7.77	16.58	+3.5%	

FIG. 43 SAMPLE DATA SHEET OF 1923 LABORATORY INVESTIGATIONS

150 Including trials, over 1300 individual charges of salt solution or shots were used, which were grouped into 161 runs. These runs were segregated into 45 groups, based on the stations, the com-

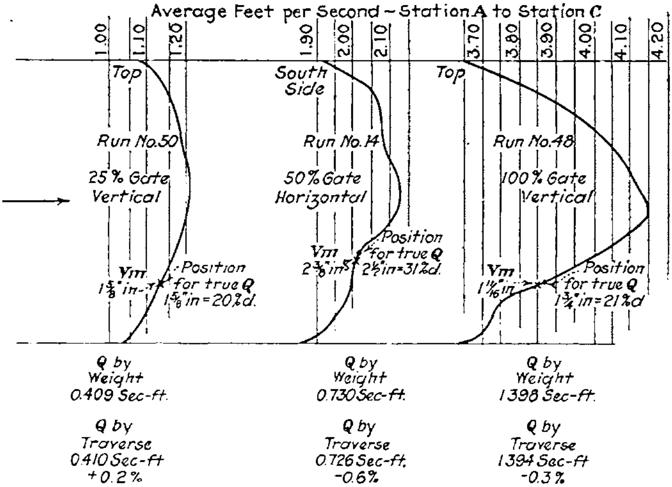

FIG. 44 TRAVERSE CURVES FOR 8-IN. STEEL PIPE
(Electrodes — 4 plates, 1 × ⅜-in. copper.)

binations of electrodes, and on the method of computing the curves which were used.

151 At the upper end of the 8-in. pipe, near its junction with the main penstock, was an 8-in. valve which was kept wide open

TABLE 13 PIPE LENGTHS AND VOLUMES AND ELECTRODES USED IN 1923 LABORATORY TESTS

Stations	Electrodes		Length, feet	Volume cu. ft.
A to B	Screen at A	Screen at B	22.57	8.142
A to B	Flat (or Imp.) at A	Screen at B	22.53	8.130
A to C	Flat at A	Flat at C	20.91	7.548
A to C	Screen at A	Flat at C	20.95	7.560
A to D	Screen at A	Flat at D	9.81	3.540
A to D	Flat at A	Flat at D	9.77	3.526
A to E	Screen at A	Screen at E	30.20	9.913
A to E	Flat at A	Screen at E	30.16	9.901
A to H	Screen at A	Flat (45°) at H	21.27	7.678
D to B	Screen at B	Flat at D	12.76	4.602
D to C	Flat at D	Flat at C	11.14	4.022
D to E	Flat at D	Screen at E	20.39	6.377
F to B	Pop at F	Screen at B	23.90	8.626
F to C	Pop at F	Flat at C	22.28	8.040

Area of 8-in. pipe = 0.361 sq. ft.
Volumes determined by weight of water contents. Checked by tape.

during the tests. The gate opening was controlled by a 4-in. valve over the weighing tank at the lower end of the pipe line. This valve was always set at least two minutes before a test to insure a uniform rate of flow, and for the same reason the swivel pipe used to turn the flow in or out of the tank was at the same angle with the perpendicular at each position and was locked in place. As a rule, all runs were repeated at three gate openings, quarter, half, and full.

152 When starting a test run, the weighing tank was emptied, the waste valve closed, and the tank was carefully weighed. On the next even minute, the operator turned the water into the tank and a few seconds later the recording meters were started and the first shot of salt was injected. Usually from five to ten

TABLE 14

Length of steel pipe used, 22.57 ft. Size, 8 in. Volume, 8.142 cu. ft.

