A Circular Towing Tank for Calibrating Plankton-net Flowmeters

by

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Abstract

A specially designed circular towing tank was developed at the Northeast Fisheries Center (NEFC) for calibrating plankton-net flowmeters ashore in order to provide more accurate volume estimates and to save valuable shipboard time. Results of a cross-calibration experiment with a flume in use at the Massachusetts Institute of Technology (MIT) demonstrated that calibration factors produced by the NEFC tank are more precise than those either from the MIT flume, from the flowmeter manufacturers, or from present methods used at sea.

Introduction

Plankton nets filter varying volumes of water depending upon the length of tow, speed of tow, and amount of clogging. A flowmeter is placed in the net's mouth to measure indirectly the volume of water strained through the net by recording the number of impeller revolutions per distance traveled. The number of impeller revolutions are then related to the volume of water necessary to generate them. Calibration is required of flowmeters before and after each cruise, however, due to variations in individual flowmeter performance.

General Oceanics Model 2030 flowmeters are used on all International Commission for the Northwest Atlantic Fisheries (ICNAF) larval herring cruises. These flowmeters have historically been calibrated before and after every cruise at sea. This process uses hours of expensive sea time and since such factors as wind, ship roll, hull turbulence, and towing distance affect flowmeters, it is an inefficient and inaccurate method of calibration.

The basic principle of calibration is to pass the flowmeter through a known distance of water (or conversely pass a known volume of water past the flowmeter) and determine the unit of distance traveled per impeller revolution (i.e., meters/revolution).

In the course of this study, six flowmeters were each calibrated 10 times. Five calibrations were made in a flume built by the Ocean Engineering Department of MIT. This flume closely resembles one built and described by

Arnold (1969) at the Lowestoft Fisheries Laboratory in England. The MIT flume uses moving water and a stationary flowmeter which require constant monitoring of the system, but provide nearly perfect laminar flow and great flexibility of operation. The same flowmeters were again calibrated five times in a specially designed towing tank at the NEFC in which the flowmeters were towed through a circular tank of water of a know circumference. Calibration of flowmeters in the NEFC is a simple operation and minimizes errors.

A description of the NEFC tank design and its operation, as well as analysis of the two sets of calibration factors derived from the two tank experiments are presented in this paper.

Description of Experimental Tanks

A 2.43-m diameter, 1,900-liter capacity, fiberglass-covered, wooden tank was used for the basic structure (Figure 1). A 0.25-hp electric motor equipped with a gear-reduction system and a right-angle drive unit was suspended above the tank on steel channel stock. This system converted the 1,725 rpm of the motor to an adjustable 0-10 rpm on the vertical right-angle shaft (Figure 2). A 13-mm aluminum dowel extended from this shaft into a Delrin bushing mounted in the center of the tank's floor. Two swing arms made of aluminum "T" stock (25 mm x 25 mm) extended out horizontally midway up the central dowel. The arms were guyed to the output shaft for support. Two short pieces of 1.25-mm diameter piano wire, which were hooked on the ends, hung from the ends of the swing arms. Each of these pieces was joined with another wire that had a coupling and a small barb and that extended down towards the base of the central dowel. Nylon twine ran from the ends of these second wires up the central shaft through eyebolts and out to the ends of the swing arms where they were fastened to small cleats. This design insured that the towing circumference remained constant and allowed for quick, easy removal and replacement of the flowmeters during a series of calibrations. A cam-operated electronic counter measured the number of revolutions. During operation the flowmeters were towed through the water for 4.901 m/rev at a speed of 81.78 cm/sec (1.57 knots).

The MIT Ocean Engineering Department's flume was used for comparison calibrations. According to Dr. J. H. Milgram of MIT (personal communication), the flow rate of the flume was within ±2% of its calibrated settings at any given point in the flume. A propeller, powered by a DC motor, forces water up through a series of filters producing laminar flow through the tank. The water then returns through a sluiceway to a holding tank. The actual flume part of the system is a 26-inch x 21-inch x 19-ft, glass-sided tank. See Arnold (1969) for a complete description of a similar flume.

