HYDRAULICS RESEARCH DIVISION

Technical Note

DATE: December 1977 REPORT NO: 77-17

TITLE: Determination of Waiting Times Between Successive Runs when Calibrating Price 622AA Type Current Meters in a Towing Tank

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REASON FOR REPORT: This report summarizes the tests conducted in the first of seven experiments to assess the performance of the Price 622AA type current meter. These experiments are conducted under Hydraulics Research Division Study H77-012.

CORRESPONDENCE FILE NO:

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1.0 INTRODUCTION

Current velocities in a river, lake or other body of water are measured by placing the current meter into the flow and recording the rate of rotation of the rotor. The relationship between the linear current velocity and the revolution of the meter rotor is normally determined by calibrating the meter in a towing tank. Current meters are calibrated by towing them at different velocities over their working range.

Each time that a meter is towed through the water, it causes a disturbance which lasts for some time depending on the size and speed of the meter. Questions have been raised regarding the need for a waiting time between successive tows to allow the water in the tank to "settle down". This report describes a series of tests conducted in the Hydraulics Division's towing tank, Figure 1.1, to provide answers to the following questions:

1. What is the minimum waiting time, if any, for a single meter calibration?
2. If waiting times are required, how do they vary with towing speed?

Answers to these questions are necessary for efficient scheduling of the calibration of a large number of current meters processed every year by the Hydraulics Research Division.

This report is the first of a series investigating the performance characteristics of the Price 622AA current meter (Engel, 1977).

2.0 EQUIPMENT AND APPARATUS

2.1 Meter Suspension

One reference Price 622AA Meter No. 1-061 drawn at random from inventory was used, with a 27 Kg (50 lb) Columbus weight together with a flat steel hanger bar as shown in Figure 2.1.

2.2 Towing Tank

The tank, constructed of reinforced concrete, founded on piles, is 122 metres long and 5 metres wide. The full depth of the tank is 3 metres of which 1.5 metres is below ground level. Normally, the water depth is maintained at 2.7 metres. Concrete was chosen for its stability, vibration reduction and to reduce possible convection currents.

At one end of the tank is an overflow weir. Waves arising from towed current meters and their suspensions are washed over the crest, reducing wave reflections. Parallel to the sides of the tank, perforated beaches serve to dampen lateral surface wave disturbances. The large cross-section of the tank also inhibits the generation of waves by the towed object.

2.3 Towing Carriage

The carriage is 3 metres long, 5 metres wide, weighs 6 tons and travels on four precision machined steel wheels.

The carriage is operated in three overlapping speed ranges:

0.5 cm/sec -	6.0 cm/sec
5.0 cm/sec -	60 cm/sec
50 cm/sec -	600 cm/sec

In all speed ranges the constant speed is well within a tolerance of ±1% of the mean. The maximum speed of 600 cm/sec can be maintained for 12 seconds within the specified tolerance. Tachometer generators connected to the drive shafts emit a voltage signal proportional to the speed of the carriage. A feedback control system uses these signals as input to maintain the constant speed within the specified tolerance.

2.4 Data Acquisition Module

For contact closure meters, such as the Price 622AA, the pulses generated by the meter rotor are transmitted to a data acquisition module in the control room. Four channels are provided since four meters may be calibrated simultaneously.

A permanent record of velocity and distance is provided by a digital printout in the control room. For contact closure meters, the number of revolutions of the meter rotor and time are also recorded on the printout. The printer can be engaged for several printing intervals from 1 to 10 seconds. The velocity and position of the carriage can also be monitored continuously on a visual display in the control room.

Time is measured with a crystal clock. The basic clock frequency is obtained from a 10 MHz oscillator contained within the frequency counter used to measure velocity. This frequency is divided down to provide a continuous 1 KHz clock which is used for overall synchronization purposes. The KHz clock is further divided down to provide a clock frequency of 100 Herts which is used for the measurement of the elapsed time between successive current meter pulses.

3.0 EXPERIMENTAL PROCEDURE

3.1 Meter Preparation

Prior to testing the meter underwent the following inspection:

(a) the diameter of the rotor was measured and recorded

(b) the pentagear was checked for binding

(c) the contact wire was cleaned and adjusted for tension to provide good contact

(d) the balance weight in the tail fin was adjusted to provide proper balancing

(e) all moving parts were lubricated

Following the inspection, the meter was hung in a wind tunnel where it was spun for two hours to ensure that all moving parts were "run in". The meter was then attached to the flat steel hanger bar, 40 cm above the 27 Kg (50 lb) weight instead of the normal 22 cm, Figure 2.1. This provided extra ensurance that turbulence created by the weight would in no way affect the meter (Engel, 1977). The meter assembly was attached to a co-axial cable which could be raised and lowered with a winch on the towing carriage.

3.2 Towing Tests

The meter was lowered into position 90 cm below the water surface and a reference marker was attached to the cable for easy repositioning of the meter at this depth after each run. The position of the winch on the towing carriage ensured that the meter was always placed on the centre line of the towing tank. The speed control was set at the desired tow speed and care was taken that the meter assembly was stable before velocity measurements were made. At the end of a run, when the carriage came to a complete stop, the assembly was winched out of the water and a stop watch started to initiate commencement of the waiting period. The carriage was then returned to its original starting position and the meter and weight assembly lowered to the cable reference mark. The water temperature was recorded once during each test and remained constant at 9.8^{o}C.

Tests were made at velocities of 20, 40, 80, 160 and 320 cm/sec. Tests were conducted, while holding a velocity fixed, over a range of waiting times which began at the shortest possible time and increased in one minute intervals up to ten minutes followed by 12, 15, 17, 20 and 30 minute intervals. Each of these series was repeated at least once.

Two complete sets of tests were conducted. In the first set a "dummy" run at the velocity being tested was made at the start in order to create the proper degree of pre-run disturbance. These tests were referred to as being under "ambient velocities". In the second set of tests each run at a fixed velocity was preceded by a "dummy" run at 320 cm/sec. These tests were referred to as "320 cm/sec reference velocity tests". These two different conditions were tested in order to see to what degree pre-run disturbance of the tank might affect the length of waiting times.

After each run the velocity data print-out from the data acquisition module was checked to ensure that there was no more than 1% deviation from the mean. The velocity together with the meter revolutions and elapsed time to measure the revolutions was then recorded for later analysis. In all cases, tests at a given constant velocity were only begun if the towing tank had remained undisturbed for at least one half day.