Run No.	No. of Tests	Gate, per cent	Q, Cu. Ft. Per Sec. by weight	Q, Cu. Ft. Per Sec. by salt	Salt, per cent	Average, per cent	Salt Injection	Computation	Group
Two screen electrodes at Station A and Station B.									
1a	7	100	1.411	1.408	−0.2		Perforated pipe	Peaks of curves or maximum deflection of meter	1
2a	18	100	1.411	1.389	−1.7				
3a	12	70	0.970	0.955	−1.5				
4a	9	25	0.391	0.387	−1.0				
5a	9	25	0.391	0.389	−0.5				
	55					−1.2			
1a	7	100	1.411	1.408	−0.2		Perforated pipe	Center of gravity of curves (by eye)	2
2a	18	100	1.411	1.399	−0.9				
3a	12	70	0.970	0.973	+0.3				
4a	9	25	0.391	0.389	−0.5				
5a	9	25	0.391	0.394	+0.8				
	55					−0.2			
143	10	100	1.356	1.376	+1.5		Pop valve	Center of gravity (by eye)	44
144	10	100	1.311	1.322	+0.9				
145	10	50	0.709	0.702	−1.0				
146	10	25	0.442	0.449	+1.6				
147	10	25	0.443	0.445	+0.5				
148	10	50	0.709	0.701	−1.1				
	60					+0.4			
Screen at Station A. 8-in. improved electrode bent downstream at angle of 45 deg. at Station C. (H) Length pipe used, 21.27 ft. − 8 in. + *d*. Volume, 7.678 cu. ft.									
149	10	50	0.714	0.718	+0.6		Pop valve	Center of gravity (by eye)	45
150	10	50	0.714	0.712	−0.3				
151	10	25	0.396	0.398	+0.5.				
152	10	25	0.398	0.397	+0.3				
153	10	100	1.326	1.322	−0.3				
154	10	100	1.322	1.318	−0.3				
	60					+0.1			

Average of 3 groups (omitting group 1 on account of peaks) = + 0.11 per cent.

shots constituted a run, but for the traverses as many as forty shots were made for one run. On the next even minute following the last shot of the run, the tank operator turned the flow of water out of the tank into the waste pipe and again the tank was carefully weighed. The intervals between the two weighings varied from three to twenty-five minutes.

Computations

153 The length and diameter of the various sections of pipe used were carefully measured and the volumes between the stations computed, but these figures were used only as preliminary

TABLE 15

Length of steel pipe used, 22.57 ft. Size, 8 in. Volume, 8.142 cu. ft.

Run No.	No. of Tests	Gate, per cent	Q, Cu. Ft. Per Sec. by weight	Q, Cu. Ft. Per Sec. by salt	Salt, per cent	Average, per cent	Salt Injection	Computation	Group
			Two screen electrodes at Station A and Station B.						
2	12	100	1.405	1.382	−1.7		Perforated pipe	Center of area by dots including all drag	3
3	8	50	0.693	0.682	−1.6				
4	6	25	0.461	0.458	−0.7				
	26					1.4			
2	12	100	1.405	1.404	−0.1		Perforated pipe	Center of area without drag	4
3	8	50	0.693	0.690	−0.4				
4	6	25	0.461	0.461	0.0				
	26					−0.2			
5	8	100	1.385	1.396	+0.8		Pop valve	Center of area by watt-hour meter (dots)	5
6	6	50	0.773	0.770	−0.4				
8	8	25	0.456	0.456	0.0				
9	13	100	1.396	1.393	−0.2				
10	6	66	0.886	0.884	−0.2				
11	6	50	0.708	0.710	+0.3				
12	5	25	0.410	0.413	+0.7				
	52				+0.1				
8	8	25	0.456	0.451	−0.9		Pop valve	Center of area by watt-meter curves (eye)	6
9	13	100	1.396	1.408	+0.9				
10	6	66	0.886	0.893	+0.8				
11	6	50	0.708	0.712	+0.6				
12	5	25	0.410	0.414	+1.0				
	38					+0.5			
23	7	100	1.410	1.414	+0.3		Open pipe at Station F	Center of area without drag (dots)	7
24	4	100	1.410	1.421	+0.8				
25	4	50	0.736	0.734	−0.3				
26	4	50	0.736	0.739	+0.4				
27	4	25	0.445	0.443	−0.5				
28	4	25	0.445	0.445	0.0				
	27					+0.1			

Average of 4 groups (omitting group 3 on account of drag) = + 0.15 per cent.