Methods

All flowmeters were calibrated in both tanks using five, 15-min test periods. Tests of longer duration were not necessary as the response was found to be linear with time (Figure 3). The General Oceanics Model 2030 flowmeter is advertised to have a linear response in the range of approximately 25-790 cm/sec (Figure 4). Due to the limited calibration precision of the MIT flume, tests at MIT were performed at lower speeds than with the NEFC unit. Tests at MIT were at a mean towing speed of 55 cm/sec or for a mean towing distance of 495 m. The tests conducted at NEFC were made at the rotor's maximum rpm producing a mean towing speed of 81 cm/sec or for a mean towing distance of 740 m. To correct for the water revolutions in the NEFC tank, the mean number of water revolutions was substracted from the electronic counter's reading for the correct distance. Both of these speeds were sufficiently above the advertised minimum threshold to produce a linear response.

Results and Conclusions

Sixty calibration factors were generated by the comparison tests (Table 1). A one-sided t-test was used to test for significant differences between the mean calibration factors for each flowmeter in each calibration system. All but one set of means (flowmeter No. 07) were significantly different at the 5% confidence level. The differences can be partially explained by the variability of water speeds encountered in the MIT flume. The impeller which drives the water requires frequent adjustment to maintain a constant flow. During the testing, the MIT flume often operated at speeds above and below the desired 55 cm/sec. These fluctuations could partially explain the greater standard deviations of the MIT flowmeter calibrations compared to those of the NEFC. No variability was observed in either speed or distance traveled in the NEFC tank.

A second one-sided t-test was performed on the standard deviations (considered as normally distributed random variables) of each flowmeter in both tanks (Table 1). The result of t = 1.81, which is the same as the critical value, indicates that the standard deviations are also of consistently lower values in the NEFC tests. This t value gives a table probability between 90 and 95% which indicates greater consistency in the NEFC calibrations. A demonstration of this is figuratively shown in Figure 5 where the standard deviations are plotted on the X axis with typical bell curves indicated above them. The assumption here is that we are dealing with a normal distribution.

A comparison of the mean and range of calibration values for each flowmeter in each calibrating system showed that the maximum error in the NEFC tank for a standard ICNAF 61-cm bongo tow was 3.1%, or approximately 21 m^3, with a mean error of 1.5% or 10.5 m^3 (Table 2). The MIT flume again showed greater fluctuation with a maximum error of 5.2% or 39 m^3, and a mean error of 3.06% or 19.8 m^3. This difference indicates that the NEFC tank's maximum error for a single flowmeter and mean error for all flowmeters is almost one-half that of the MIT flume. Calibrations at sea commonly vary as much as 66 m^3 or 10% of the total tow.

The mean calibration factors were then compared to the General Oceanics calibration factor, 0.0271 m/rev, which is common to all of the Model 2030 flowmeters (Figure 4). This study indicates that the MIT flume's mean calibration factor of 0.0282 m/rev is closer to the manufacturer's suggested calibration factor than the NEFC tank's calibration factor with a mean of 0.0291 m/rev. According to C. E. Casagrande, President of General Oceanics, (personal communication) the General Oceanics calibration factor was based on a series of 15-m tows made several years ago. Tows of such short distance probably would not reveal any significant differences between flowmeters. The tests made in the MIT flume and the NEFC tank were of sufficient duration (495 and 740 m) to select individual differences between flowmeters and are, therefore, probably more reliable. Also, there have been numerous design changes in the General Oceanics flowmeter since this calibration factor was determined, and yet their original calibration curve (Figure 3) is still in use.

The analyses presented in this paper have shown that differences between individual flowmeters are greater than those between tanks. Consequently, calibration factors produced by the NEFC tank are more accurate and precise than the factory specifications and the calibration made at sea.

Literature Cited

Arnold, G. P. 1969. A flume for behavior studies of marine fish. J. Exp. Biol. 51: 671-679.

Table 1. Flowmeter calibration factors from both tanks with the means, standard deviations, and t-test results.