The data for the ambient "velocity" tests are given in Appendix A and the data for the "320 cm/s reference velocity" tests are given in Appendix B.

4.0 DATA ANALYSIS

4.1 Effect of Waiting Times at Ambient Velocity Conditions

Values of N were plotted (N=revolutions/sec) versus waiting time T for fixed values of towing speed V in Figure 4.1. The plotted data represent two tests for each velocity conducted on different days. The data clearly "imply" noticeably different curves. It is not clear why this occurs since great care was taken to create the same ambient conditions for each day. To assess the significance of this apparent anomaly, the average percent error between the two tests was computed by taking the data of the first day as reference base and computing the difference from the data of the second day for each waiting time tested. This was done for each constant velocity and the average and standard deviation of the percent error are given in Table 4.1. The percent error clearly decreases as speed increases.

When the velocity is 20 cm/sec, Grindley (1971) has shown that the uncertainty in a calibration of the Price 622AA meter is about two percent. The difference between the two tests at this speed from Table 4.1 is clearly less and hence for present purposes is considered insignificant. For velocities greater than 30 cm/sec, the relationship between velocity and revolutions/sec (i.e. calibration curve) is linear (Engel, 1976). In this region, a typical equation for the Price 622AA meter is given by

$$V = 67.5\,N + 1.00 \qquad \text{... 4.1}$$

where: V = velocity in cm/s

N = rev/sec

The relative error in N due to an error in V can thus be expressed as

$$\frac{dN}{N} = \frac{1}{67.5}\left[67.5 + \frac{1.00}{N}\right]\frac{dV}{V} \qquad \text{... 4.2}$$

Since the relative error of V for the towing carriage is $\pm 1\%$ then the relative percent error in N is

$$\frac{dN}{N} = \left[1.000 + \frac{0.0148}{N}\right]\% \qquad \text{... 4.3}$$

Other system errors, such as measurement of time to obtain N, are very small in relation to errors in V and may be ignored. Therefore, the relative error expressed by Equation 4.3 is a sufficiently accurate estimate for present purposes.

Values of dN/N in percent from Equation 4.3 are given in Table 4.2. The results clearly show that the differences in the two tests from Table 4.1 are always less than the allowable relative error for the same velocities in Table 4.2. The average differences are probably due to the meter itself and may result from minor differences in bearing friction, etc. Therefore, they may be considered to be the systematic errors, whereas the standard deviation of these differences reflect the random element of the calibration error.

The data of the two tests clearly indicate an effect on N as a result of towing the meter at the same speed after different waiting times. At the longer waiting times (i.e. T>20 min), the values of N for all speeds tested are relatively constant. However, for values of T<20 minutes at V=20 cm/sec and for values of T<10-15 minutes for V>20 cm/s, there is a distinct reduction in the value of N. This clearly indicates that some consideration must be given to waiting times between successive tows when prior disturbances in the tank are due only to the meter assembly being towed at the test speed.

4.2 Effect of Disturbance of Ambient Test Conditions

Values of N versus T from the "320 cm/sec reference velocity data were superimposed on the plots of Figure 4.1. These composites are given in Figure 4.2. These data also show that the greatest effect on N occurs when waiting times between tows at a given speed are small. This decreases as T increases and N once again becomes sensibly constant when waiting times are large. When V=20 cm/sec, it can be seen that values of N are considerably lower for values of T<7 minutes when compared with the previous tests. When V>20 cm/sec, the effects on N overall are not so clearly distinguishable. Indeed, for present purposes and within the bounds of permissible error discussed in Section 4.1, the data for the "320 cm/sec reference velocity" and for the "ambient velocity" conditions may be considered to be identical at least for velocities greater than 20 cm/sec.

4.3 Relationship Between Minimum Waiting Time and Towing Speed

Since the two data sets plotted in Figure 4.3 may be considered as practically identical, then determination of the minimum waiting time may be enhanced by approximating the plotted data by an average curve. These curves are shown superimposed on the combined data sets in Figure 4.3. Ideally, the effect on N begins at that point where the average curve departs from the horizontal segment (i.e. constant N). The corresponding value of T would logically be the minimum waiting time. However, such ideal waiting times are not realistic since they imply greater accuracy than can be achieved.

A more realistic minimum T is one for which the departures in N from the constant value are just within the "permissible" error of the meter calibration at the given velocity. These departures in N can be computed using the values of dN/N from Table 4.2, and are given together with the corresponding minimum waiting times in Table 4.3. The data from Table 4.3 were plotted as Figure 4.4.

The waiting times vary from T=10 minutes at V=20 cm/sec to T=0 minutes at V=320 cm/sec. However, considering the subjectiveness in obtaining the values of T and the inevitable scatter in these values, it was felt that the data could best be represented by a "smooth" curve rather than place too much emphasis on each individual point. Furthermore, it is the contention of the writers that as T decreases with increasing V, the rate of change of T would become progressively less and thus T would always be greater than zero over the practical range of calibration speeds. It was found that a curve given by

$$T_{min} = \frac{45}{V^{1/2}} \qquad \text{... 4.4}$$

where T_{min} = minimum waiting time

provided a reasonable approximation of the test results. This equation is also given on Figure 4.4. When V=320 cm/sec, T_{min}=2.5 minutes which is close to the minimum waiting time attainable with the towing carriage used in these tests. Therefore, from a practical standpoint, waiting times are only a concern for speeds less than 320 cm/sec.

The curve of Equation 4.4 in Figure 4.4 indicates a rapid increase in required waiting time when towing speeds become less than 100 cm/sec. For speeds greater than 100 cm/sec, the reduction in minimum waiting time is small for large changes in towing speed up to 320 cm/sec when the minimum attainable time of two minutes is reached. It is also worth noting that the results indicate a waiting time of less than ten minutes for speeds greater than 20 cm/sec which has usually been the adopted waiting time for regular Price meter calibrations.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 The waiting time is the minimum time that allows any previous disturbance to decay to a level which does not affect the calibration at the selected velocity.

5.2 For a Price 622AA current meter, the waiting time between runs varies inversely as the square root of the test velocity. The equation is

$$T_{min} = \frac{45}{V^{1/2}}$$

where T = minimum waiting time in minutes
V = test velocity in cm/s.

5.3 Disturbances prior to a calibration run do not affect the minimum waiting time significantly.

5.4 The above criteria cannot be applied to simultaneous calibration of more than one meter. Further tests are required to determine waiting time for such conditions.