TABLE 16

Length of steel pipe used, 22.57 ft. Size, 8 in. Volume, 8.142 cu. ft.

Run No.	No. of Tests	Gate, per cent	Q, Cu. Ft. Per Sec. by weight	Q, Cu. Ft. Per Sec. by salt	Salt, per cent	Average, per cent	Salt Injection	Computation	Group
			Two screen electrodes at Station A and Station B.						
38	6	100	1.409	1.397	−0.9		Open pipe at Station G	Center of area without drag	8
39	7	50	0.727	0.725	−0.3				
40	5	25	0.431	0.431	0.0				
	18					−0.4			
41	5	100	1.404	1.399	−0.4		Perforated pipe at Station G	Center of area without drag	9
42	5	100	1.406	1.405	−0.1				
	10					−0.3			
86	5	50	0.729	0.727	−0.3		Pop valve	Center of area	10
87	5	100	1.370	1.375	+0.4				
90	6	100	1.372	1.370	−0.1				
	16					0.0			
92	5	100	1.373	1.375	+0.2		Pop valve	Center of area	11
94	7	50	0.719	0.716	−0.4				
95	5	25	0.427	0.428	+0.2				
	17					0.0			
141	6	100	1.317	1.309	−0.6		Pop valve	Center of area	12
142	2	25	0.427	0.427	0.0				
	8					−0.3			

Average of 5 groups = − 0.18 per cent.
Average of 3 sheets (Nos. 2, 3, and 4) all with two screen electrodes at A and B (12 groups, 51 runs and 387 shots), = + 0.07 per cent.

values. A more accurate method of determining the volume, that is, by weighing the same volume of water, was used for the final computations. The section of the pipe was blanked off except for vent holes and filled with water. This water was carefully drawn off into a tank and weighed on calibrated scales. Temperature corrections were made, and the operation repeated and checked.

TABLE 17

Length of steel pipe used, 20.95 ft. Size, 8 in. Volume, 7.560 cu. ft.

Run No.	No. of Tests	Gate, per cent	Q, Cu. Ft. Per Sec. by weight	Q, Cu. Ft. Per Sec. by salt	Salt, per cent	Average, per cent	Salt Injection	Computation	Group
		Screen at Station A. 8-in. improved electrode at Station C.							
20	6	50	0.622	0.627	+0.8		Pop valve	Center of Area	13
21	10	100	1.397	1.410	+0.9				
	16					+0.9			
31	5	100	1.402	1.418	+1.1		Open pipe	Center of area without drag	14
33	5	50	0.740	0.741	+0.1				
34	6	25	0.449	0.452	+0.7				
	16					+0.6			
35	5	25	0.449	0.451	+0.4		Perforated pipe above 8-in. ell.	Center of area without drag	15
36	8	50	0.738	0.741	+0.4				
37	7	100	1.407	1.404	−0.2				
	20					+0.2			
44	6	100	1.407	1.415	+0.6		Perforated pipe below 8-in. ell.	Center of area without drag	16
45	7	50	0.713	0.718	+0.7				
46	5	25	0.425	0.429	+0.9				
	18					+0.7			
85	6	50	0.729	0.727	−0.3		Pop valve	Center of area	17
88	6	100	1.370	1.362	−0.6				
89	5	100	1.372	1.377	+0.4				
	17					−0.2			
		Average of 5 groups (14 runs and 87 shots) = + 0.42 per cent.							
		Screen at Station A. 8-in. flat electrode at Station C.							
7a	6	25	0.401	0.406	+1.3		Perforated pipe and pop valve	Center of gravity (eye)	18
16	6	100	1.395	1.416	+1.5				
17	5	40	0.620	0.637	+2.7				
	17					+1.8			
		Two 8-in. flat electrodes at Station A and Station C.							
122	5	50	0.716	0.746	+4.2		Pop valve	Center of area	19
128	5	100	1.307	1.345	+2.9				
132	5	25	0.439	0.455	+3.6				
	15					+3.6			

Table 13 shows the lengths and volumes used. Fig. 43 is a sample data sheet of the 1923 laboratory investigations.