Flowmeter No.	09	16	07	22	12	08	Mean
				MIT Flume, 10 June 1976			
M/rev	0.0289	0.0293	0.0276	0.0272	0.0278	0.0284	-
	0.0287	0.0291	0.0282	0.0283	0.0279	0.0270	-
	0.0287	0.0290	0.0280	0.0282	0.0282	0.0287	-
	0.0288	0.0289	0.0276	0.0280	0.0283	0.0274	-
	0.0290	0.0288	0.0270	0.0280	0.0282	0.0279	-
Mean	0.0288	0.0290	0.0270	0.0279	0.0281	0.0279	0.0282
Standard deviation	0.00013	0.00019	0.00046	0.00043	0.00021	0.00069	0.0003
				NEFC Tank, 15 June 1976			
M/rev	0.0295	0.0293	0.0276	0.0292	0.0282	0.0297	-
	0.0298	0.0296	0.0281	0.0295	0.0284	0.0298	-
	0.0297	0.0299	0.0280	0.0294	0.0285	0.0297	-
	0.0298	0.0296	0.0281	0.0294	0.0282	0.0298	-
	0.0297	0.0300	0.0285	0.0295	0.0286	0.0297	-
Mean	0.0297	0.0296	0.0280	0.0294	0.0283	0.0297	0.0291
Standard deviation	0.00012	0.00027	0.00032	0.00012	0.00018	0.00005	0.0002
t-test values for mean calibration factors of each flowmeter[a]	11.00[b]	4.37[b]	1.51	7.25[b]	2.38[b]	5.94[b]	5.41
t-test values for mean standard deviations of each tank[c]	-	-	-	-	-	-	1.81

[a]Confidence level = 5%; critical value = 1.86.

[b]Significant difference.

[c]Confidnece level = 5%; critical value = 1.81.

Table 2. Ranges in calibrations recorded for all flowmeters in both tanks translated into meters traveled, cubic meters of water filtered (during 8,000 revolutions or the equivelent of a 100-m ICNAF double oblique tow), and the absolute and percentage differences between the two.

Flowmeter No.	Calibration factor	Meters traveled	Cubic meters filtered[a]	Difference in cubic meters filtered	Percent change
			MIT Flume		
09	0.0287	2,296	670.9		
	0.0290	2,320	678.0	7.1	1.0
16	0.0288	2,304	673.3		
	0.0293	2,344	685.0	11.7	1.7
07	0.0270	2,160	631.2		
	0.0280	2,240	654.6	23.4	3.7
22	0.0270	2,176	635.9		
	0.0283	2,264	661.6	25.7	4.0
12	0.0278	2,224	649.9		
	0.0283	2,264	661.6	11.7	1.8
08	0.0270	2,160	631.2		
	0.0287	2,296	670.9	39.7	6.2
Mean				19.8	3.06
			NEFC Tank		
09	0.0295	2,360	689.7		
	0.0298	2,384	696.7	7	1.0
16	0.0293	2,344	685.0		
	0.0300	2,400	701.3	16.3	2.3
07	0.0276	2,208	645.2		
	0.0285	2,280	666.3	21.1	3.1
22	0.0292	2,336	682.6		
	0.0295	2,360	689.7	7.1	1.0
12	0.0282	2,256	659.3		
	0.0286	2,288	668.6	9.3	1.3
08	0.0297	2,376	694.3		
	0.0298	2,384	696.7	2.4	0.3
Mean				10.5	1.5

[a] Includes tenths of a revolution (sixth digit of General Oceanic flowmeters). Formula for cubic meters of water filtered (M^3) is:

$$M^3 = A\,(80{,}000 \cdot CF),$$

where: A = area of mouth of net, and

CF= calibration factor.

Figure 1. NEFC flowmeter-testing tank.

Figure 2. Schematic diagram of flowmeter propulsion system in NEFC tank. A = vertical right-angle shaft; B = cam-operated electronic counter; C = guy wires for arms; D = aluminum dowel; E = Delrin bushing; F = swing arms; G = piano wire; H = coupling; I = small barb; J = nylon twine; K = eyebolt; L = cleat; and M = flowmeter location.

Figure 3. Relationship between the number of flowmeter revolutions in the NEFC tank and the number of impeller revolutions on the flowmeter.