5.5 The results of these tests cannot be assumed to apply to other types of meters.

ACKNOWLEDGEMENTS

The writers wish to express their gratitude to Mr. C. Bil who conducted the tests and reduced all the data for analysis. Mr. Bill was ably assisted by Mr. B. Leaney and J. Dalton during the execution of the tests.

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TABLE 4.1 PERCENT DIFFERENCE IN SUCCESSIVE DATA SETS		
V cm s	E%	S_E
20	1.51	.50
40	.84	.21
80	.55	.29
160	.45	.18
320	.27	.16

E = difference in N between data sets on different days at a given waiting time

S_E = Standard deviation about average E

TABLE 4.2 PERMISSIBLE RELATIVE ERROR IN N		
V cm/s	N rev/sec	$\frac{dN}{N}$ %
20	.286	1.750
40	.574	1.028
80	1.161	1.013
160	2.325	1.006
320	4.666	1.003

TABLE 4.3	MINIMUM WAITING TIMES			
V cm/sec	N(const) rev/sec	$\frac{dN}{N}$	N_{min} rev/sec	T_{min}
20	.285	.0175	.280	9
40	.576	.0128	.568	7
80	1.163	.01013	1.151	6
160	2.330	.01006	2.307	4.5
320	4.666	.01003	4.619	0

APPENDIX A
DATA OF AMBIENT VELOCITY TESTS

TABLE A-1 TESTS AT V = 20 cm/s

RUN NO.	REVOLUTIONS	TIME (sec)	N (rev/sec)	V (cm/sec)	T minutes
TEST SET #1	September 26				
1	Dummy Run				
2	25	89.29	.280	19.931	2
3	25	89.25	.280	20.024	3
4	25	89.41	.280	20.020	4
5	25	89.69	.279	20.023	5
6	25	89.08	.281	20.024	6
7	25	88.31	.283	20.065	7
8	25	88.88	.281	19.999	8
9	25	88.55	.282	20.063	9
10	25	87.85	.285	20.015	10
11	25	87.24	.287	20.049	12
12	25	87.10	.287	19.964	15
13	25	86.57	.289	20.021	17
14	25	86.99	.287	19.968	20
15	25	86.73	.288	20.015	30
TEST SET #2					
1	Dummy Run				
2	25	90.17	.277	19.951	2
3	25	90.10	.277	20.031	3
4	25	90.67	.276	20.019	4
5	25	90.93	.275	20.032	5
6	25	90.49	.276	20.022	6
7	25	90.11	.277	20.015	7
8	25	90.01	.278	20.005	8
9	25	89.23	.280	20.037	9
10	25	89.30	.280	20.005	10
11	25	89.22	.280	19.997	12
12	25	88.66	.282	20.059	15
13	25	88.35	.283	20.048	17
14	25	88.07	.284	19.978	20
15	25	88.07	.284	20.043	30

TABLE A-2 TESTS AT V = 40 cm/sec

RUN NO.	REVOLUTIONS	TIME (sec)	N (rev/sec)	V (cm/sec)	T minutes
TEST SET #1	October 5				
1	Dummy Run				
2	40	69.88	.572	39.993	2
3	40	69.92	.572	40.010	3
4	40	70.36	.569	39.991	4
5	40	70.37	.568	39.958	5
6	40	70.31	.569	40.007	6
7	40	70.16	.570	39.980	7
8	40	70.20	.570	40.987	8
9	40	69.81	.573	40.066	9
10	40	69.53	.575	40.092	10
11	40	69.51	.575	40.023	12
12	40	69.58	.575	29.967	15
13	40	69.53	.575	39.971	17
14	40	69.41	.576	40.021	20
15	40	69.41	.579	39.957	30
TEST SET #2	October 6				
1	Dummy Run				
2	40	70.25	.569	40.021	2
3	40	70.79	.565	40.034	3
4	40	70.99	.563	40.042	4
5	40	70.99	.563	40.048	5
6	40	70.87	.564	40.056	6
7	40	70.78	.565	40.003	7
8	40	70.74	.565	40.020	8
9	40	70.23	.570	39.986	9
10	40	70.19	.570	39.999	10
11	40	70.14	.570	39.985	12
12	40	70.12	.570	39.986	15
13	40	70.01	.571	39.995	17
14	40	69.79	.573	40.123	20
15	40	69.76	.573	40.097	30

TABLE A-3 TESTS AT V = 80 cm/sec

RUN NO.	REVOLUTIONS	TIME (sec)	N (rev/sec)	V (cm/sec)	T minutes
TEST SET #1	October 7				
1	Dummy Run				
2	75	65.10	1.152	79.951	2
3	75	65.55	1.144	79.949	3
4	75	65.68	1.142	79.939	4
5	75	65.80	1.140	79.885	5
6	75	65.53	1.145	79.912	6
7	75	65.30	1.149	80.020	7
8	75	65.12	1.152	79.955	8
9	75	64.97	1.154	79.870	9
10	75	64.84	1.157	79.805	10
11	75	64.85	1.157	80.087	12
12	75	64.80	1.157	79.663	15
13	75	64.81	1.157	79.952	17
14	75	64.67	1.160	79.596	20
15	75	64.61	1.161	79.904	30
TEST SET #2	October 11				
1	Dummy Run				
2	75	65.23	1.150	79.566	2
3	75	65.08	1.152	80.217	3
4	75	65.27	1.149	79.809	4
5	75	64.92	1.155	79.643	5
6	75	65.10	1.152	79.839	6
7	75	65.31	1.148	79.832	7
8	75	64.84	1.157	79.842	8
9	75	64.58	1.161	80.155	9
10	75	64.36	1.165	80.231	10
11	75	64.46	1.164	80.130	12
12	75	64.40	1.165	80.263	15
13	75	64.61	1.161	80.138	17
14	75	64.48	1.164	80.189	20
15	75	64.87	1.156	79.930	30