154 A discussion of the various methods of computing the discharge from the curves will be found in Section III of this paper. In these tests on the 8-in. pipe the curves obtained were usually symmetrical, so that the axis of the theoretically correct center of gravity coincided with the easily determined center of area. Since the main object was to compare the results by weight with the results computed from this center of area as determined by the integrator dots, that method of computing curves was usually

TABLE 18

Length of steel pipe used, 22.53 ft. Size, 8 in. Volume, 8.130 cu. ft.

Run No.	No. of Tests	Gate, per cent	Q, Cu. Ft. Per Sec. by weight	Q, Cu. Ft. Per Sec. by salt	Salt, per cent	Average, per cent	Salt Injection	Computation	Group
		8-in. improved electrode at Station A. Screen at Station B.							
80	6	100	1.394	1.399	+0.4		Pop valve	Center of area	20
81	6	50	0.721	0.723	+0.3				
82	6	25	0.434	0.436	+0.5				
	18					+0.4			
100	10	100	1.401	1.392	−0.6		Pop valve	Center of area	21
101	5	50	0.719	0.715	−0.6				
102	6	25	0.438	0.440	+0.5				
104	7	100	1.404	1.411	+0.5				
	28					−0.1			
109	5	25	0.424	0.428	+0.9		Pop valve	Center of area	22
110	5	50	0.722	0.727	+0.7				
113	5	100	1.400	1.395	−0.4				
	15					+0.4			
108	5	25	0.424	0.425	+0.2		Perforated pipe	Center of area without drag	23
111	4	50	0.722	0.712	−1.4				
112	5	100	1.400	1.380	−1.4				
	14					−0.8			
108	5	25	0.425	0.418	−1.4		Perforated pipe	Center of area with drag	24
111	4	50	0.722	0.692	−4.1				
112	5	100	1.400	1.328	−3.9				
	14					−3.1			

Average of 4 groups, consisting of 13 runs and 75 shots = − 0.01 per cent.
Omit group 24 on account of method of computation.

TABLE 19

Length of steel pipe used, 22.53 ft. Size, 8 in. Volume, 8.130 cu. ft.

Run No.	No. of Tests	Gate, per cent	Q, Cu. Ft. Per Sec. by weight	Q, Cu. Ft. Per Sec. by salt	Salt, per cent	Average, per cent	Salt Injection	Computation	Group
		8-in. flat electrode at Station A. Screen at Station B.							
129	10	100	1.304	1.299	−0.4		Pop valve	Center of area	25
130	5	50	0.708	0.707	−0.1				
131	5	25	0.439	0.441	+0.5				
134	5	25	0.439	0.440	+0.2				
	25					−0.04			
		Pipe 23.90 ft. long. Volume = 8.626 cu. ft. Signal on pump for introduction. Screen at Station B.							
91	5	100	1.373	1.374	+0.1		Pop valve	Center of area	31
93	5	50	0.719	0.713	−0.8				
96	5	25	0.427	0.428	+0.2				
	15					−0.17			

Average of 2 groups (7 runs and 40 shots) = − 0.09 per cent.

Two 8-in. flat electrodes at Station A and Station C.

Run No.	No. of Tests	Gate, per cent	Q by weight	Q by salt	Salt, per cent	Average, per cent	Salt Injection	Computation	Group
125	5	50	0.716	0.717	+0.1	+0.1	Perforated pipe	Center of area with drag	38

Two errors balance each other.

TABLE 20

Length of steel pipe used, 20.91 ft. Size, 8 in. Volume, 7.548 cu. ft.

