THE UNIVERSITY OF MICHIGAN

INDUSTRY PROGRAM OF THE COLLEGE OF ENGINEERING

PERFORMANCE OF A SIMPLIFIED LOW-FLOW RATE COLD-WATER DEAERATOR

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INTRODUCTION

This report covers the preliminary investigations conducted to determine those factors covering the design of a simple, low-flow rate cold-water deaerating unit (1.0 - 1.5 gpm) to be used in a cavitation study research facility. It was found initially that a suitable unit could not be procured commercially.

A previous study(1) showed that substantial deaeration could be achieved by simply spraying the water into a highly evacuated space. This report is primarily concerned with evaluating the effects of the following design parameters on the deaeration potential for such a unit:

1) change in flow rate
2) change of absolute pressure (vacuum) in evacuated space
3) change in size (diameter)
4) change in fluid free surface area

DESCRIPTION OF APPARATUS

Figure 1 shows a cross-sectional view of the main body of the deaerating unit. It consists of a 6" diameter by 36" long steel pipe, flanged at both ends, and fitted with a sight glass.

The upper flange is drilled and tapped concentrically to receive a stainless steel "Sprayco H-5-D, Hollow Cone, Fine Spray, Medium Angle"* spray nozzle. An additional hole is provided for a vacuum-source connection; this hole is fitted internally with a baffle plate to prevent

* Manufactured by Spray Engineering Co., Burlington, Mass.