TABLE A-4 TESTS AT V = 160 cm/sec

RUN NO.	REVOLUTIONS	TIME (sec)	N (rev/sec)	V (cm/sec)	T minutes
TEST SET #1	October 21				
1	Dummy Run				
2	80	34.63	2.310	159.981	2
3	80	34.41	2.325	159.714	3
4	80	34.54	2.316	160.010	4
5	80	34.53	2.317	159.676	5
6	80	34.49	2.320	160.170	6
7	80	34.62	2.311	159.867	7
8	80	34.65	2.309	159.926	8
9	80	34.45	2.322	159.849	9
10	80	34.45	2.322	159.907	10
11	80	34.39	2.326	159.954	12
12	80	34.38	2.327	160.139	15
13	80	34.39	2.326	160.059	17
14	80	34.35	2.329	160.116	20
15	80	34.32	2.331	159.123	30
TEST SET #2	November 7				
1	Dummy Run				
2	80	34.61	2.311	159.741	2
3	80	34.63	2.310	159.721	3
4	80	34.75	2.302	159.548	4
5	80	34.63	2.310	159.972	5
6	80	34.72	2.304	160.124	6
7	80	34.67	2.307	159.907	7
8	80	34.53	2.317	160.006	8
9	80	34.66	2.308	160.046	9
10	80	34.62	2.311	160.012	10
11	80	34.65	2.309	160.037	12
12	80	34.50	2.319	160.134	15
13	80	34.53	2.317	160.012	17
14	80	34.45	2.322	160.068	20
15	80	34.40	2.326	160.001	30

TABLE A-5 TESTS AT V = 320 cm/sec

RUN NO.	REVOLUTIONS	TIME (sec)	N (rev/sec)	V (cm/sec)	T minutes
TEST SET #1	November 8				
1	Dummy Run				
2	100	21.46	4.660	319.953	2
3	100	21.58	4.634	319.954	3
4	100	21.56	4.638	319.886	4
5	100	21.54	4.643	320.102	5
6	100	21.49	4.653	320.269	6
7	100	21.55	4.640	320.267	7
8	100	21.46	4.660	320.208	8
9	100	21.46	4.660	320.246	9
10	100	21.47	4.658	320.119	10
11	100	21.47	4.658	320.067	12
12	100	21.43	4.666	320.026	15
13	100	21.39	4.675	319.979	17
14	100	21.39	4.675	320.139	20
15	100	21.33	4.688	319.978	30
TEST SET #2	November 10				
1	Dummy Run				
2	100	21.50	4.651	319.642	2
3	100	21.56	4.638	319.908	3
4	100	21.58	4.634	320.016	4
5	100	21.58	4.634	320.062	5
6	100	21.57	4.636	319.987	6
7	100	21.62	4.625	319.927	7
8	100	21.57	4.636	320.150	8
9	100	21.52	4.647	320.044	9
10	100	21.52	4.647	319.986	10
11	100	21.45	4.662	319.989	12
12	100	21.46	4.660	319.846	15
13	100	21.45	4.662	320.046	17
14	100	21.48	4.655	319.901	20
15	100	21.46	4.660	320.092	30

APPENDIX B

DATA OF 320 cm/sec REFERENCE VELOCITY TESTS

TABLE B-1 TESTS AT V = 20 cm/sec

RUN NO.	REVOLUTIONS	TIME (sec)	N (rev/sec)	V (cm/sec)	T minutes
TEST SET #1	November 15				
1	Dummy Run			320	-
2	25	93.99	.266	20.016	2
3	25	93.19	.268	20.021	5
4	25	92.24	.271	20.005	7
5	25	89.69	.279	20.007	10
6	25	88.54	.282	20.005	15
7	25	87.65	.285	20.016	20
8	25	92.04	.271	20.002	12
9	25	89.37	.279	20.010	17
10	25	88.49	.282	20.009	30
11					
12					
13					
14					
15					
TEST SET #2	December 8				
1	Dummy Run			320	
2	25	93.42	.268	20.009	3
3	25	93.23	.271	20.008	5
4	25	91.33	.274	20.009	7
5	25	89.58	.279	20.005	10
6	25	89.01	.281	20.003	12
7	25	88.10	.284	20.002	15
8	25	88.35	.283	20.008	20
9	25	88.29	.283	20.006	33
10	25				
11					
12					
13					
14					
15					

TABLE B-2 TESTS AT V = 40 cm/sec

RUN NO.	REVOLUTIONS	TIME (sec)	N (rev/sec)	V (cm/sec)	T minutes
TEST SET #1	November 22				
1	Dummy Run			320	
2	40	71.12	.562	40.015	3
3	40	70.73	.566	40.021	5
4	40	70.12	.570	40.016	7
5	40	69.62	.575	40.027	10
6	40	69.40	.576	40.105	12
7	40	69.12	.579	40.069	15
8	40	69.06	.579	40.005	17
9	40	68.94	.580	40.029	20
10	40	69.58	.575	40.004	30
11					
12					
13					
14					
15					
TEST SET #2	December 8				
1	Dummy Run			320	
2	40	70.71	.566	3	
3	40	71.07	.563	5	
4	40	70.40	.568	7	
5	40	70.17	.570	10	
6	40	70.07	.571	12	
7	40	70.12	.570	15	
8	40	69.43	.576	20	
9	40	69.08	.579	30	
10					
11					
12					
13					
14					
15					

TABLE B-3 TESTS AT V = 80 cm/sec

RUN NO.	REVOLUTIONS	TIME (sec)	N (rev/sec)	V (cm/sec)	T minutes
TEST SET #1	November 22				
1	Dummy Run			320	
2	75	65.33	1.148	80.020	3
3	75	65.30	1.149	80.036	5
4	75	65.18	1.151	80.050	7
5	75	64.72	1.159	80.056	10
6	75	64.53	1.162	79.994	12
7	75	63.72	1.177	80.034	30
8	75	64.35	1.166	80.054	20
9					
10					
11					
12					
13					
14					
15					
TEST SET #2					
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					

TABLE B-4 TESTS AT V = 160 cm/sec

RUN NO.	REVOLUTIONS	TIME (sec)	N (rev/sec)	V (cm/sec)	T minutes
TEST SET #1	November 24				
1	Dummy Run			320	
2	80	34.59	2.313	160.138	3
3	80	34.75	2.302	160.055	5
4	80	34.56	2.315	160.020	7
5	80	34.43	2.324	159.999	10
6	80	34.19	2.340	160.100	12
7	80	34.15	2.343	160.019	15
8	80	34.23	2.337	160.040	20
9	80	34.20	2.339	160.034	30
10					
11					
12					
13					
14					
15					
TEST SET #2					
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					