Run No.	No. of Tests	Gate, per cent	Q, Cu. Ft. Per Sec. by weight	Q, Cu. Ft. Per Sec. by salt	Salt, per cent	Average, per cent	Salt Injection	Computation	Group
Two 8-in. improved electrodes at Station A and Station C.									
74	5	25	0.447	0.445	−0.4		Pop valve	Center of area	26
78	6	100	1.381	1.386	+0.4				
117	5	100	1.398	1.388	−0.7				
121	5	50	0.721	0.719	−0.3				
	21					−0.2			
97	5	25	0.456	0.454	−0.4		Pop valve	Center of area	27
98	6	50	0.732	0.726	−0.8				
99	10	100	1.400	1.400	0.0				
103	5	100	1.404	1.408	+0.3				
	26					−0.2			
75	5	25	0.447	0.448	+0.2		Perforated pipe below 8-in. ell.	Center of area without drag	28
79	5	100	1.381	1.368	−0.9				
	10					−0.4			
105	5	100	1.405	1.404	−0.1		Perforated pipe above 8-in. ell.	Center of area without drag	29
106	5	50	0.725	0.724	−0.1				
107	6	25	0.423	0.425	+0.5				
	16					+0.1			
105	5	100	1.405	1.363	−3.0		Perforated pipe above 8-in. ell.	Center of area with drag	30
106	5	50	0.725	0.718	−1.0				
107	6	25	0.423	0.418	−1.2				
	16					−1.7			

Average of 4 groups (13 runs and 73 shots) = − 0.16 per cent.
Group 30 omitted on account of method of computation.

TABLE 21

Length of steel pipe used, 20.95 ft. Size, 8 in. Volume, 7.560 cu. ft.

Run No.	No. of Tests	Gate, per cent	Q, Cu. Ft. Per Sec. by weight	Q, Cu. Ft. Per Sec. by salt	Salt, per cent	Average, per cent	Salt Injection	Computation	Group
Traverses									
Screen at Station A. ⅜-in. electrode at Station C.									
13	41	25	0.416	0.420	+1.0		Pop valve	By equal-area method	32 Hor.
14	42	50	0.730	0.726	−0.6				
15	41	100	1.394	1.378	−1.1				
3	124					−0.2			
47	35	100	1.399	1.402	+0.2		Pop valve	By equal-area method	33 Vert.
48	33	100	1.398	1.394	−0.3				
50	31	25	0.409	0.410	+0.2				
3	99					+0.1			

Average of 2 groups, 6 traverses = − 0.10 per cent.

Screen at Station A. ⅜-in. electrode at Station C, held at a fixed point which was computed from the above traverses.

Run No.	No. of Tests	Gate, per cent	Q, Cu. Ft. Per Sec. by weight	Q, Cu. Ft. Per Sec. by salt	Salt, per cent	Average, per cent	Salt Injection	Computation	Group
55	10	100	1.400	1.410	+0.4		Pop valve	Center of area	34 Vert.
57	11	50	0.727	0.727	0.0				
58	10	25	0.439	0.443	+0.9				
3	31					+0.4			
59	10	100	1.397	1.423	+1.9		Pop valve	Center of area	35 Hor.
60	10	50	0.723	0.729	+0.8				
61	10	25	0.431	0.426	−1.8				
3	30					+0.3			

Average of 2 groups, 6 points = + 0.37 per cent.

followed. However, other methods of computation, such as curves by other meters, using peaks of curves, center of gravity of curves as determined by eye, with and without the drag at the ends of the curves, as well as the curves and dots made with poor salt-injection pipes, such as an open-ended pipe and a perforated pipe instead of a pop valve, were all used to determine the amount of variation.

155 As in the laboratory investigations in 1922, when the salt velocity method was compared with results by weir and

TABLE 22

Length of steel pipe used, 9.77 ft. Size, 8 in. Volume, 3.526 cu. ft.