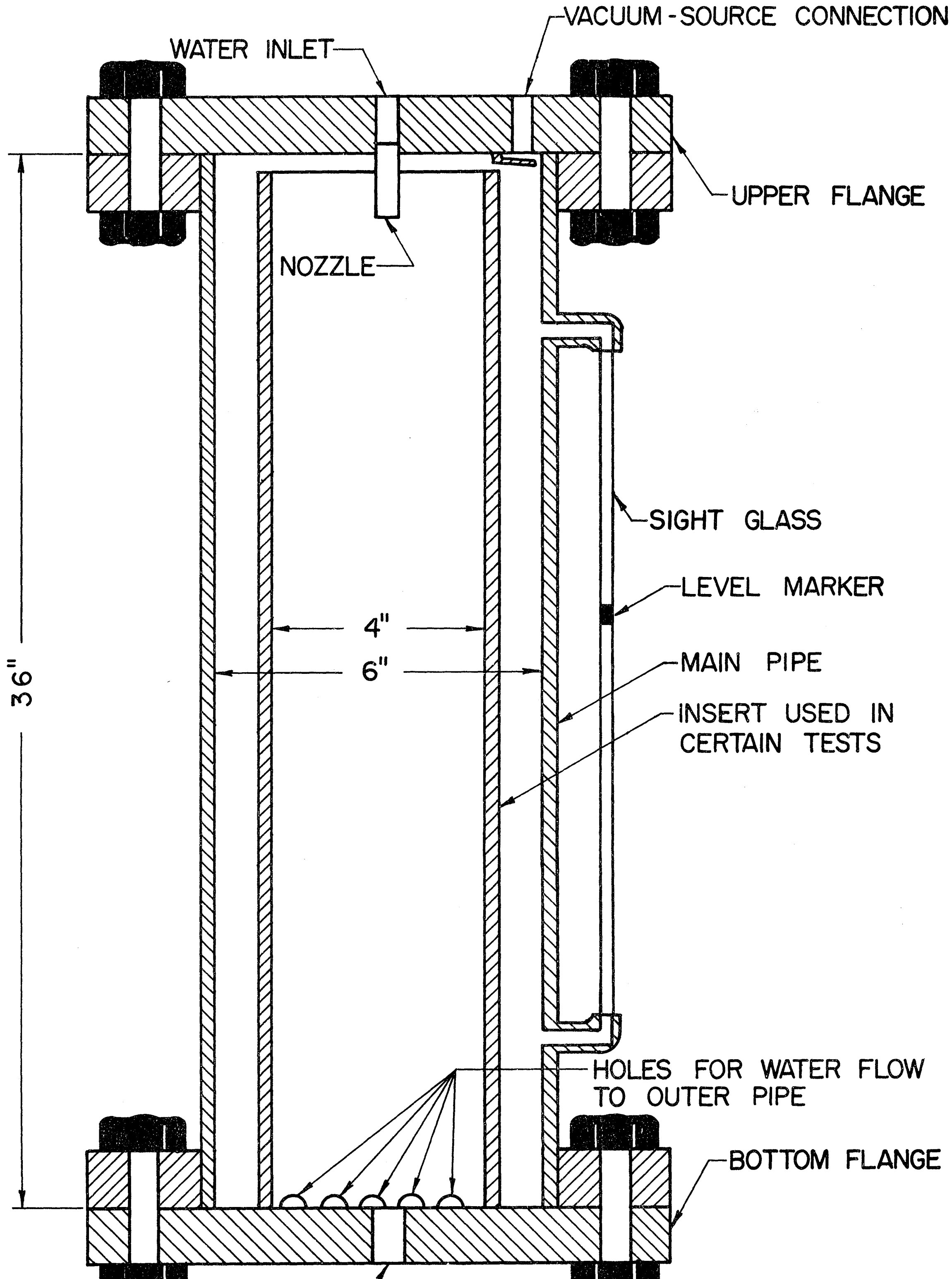

Figure 1. Cross-Sectional View of Main Body of Deaerating Unit.

spray carry-over into the vacuum system. The bottom flange is drilled and tapped concentrically to accomodate a drain valve.

Figure 1 also shows how a 4" diameter by 35" long steel pipe was concentrically fitted into the unit when experimental runs were made to determine gross effects of pipe diameter change on deaeration potential.

In the previous experimentation,(1) a screen supported by a tripod was fitted into the lower half of the unit and covered with three pounds of 1/4" Rashig rings. This was done as the first phase of determining the gross effect on percent deaeration* of increasing the exposed fluid surface area. In Figure 1, the tripod and Rashig rings have been removed.

Figure 2 shows a schematic of the complete experimental set-up. In operation, water is sprayed through the nozzle into the evacuated space, and collects in the pipe. Samples of water, taken before and after the run, are tested and the percent deaeration determined. Vacuum is maintained and regulated through the use of a "Penberthy 182A Water Jet Exhauster".**

TEST PROCEDURE

The experimental test runs were made using the following procedure (Figure 2):

1) Water was admitted into the storage tank and allowed to drain for a short period of time, after which a water

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* $\text{Percent Deaeration} = \frac{\text{Initial Air Content} - \text{Final Air Content}}{\text{Initial Air Content}} \times 100$