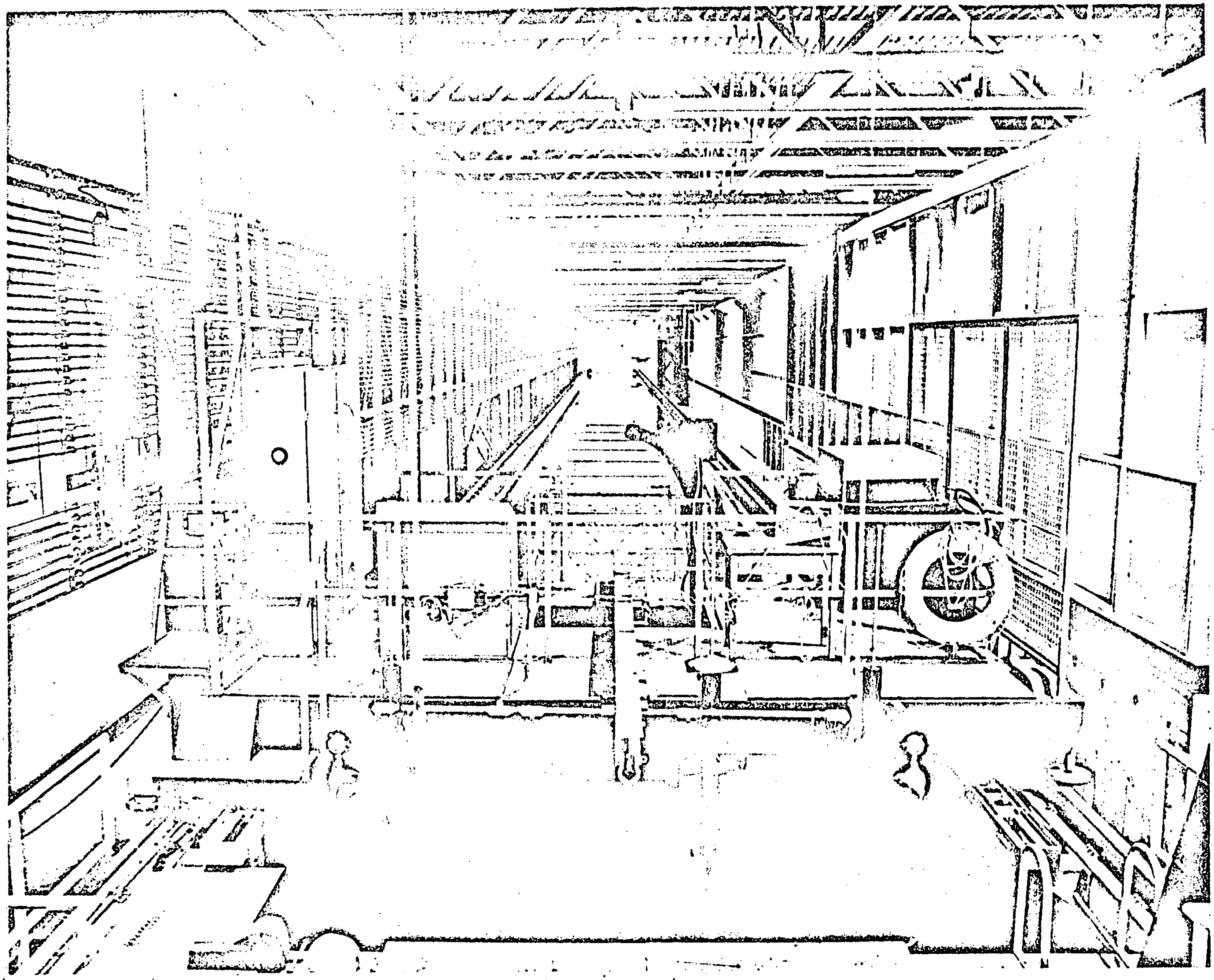


Figure 1.1 TOWING CARRIAGE AND TANK

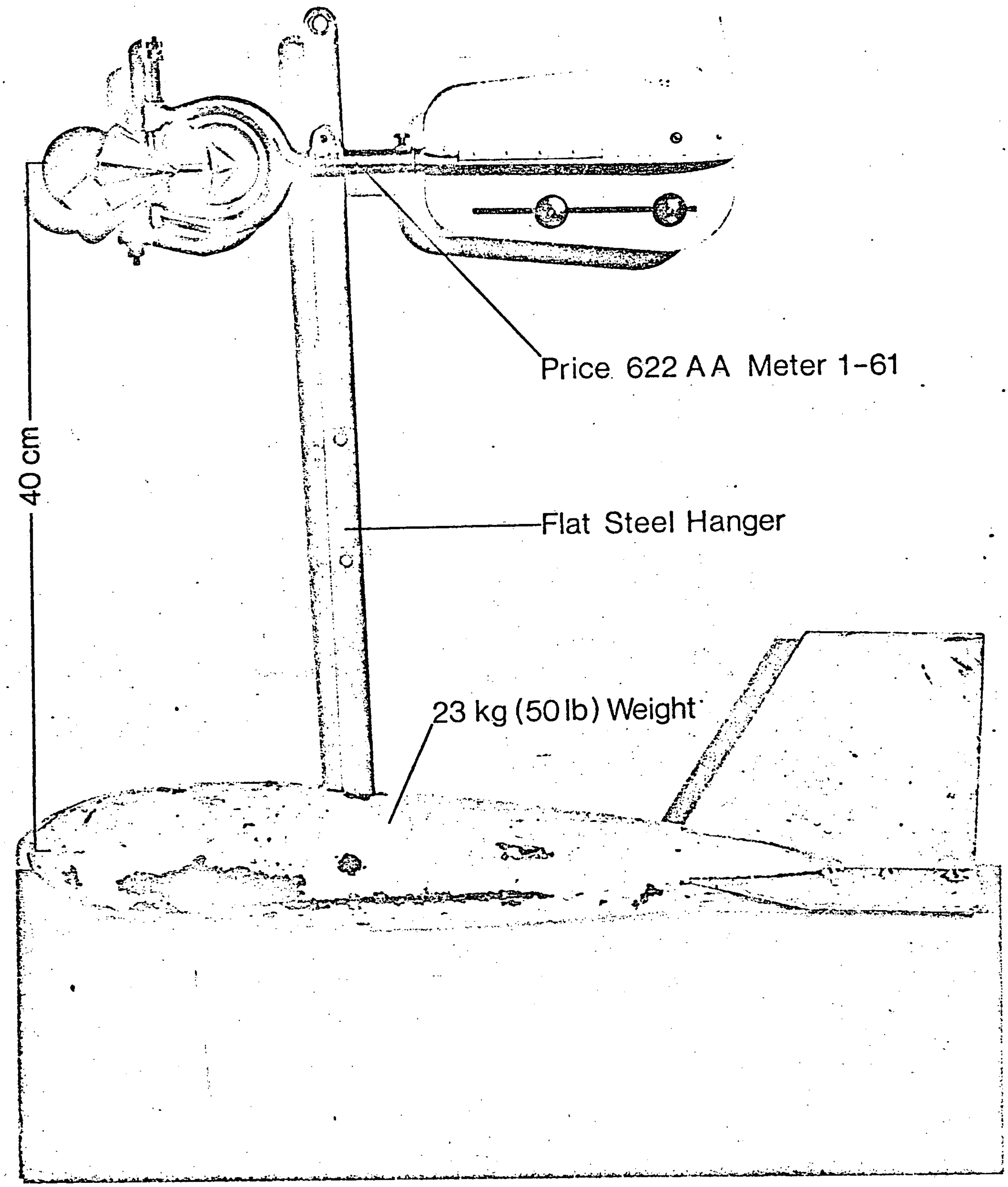


Figure 2.1 CURRENT METER ASSEMBLY