Run No.	No. of Tests	Gate, per cent	Q, Cu. Ft. Per Sec. by weight	Q, Cu. Ft. Per Sec. by salt	Salt, per cent	Average, per cent	Salt Injection	Computation	Group
			Two 8-in. improved electrodes at Station A and Station D.						
114	5	100	1.406	1.410	+0.3	+0.3	Pop valve	Center of area	36
			Two 8-in. flat electrodes at Station A and Station D.						
122	5	50	0.716	0.744	+4.0		Pop valve	Center of area	37
123	5	50	0.716	0.742	+3.3				
127	5	100	1.307	1.331	+1.8				
128	5	100	1.307	1.367	+4.6				
132	5	25	0.439	0.454	+3.4				
133	5	25	0.439	0.454	+3.4				
	30					+3.4			
125	5	50	0.716	0.717	+0.1	+0.1	Perforated pipe	Center of area with drag	38
			Screen at Station A. 8-in. flat electrode at Station D.						
134	5	25	0.439	0.454	+3.7		Pop valve	Center of area	39
135	5	100	1.300	1.350	+3.8				
138	5	50	0.709	0.739	+4.2				
139	5	25	0.429	0.448	+4.4				
	20					+4.0			

On run No. 125, two errors, flat final electrode and computing curves with drag (one plus and one minus), cancel each other. Not reliable.

venturi meter, and the method of computing curves by fixing the axis of the center of gravity by eye gave results varying less than one per cent from the true Q, that method of computation applied to these 1923 tests gave results within one-half of one per cent from the results by weight.

156 Traverses were made across the pipe in both vertical and horizontal positions. The discharge was computed by plotting velocities at different positions in the pipe and using the equal-area method for computing the total discharge. It will be noted that these velocities are not instantaneous velocities at the electrode, but are average velocities between the introduction and the final electrodes. Fig. 44 shows sample traverse curves.

Results

157 Summaries of the results of these tests are given in Tables 14 to 23, inclusive. Analyses of these summaries are given in Table 25. All averages are weighted for number of shots per run.

158 Summarizing all of the tests shows that 36 groups, consisting of 123 runs and 1012 shots, indicated discharges which differed from the discharge by weight by only 0.05 per cent. This

TABLE 23

Length of steel pipe used, 11.14 ft. Size, 8 in. Volume, 4.022 cu. ft.

Run No.	No. of Tests	Gate, per cent	Q, Cu. Ft. Per Sec. by weight	Q, Cu. Ft. Per Sec. by salt	Salt, per cent	Average, per cent	Salt Injection	Computation	Group
Two 8-in. improved electrodes at Station D and Station C.									
115	5	100	1.406	1.416	+0.7		Pop valve	Center of area	40
116	5	100	1.407	1.404	−0.2				
120	5	50	0.721	0.715	−0.8				
	15					−0.1			
8-in. improved electrode at Station D. Screens at Station B. Pipe, 12.76 ft. long. Volume, 4.605 cu. ft.									
118	5	100	1.398	1.387	−0.8		Pop valve	Center of area	41
119	5	50	0.721	0.722	+0.1				
	10					−0.4			
Two screen electrodes at Station A and Station E. Steel pipe (8 in., 6 in., and 4 in. diam.) 30.20 ft. long. Volume, 9.913 cu. ft.									
135	5	100	1.300	1.305	+0.4		Pop valve	Center of area	42
138	5	50	0.709	0.711	+0.3				
139	5	25	0.429	0.432	+0.7				
	15					+0.5			
8-in. flat electrode at Station A. Screens at Station E. Pipe, 30.16 ft. long. Volume, 9.901 cu. ft.									
124	5	50	0.716	0.713	−0.4		Perforated pipe	Center of area with drag	43
123	5	50	0.716	0.709	−1.0		Pop valve	Center of area	
127	5	100	1.307	1.299	−0.6				
133	5	25	0.439	0.442	+0.7				
	20					−0.3			

Average of 4 groups (12 runs and 60 shots) = − 0.09 per cent.

is practically an exact check. This summary omits trial shots and all runs with known sources of error, such as flat parallel plates for the final electrodes, computations from the peaks of curves or with the drag on the curves using poor designs of salt-injection pipes.