**Penberthy Manufacturing Co., Detroit, Michigan

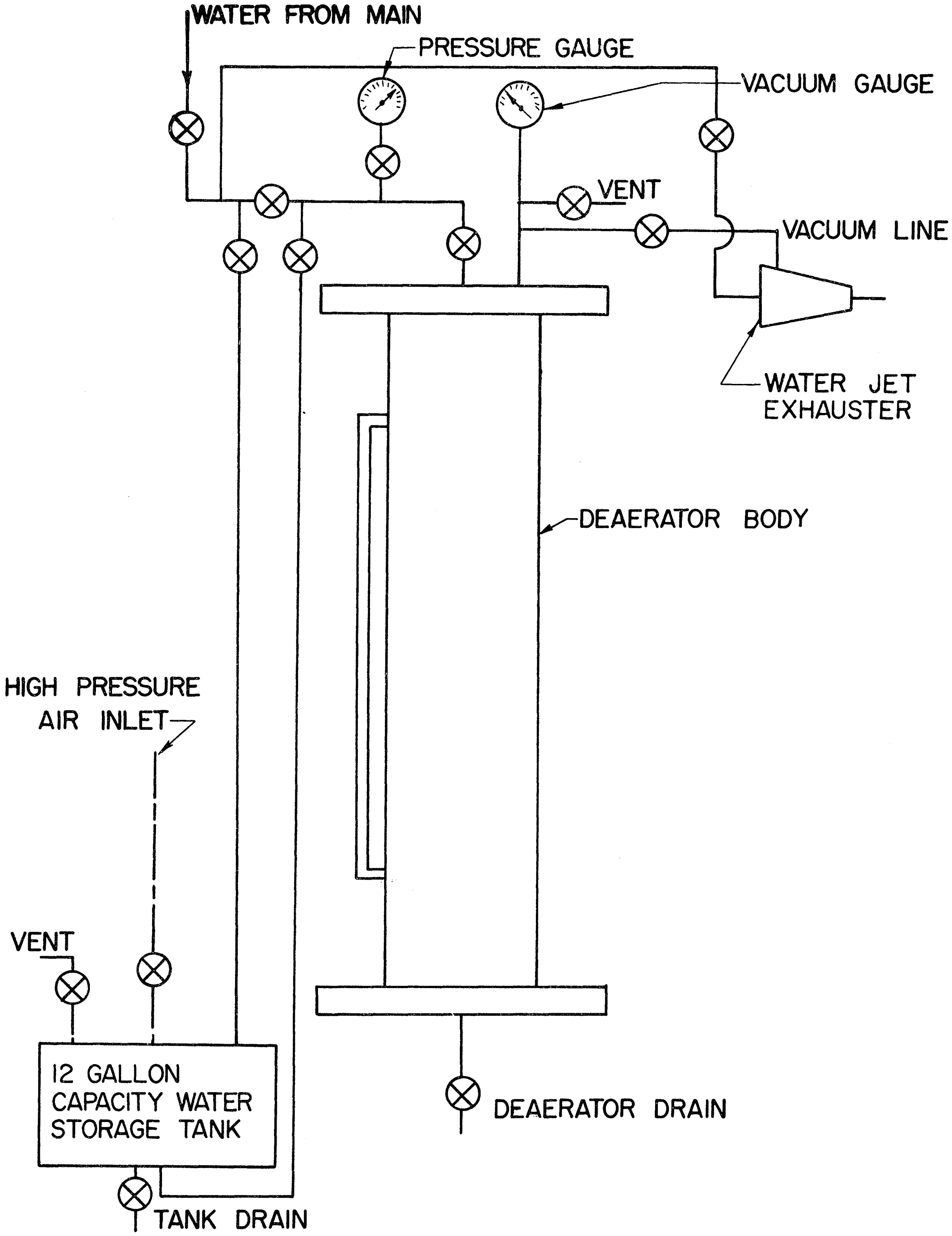

Figure 2. Schematic of Complete Experimental Set-Up.

sample was collected in a clean, thoroughly rinsed glass bottle, and the bottle tightly capped.

2) The vacuum system was started and the tank evacuated to a predetermined absolute pressure. Water was then admitted to the nozzle inlet valve at a predetermined pressure from which the differential pressure across the nozzle corresponding to a certain flow rate can be calculated. For the low flow rates, this pressure was obtained directly from the tap water supply line to the nozzle; for the higher flow rates, the 12 gallon tank was filled with water and then pressurized from a compressed air line in order to reach values higher than those available from the tap water.

3) The inlet valve to the deaerator body was then opened and the water was allowed to spray into the evacuated space until a certain level was reached as marked on the sight glass, after which the inlet valve was closed.

4) The vacuum system was secured and the deaerator body vent valve opened to equalize the pressure inside the unit with atmosphere. The drain valve was then opened and approximately half the water allowed to drain out before a sample was collected in a clean glass bottle, and the bottle tightly capped.

5) The air content in each of the water samples was then found using a Van Slyke apparatus, and the percent of deaeration obtained by making the necessary calculations. A sketch of the Van Slyke apparatus, theory of operation, test procedure, and sample calculations will be found in the Appendix.

EXPERIMENTAL RESULTS

The nozzle flow-rate as a function of pressure differential across the nozzle, as specified by the nozzle manufacturer, was checked and found to be substantially correct. Hence, the manufacturer's specifications were used for the test calculations, and are shown in Figure 3.

Table I lists the data from the previous investigation(1) in which the pipe diameter was 6" and the three pounds of Rashig rings were used as previously explained. The percent deaeration values were recalculated for this report due to a fault found in the Van Slyke procedure;* however, since the percentage change in values after this recalculation was quite small, the interpretation of the gross effects derived from these data remains the same, except as particularly noted later in this report.

Table II lists the data and calculated percent deaeration for a series of runs in the 6" diameter pipe, similar to those given in Table I, except in this case the Rashig rings have been removed.

Tables III and IV list the data and calculated percent deaeration for runs using the 4" diameter pipe "insert" (no Rashig rings).

For the test runs listed in Tables I, II, and III, the Van Slyke "tap water" readings were of the order of 150 mm Hg., or 1.7% air by volume (saturation at atmospheric pressure). During the high flow-rate test runs listed in Table IV, it was found necessary to pressurize the water with compressed air in order to obtain inlet pressures higher than the 50 psig available in the supply line. For these runs, the Van Slyke "tap water"

* Refer to Step 7b) in Van Slyke, "Test Procedure", Appendix.