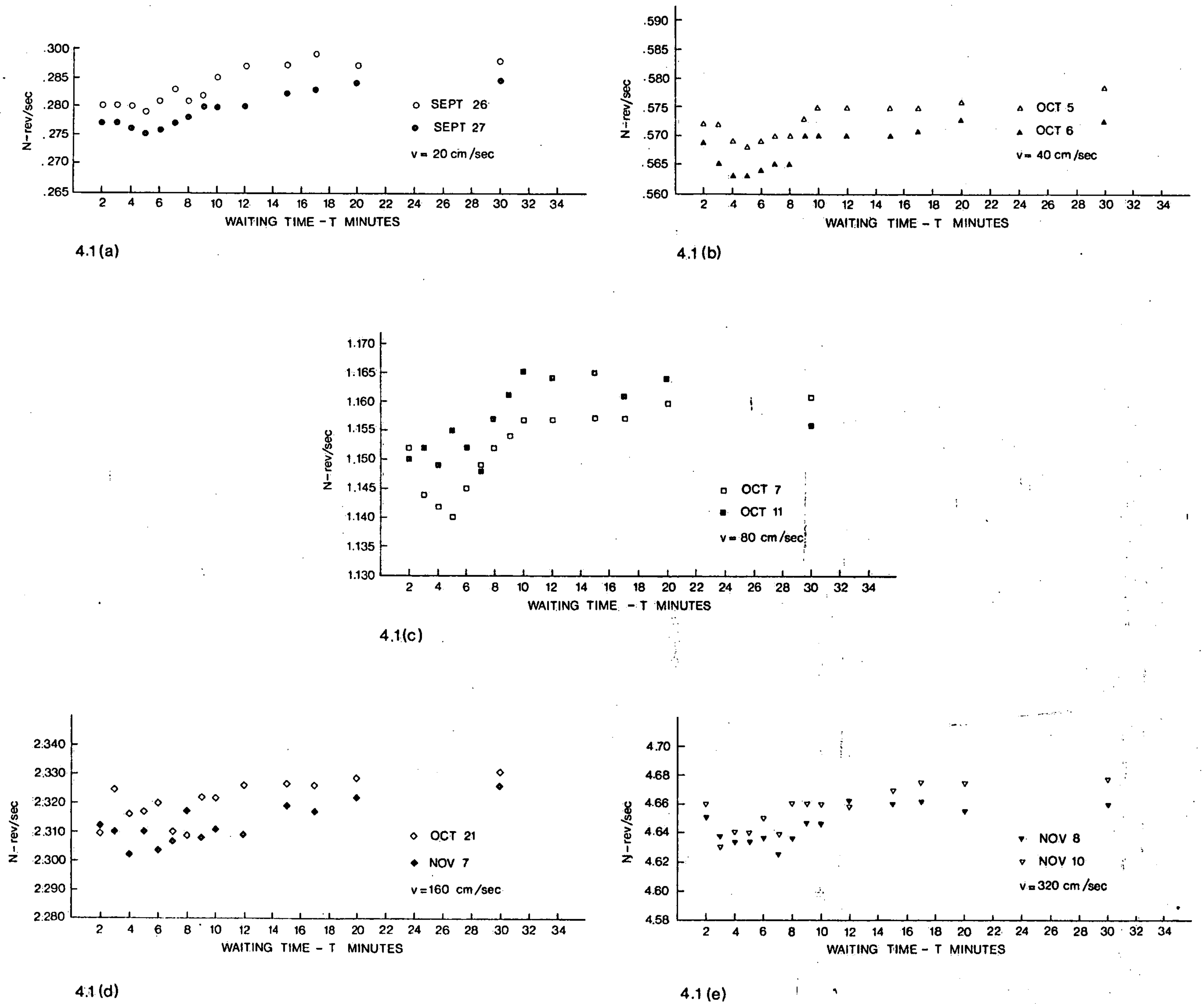
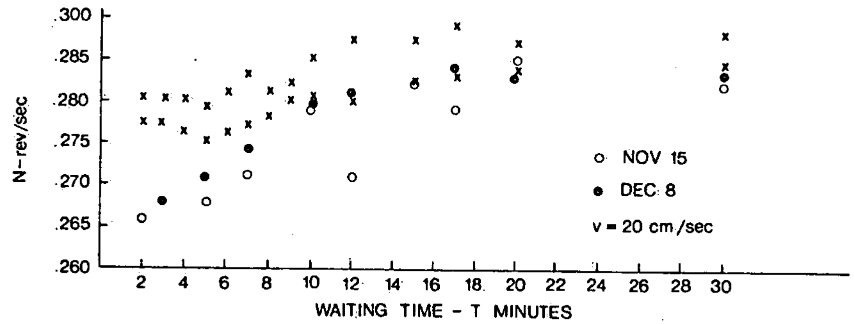
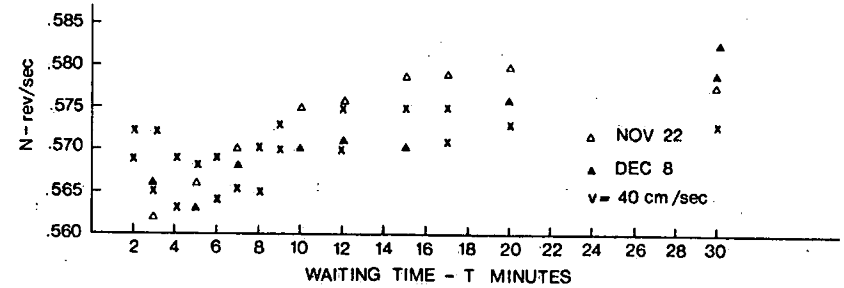