Figure 4. Relationship between the velocity of the flowmeter in the water and the readings on the flowmeter. The actual data points for the counts/sec data were mean values from tests of four flowmeters. These mean values were within $\pm$ 3% of all test values for water velocities $\geq$35 cm/sec. The values for individual flowmeters were linear to within $\pm$ 1% for all water velocities $\geq$35 cm/sec.

Figure 5. Typical bell curves for the standard deviations of flowmeter calibration values generated in both tanks.

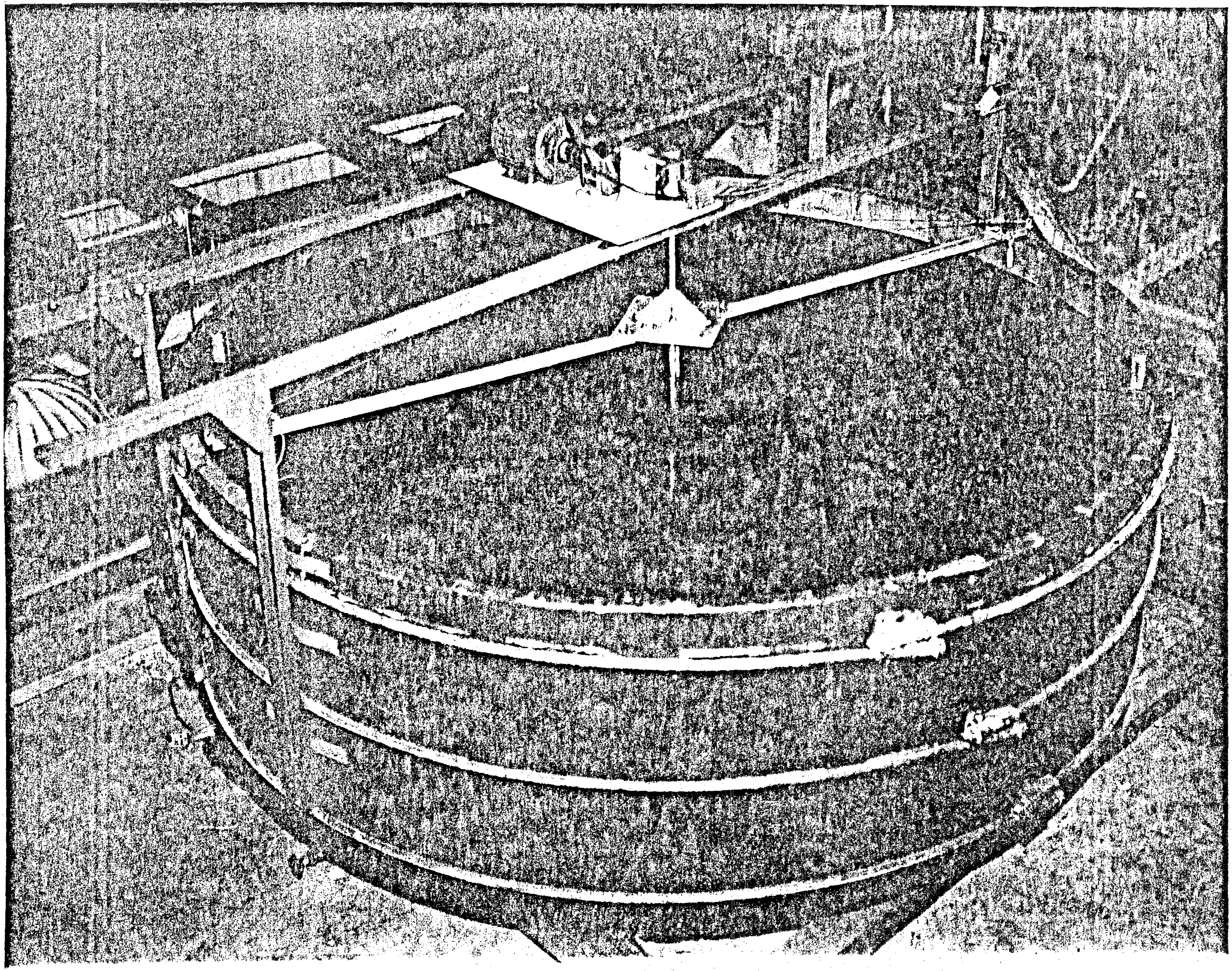


Fig.1

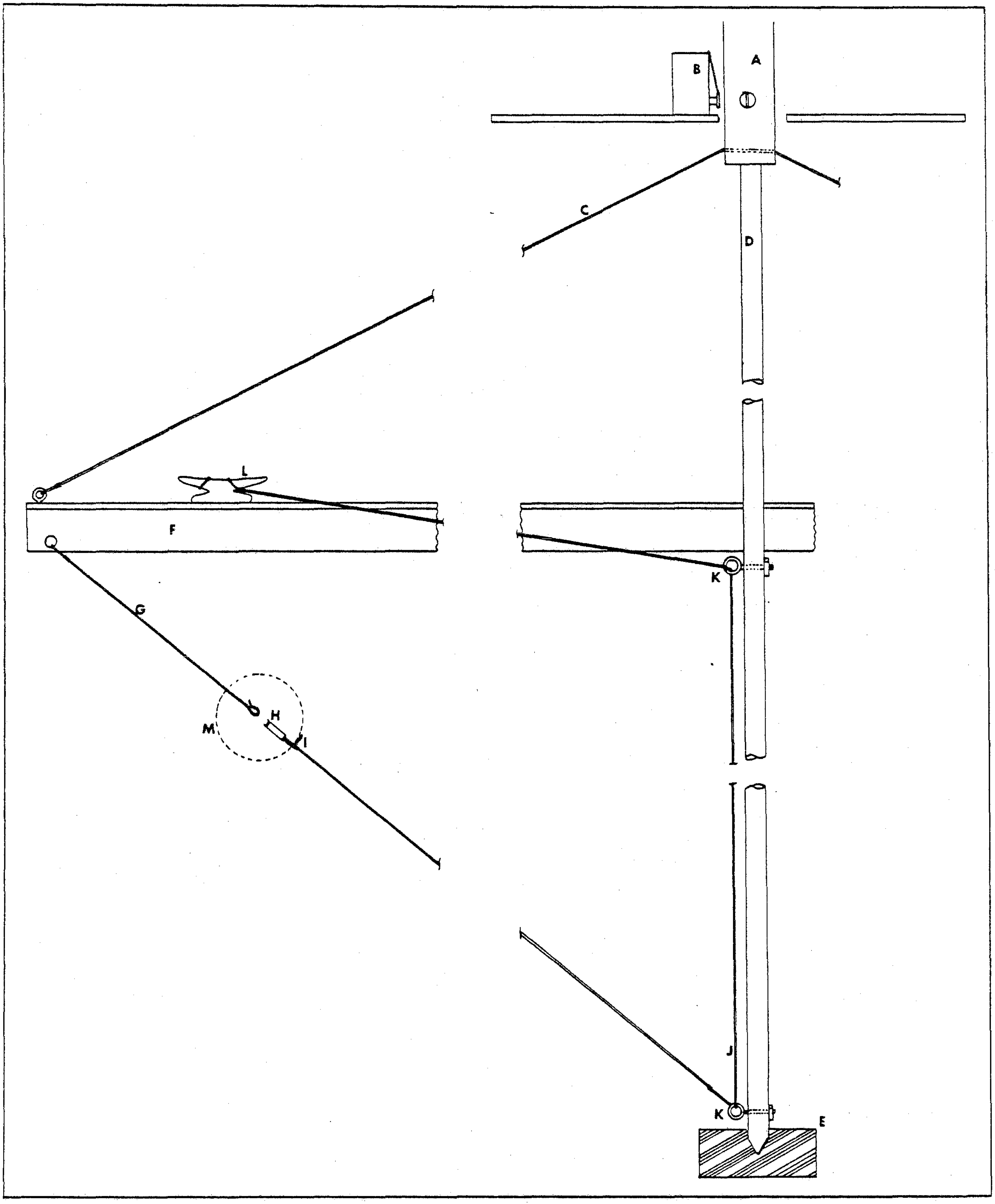
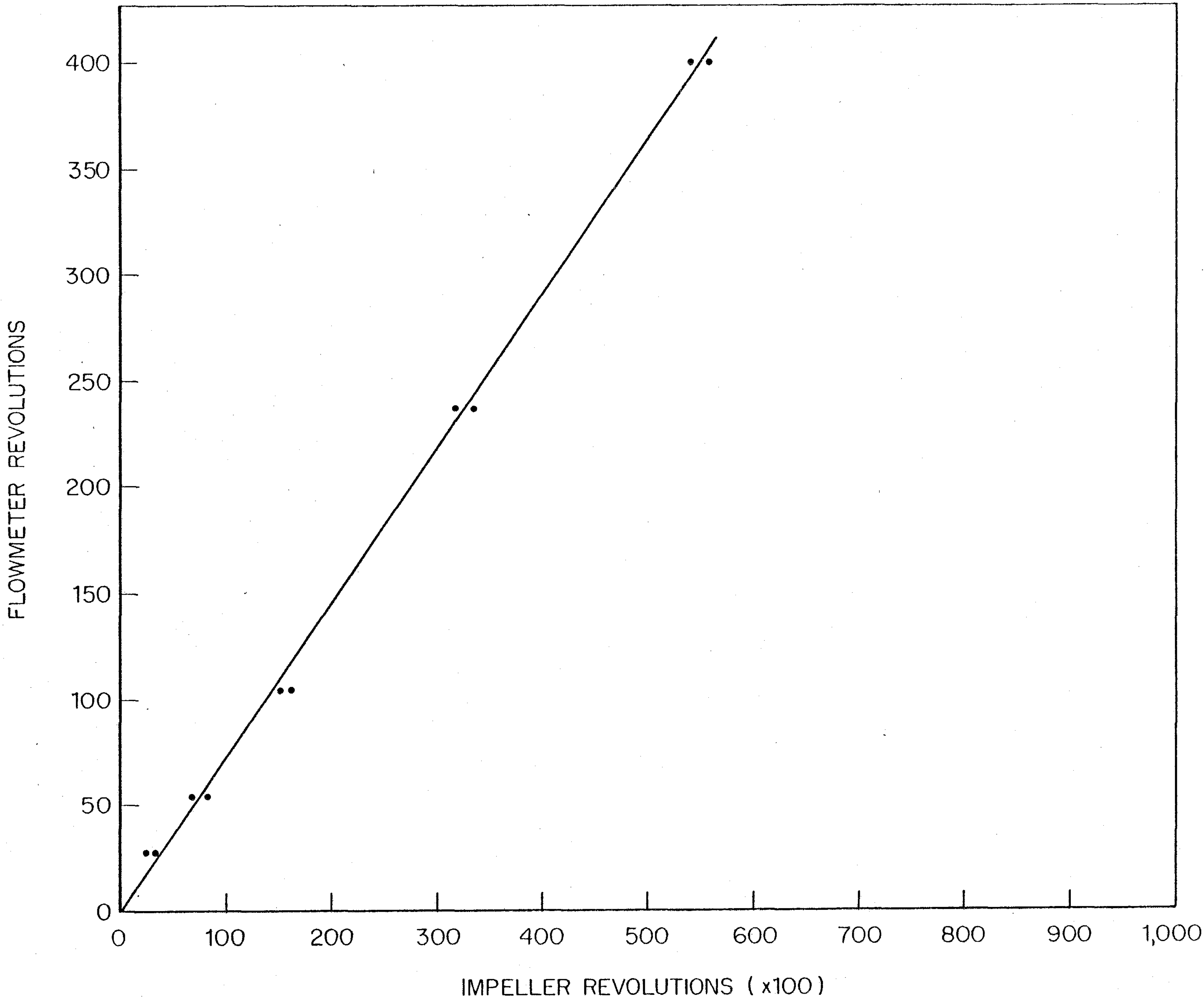
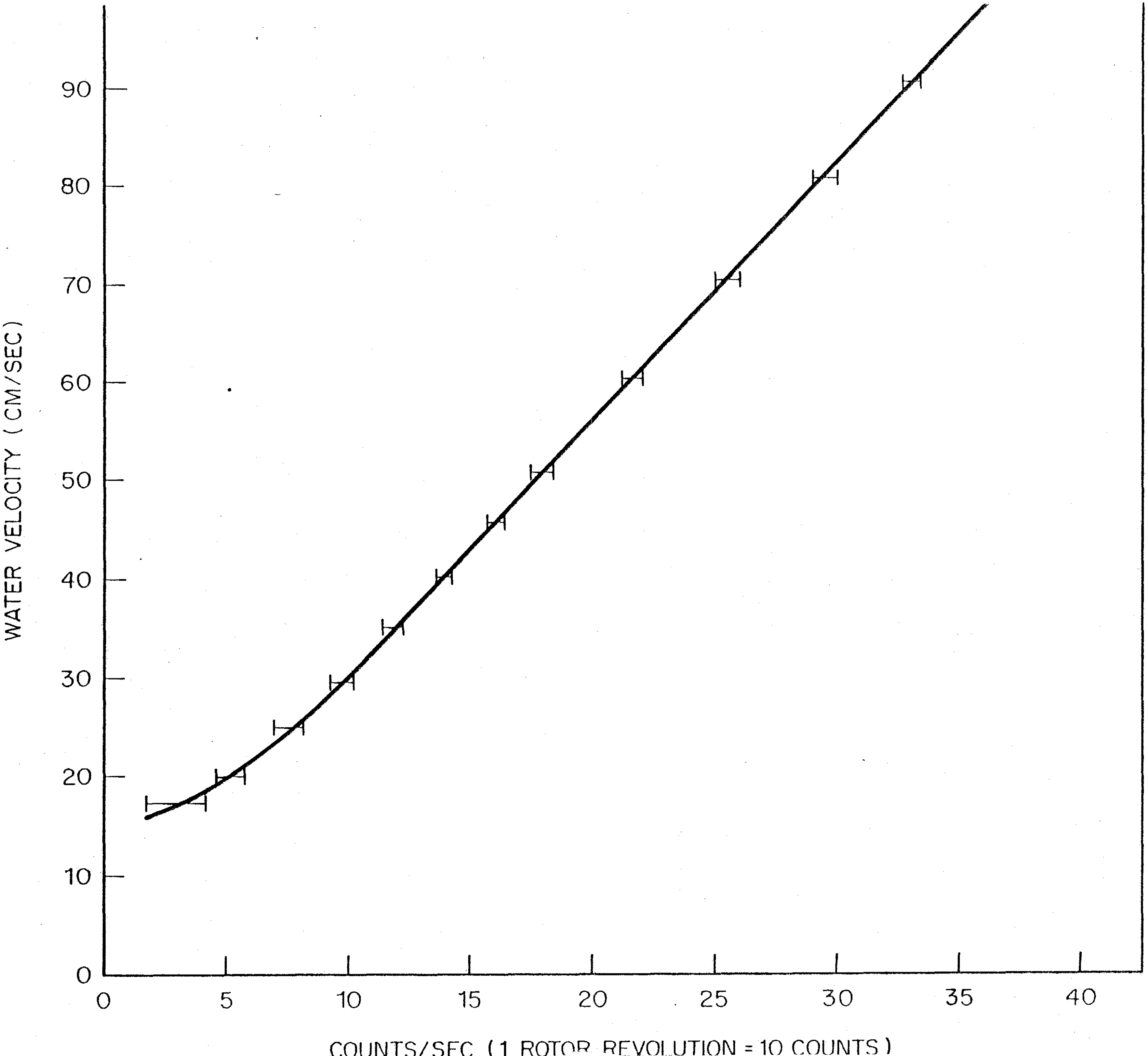


Fig.2

Fig.3



FLOWMETER REVOLUTIONS
400
350
300
250
200
150
100
50
0
0
100
200
300
400
500
600
700
800
900
1,000
IMPELLER REVOLUTIONS (x100)



WATER VELOCITY (CM/SEC)
0
10
20
30
40
50
60
70
80
90
0
5
10
15
20
25
30
35
40
COUNTS/SEC (1 ROTOR REVOLUTION = 10 COUNTS)

Fig.4

Fig.5