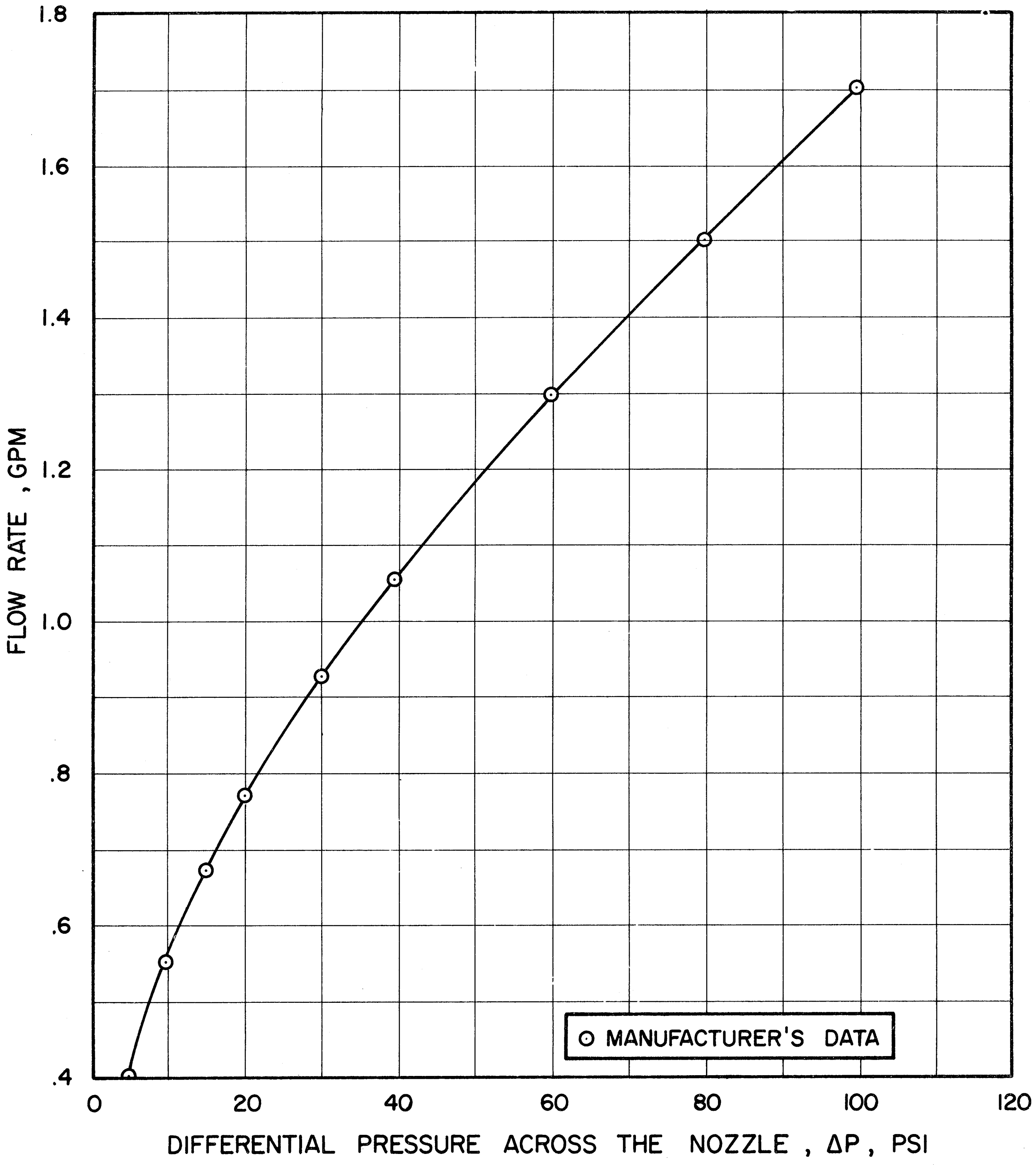

Figure 3. Flow Rate vs Differential Pressure (Sprayco H-5-D Nozzle)

TABLE I

RECALCULATED DATA FROM PREVIOUS EXPERIMENTATION
(6" Diameter Deaerator, With Rashig Rings)

Deaerator Readings				Van Slyke Readings		
Nozzle Pressure (psia)		ΔP psi	Flow Rate Gpm	Manometer Readings "Hg.	Average Manometer Readings "Hg.	Percent Deaeration
Inlet	Outlet					
36.7	3.2	33.5	.98	99		
36.7	3.2	33.5	.98	98	99	80.75
36.7	3.2	33.5	.98	100		
22.7	3.2	19.5	.76	91		
22.7	3.2	19.5	.76	92	92	82.60
22.7	3.2	19.5	.76	92		
36.7	7.2	29.0	.92	149		
36.7	7.2	29.0	.92	155	152	66.40
36.7	7.2	29.0	.92	152		
27.2	7.2	20.0	.77	152		
27.2	7.2	20.0	.77	160	156	67.40
27.2	7.2	20.0	.77	156		
43.2	9.7	33.5	.98	180		
43.2	9.7	33.5	.98	179	180	60.20
43.2	9.7	33.5	.98	182		
29.7	9.7	20.0	.77	173		
29.7	9.7	20.0	.77	174	174	61.70
29.7	9.7	20.0	.77	175		