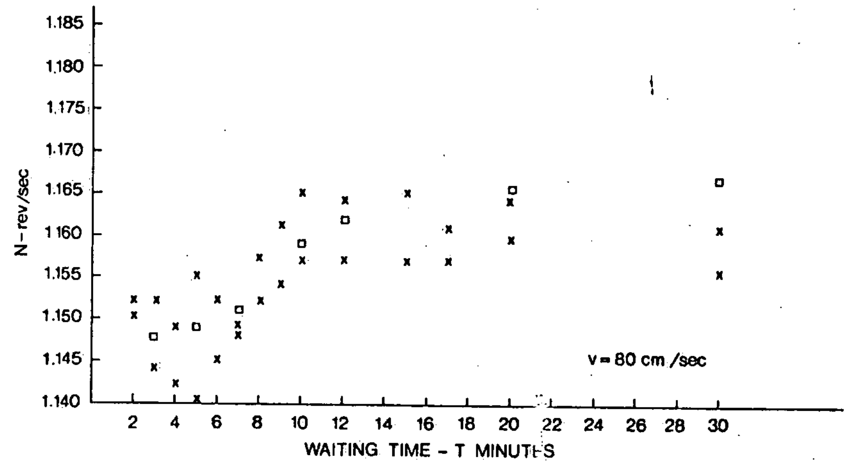
FIGURE 4.1 EFFECT OF WAITING TIME ON METER RESPONSE



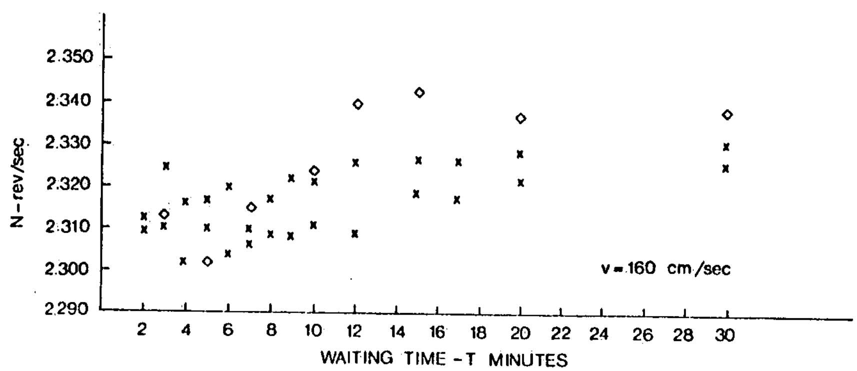
4.2 (a)



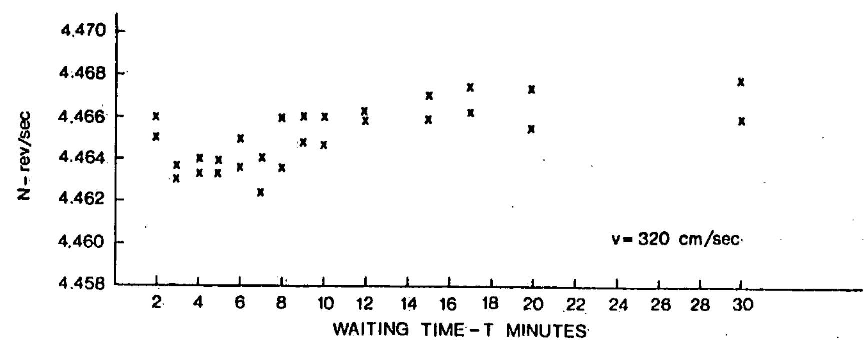
4.2 (b)



4.2 (c)

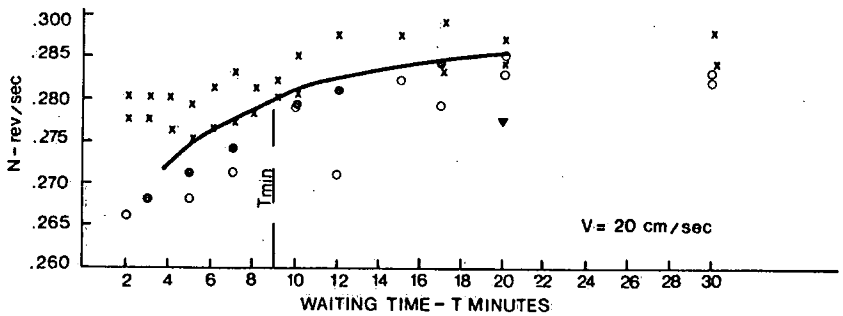


4.2 (d)

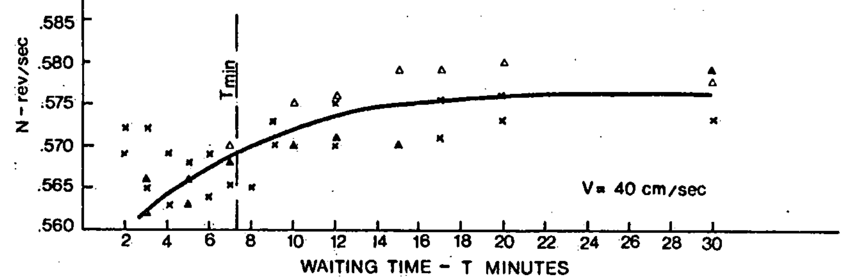


4.2 (e)

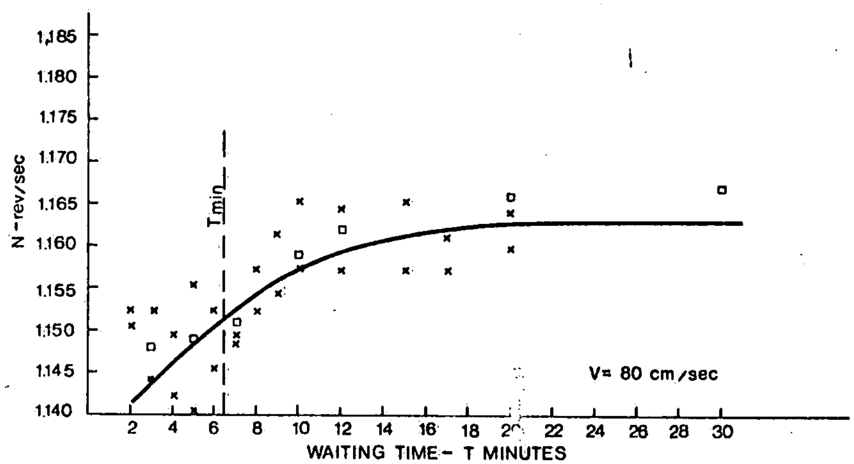
FIGURE 4.2 EFFECT OF 320 cm sec DUMMY RUNS ON METER RESPONSE
(× DATA FROM FIGURE 4.1)