159 The errors when using one pair of so-called "flat" final electrodes in a circular pipe varied from +2 to +4 per cent at different stations, due to giving the fast water in the center of the pipe a greater proportional length of electrode than the slow water near the walls of the pipe. The traverse curves in Fig. 41 show that the velocity of the center water averages 13 per cent greater

than the velocity of the water near the wall of the pipe. Other traverses on larger pipes of uniform diameter indicate a difference of from 7 to 12 per cent. An improved electrode was designed to correct this error. (See Fig. 40.)

160 The errors when using a perforated pipe for the salt injection and computing curves with all the drag included, vary from − 1 to − 3 per cent. The term "drag" is used to denote the dragging out of the pen curves as they approach the final appearance of the salt. With open or perforated distribution pipes this drag is caused by the continuing flow or oozing of the salt solution after the controlling valve has been closed. For a comparison of curves using a perforated-pipe introduction and showing a pronounced drag and of curves using a pop valve for the introduction and showing little or no drag, see Fig. 41, tests 988 and 989. Run 125, using a perforated pipe for the salt injection and one pair of flat electrodes at either stations A, C, or D, gave results only 0.1 per

TABLE 24 SUMMARY OF ALL TESTS SHOWN IN DETAIL IN TABLES 14 TO 24

For 36 groups, 123 runs, and 1012 shots, Q by salt differs from Q by weight by + 0.05 per cent. This omits trial runs, runs with flat final electrodes, and runs which have been computed with known errors for purposes of comparison, such as peaks and drags.

Analysis for gate opening shows full gate slightly more accurate, but the difference is too small to consider.

Analysis for station at which final electrode is located shows nothing conclusive.

Analysis for Type of Final Electrode

Electrode	Groups	Runs	Shots	Salt per cent
Screen	21	80	547	− 0.01
Flat	4	16	82	+ 3.23
Improved	11	31	180	+ 0.06
Traverse	4	12	285	− 0.09
	40	139	1094	

cent in error, but this was because the errors due to those two sources balanced.

161 Analyzing the summaries for the various gate openings shows that the results are slightly better for full gate, but the difference is too slight to be of importance or conclusive.

162 Analyzing the summaries for the various stations used shows nothing conclusive except the accuracy of the method for any section of pipe. The results between A and E (+ 0.03 per cent), a section including 8-in., 6-in., and 4-in. pipe, were fully as accurate as when a section of 8-in. pipe alone was used.

163 Analyzing for the various electrodes shows that two screen electrodes gave the closest results with the results by the short traverse electrodes, and the results by the long improved electrodes almost equally close, while the flat final electrodes introduced a three per cent error.

164 Another method of correcting the error caused by using one pair of parallel plates for final electrodes in a circular pipe was also used. Two pairs of parallel plates were used, the upper one

placed a considerable distance below the salt-introduction station. The section of penstocks between electrodes and the center of gravity of the two salt curves were used in computations. This method has been used successfully on commercial tests.

Conclusions

165 These tests proved that when properly conducted the salt velocity method of water measurement checks the discharge by weight, which is the most accurate known method of measuring water. For short pipes the following items of apparatus and methods of computation were proven or confirmed:

a That a tight quick-closing pop valve is most suitable for salt injection.

b That other methods of salt injection can be used, but correct results are obtained only by applying an arbitrary and consequently inaccurate correction.

c That it makes very little difference what form of electrode is used at the introduction when the salt-injection pipe is very close.

d That screens or grids are ideal for both introduction and final electrodes.

e That an improved plate construction with proper spacing for the final electrodes gives very accurate results.

f That a traverse with short final electrodes gives equally accurate results.

g That the same electrodes held at a fixed point, determined by the traverse, also show accurate results.

h That computations based on the center of area as determined by a watt-hour meter and a series of jump-spark dots simplify the work and give accurate results.

i That tests can be repeated indefinitely and still check.

j That the apparatus and methods of computation used in the commercial tests were proven to be theoretically and practically correct, and the results obtained were accurate and reliable.

166 And finally, the authors believe that the salt velocity method of water measurement is correct in theory and in practice, that it is applicable to any form or size of flume, pipe, or penstock, and that, in a few years, its simplicity and accuracy will make it an accepted standard method of water measurement.

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