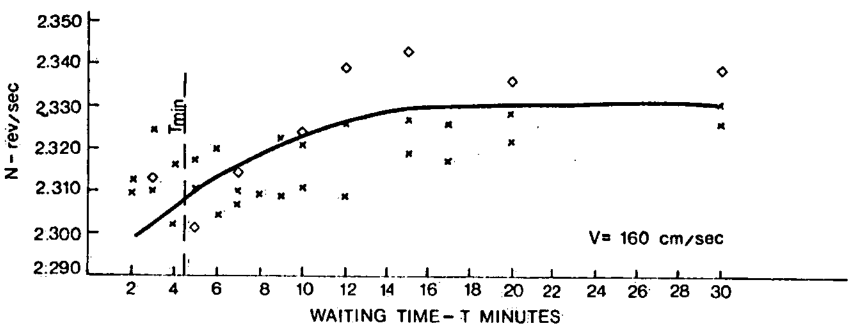
4.3 (a)



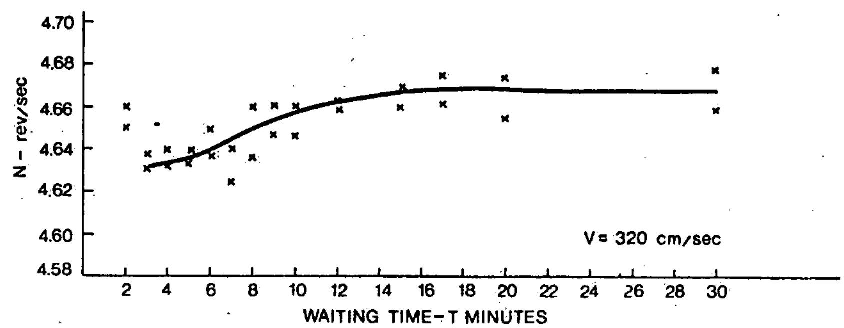
4.3 (b)



4.3 (c)



4.3 (d)



4.3 (e)

FIGURE 4.3 AVERAGE N-T CURVES TO DETERMINE T MIN.

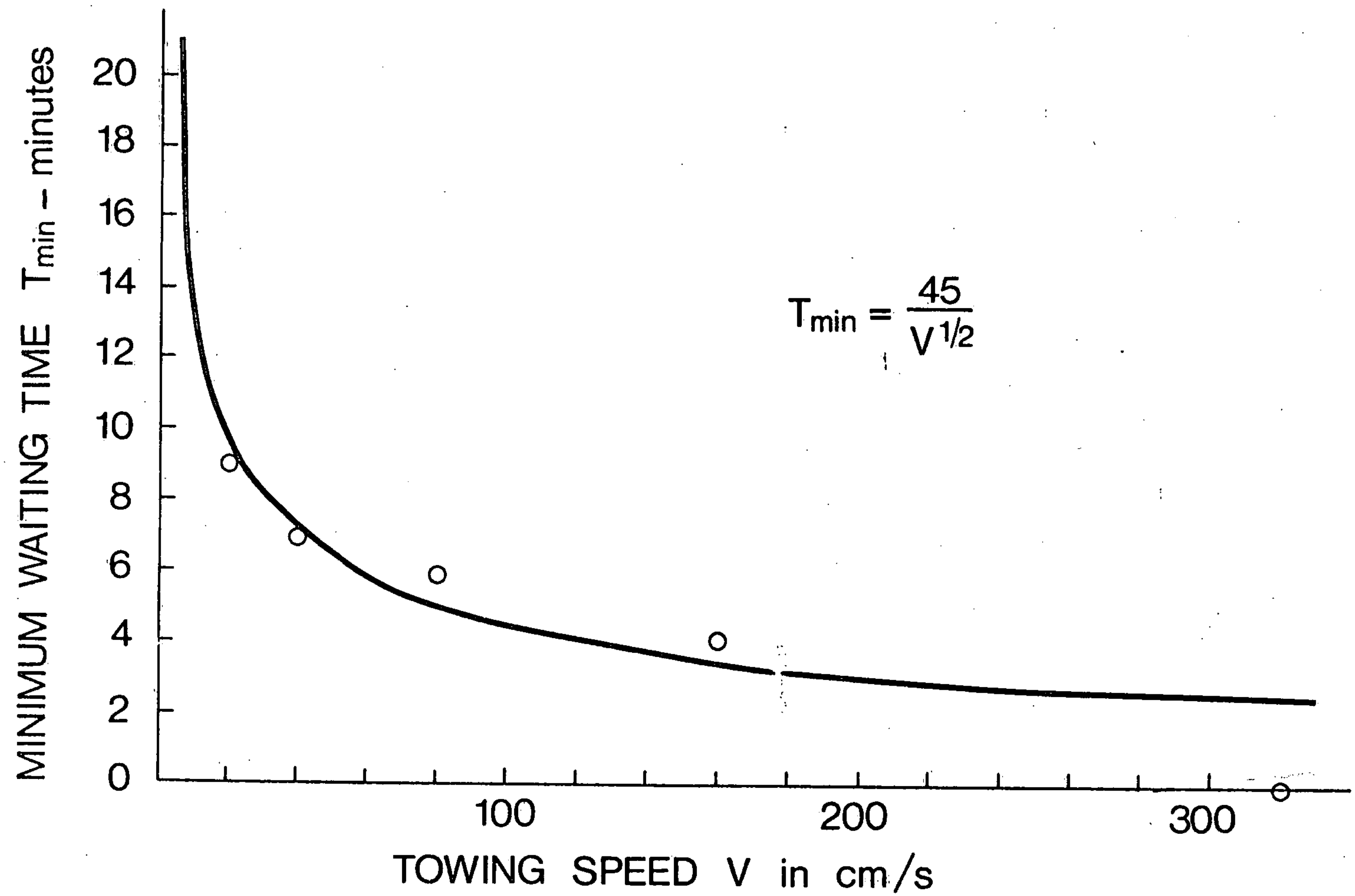


FIGURE 4.4 VARIATION OF MINIMUM WAITING TIME WITH TOWING SPEED.

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