TABLE II

EXPERIMENTAL DATA LOW INLET PRESSURES
(6" Diameter Deaerator, Without Rashig Rings)

Deaerator Readings				Van Slyke Readings		
Nozzle Pressure (psia) Inlet	Outlet	ΔP psi	Flow Rate GPM	Manometer Readings "Hg	Average Manometer Readings "Hg	Percent Deaeration
49.7	.50	49.2	1.19	47		
49.7	.50	49.2	1.19	48	47.0	77.30
49.7	.50	49.2	1.19	46		
24.7	.50	24.2	.84	50		
24.7	.50	24.2	.84	51	50.0	75.00
24.7	.50	24.2	.84	49		
49.7	7.34	42.36	1.11	110		
49.7	7.34	42.36	1.11	108	108.6	29.40
49.7	7.34	42.36	1.11	108		
24.7	7.34	17.36	.72	112		
24.7	7.34	17.36	.72	114	113.5	25.60
24.7	7.34	17.36	.72	115		
49.7	13.23	36.47	1.03	142		
49.7	13.23	36.47	1.03	141	141.0	4.24
49.7	13.23	36.47	1.03	140		
24.7	13.23	11.64	.58	144		
24.7	13.23	11.64	.58	143	143.3	2.64
24.7	13.23	11.64	.58	143		

TABLE III

EXPERIMENTAL DATA LOW INLET PRESSURES

(4" Diameter Deaerator, Without Rashig Rings)

Deaerator Readings				Van Slyke Readings		
Nozzle Pressure (psia) Inlet	Outlet	ΔP psi	Flow Rate GPM	Manometer Readings "Hg	Average Manometer Readings "Hg	Percent Deaeration
49.7	.50	49.2	1.19	52		
49.7	.50	49.2	1.19	53	52	73.20
49.7	.50	49.2	1.19	51		
24.7	.50	29.2	.84	54		
24.7	.50	29.2	.84	56	55	70.90
24.7	.50	29.2	.84	55		
49.7	7.34	42.36	1.11	112		
49.7	7.34	42.36	1.11	114	112	27.10
49.7	7.34	42.36	1.11	110		
24.7	7.34	17.36	.72	116		
24.7	7.34	17.36	.72	115	116	23.50
24.7	7.34	17.36	.72	117		
49.7	13.23	36.47	1.03	142		
49.7	13.23	36.47	1.03	144	143	2.94
49.7	13.23	36.47	1.03	143		
24.7	13.23	11.64	.58	144		
24.7	13.23	11.64	.58	145	145	1.18
24.7	13.23	11.64	.58	146		

TABLE IV

EXPERIMENTAL DATA HIGHER INLET PRESSURES

(4" Diameter Deaerator, Without Rashig Rings)

Deaerator Readings				Van Slyke Readings		
Nozzle Pressure (psia) Inlet	Nozzle Pressure (psia) Outlet	ΔP psi	Flow Rate GPM	Manometer Readings "Hg	Average Manometer Readings "Hg	Percent Deaeration
99.7	.50	99.2	1.69	42		
99.7	.50	99.2	1.69	43	42	84.50
99.7	.50	99.2	1.69	41		
64.7	.50	64.2	1.38	45		
64.7	.50	64.2	1.38	43	44	83.20
64.7	.50	64.2	1.38	44		
99.7	7.34	92.36	1.63	106		
99.7	7.34	92.36	1.63	105	105	38.20
99.7	7.34	92.36	1.63	104		
64.7	7.34	57.36	1.29	107		
64.7	7.34	57.36	1.29	107	107	36.70
64.7	7.34	57.36	1.29	107		
99.7	13.23	86.47	1.22	156		
99.7	13.23	86.47	1.22	157	157	12.55
99.7	13.23	86.47	1.22	158		
64.7	13.23	51.47	1.58	156		
64.7	13.23	51.47	1.58	157	157	11.10
64.7	13.23	51.47	1.58	157		

readings were of the order of 175 mm Hg. due to additional air being dissolved because of the higher air pressures applied to the water (although time of contact was not sufficient to achieve saturation at these pressures).

DISCUSSION OF RESULTS

The "Percent Deaeration vs Differential Pressure" data of Tables I and II are plotted on Figures 4 and 5, respectively, and those of Tables III and IV on Figure 6, for the following comparison purposes:

1) Change in Flow Rate:

Figures 5 and 6 show that as the flow rate (i.e., nozzle differential pressure) increases, the percent deaeration increases. It will be noted that Figure 4 shows a slope in the opposite direction. However, it was found that these readings were erroneous due to a fault in the Van Slyke apparatus procedure, so that it is believed that the trend is in error. It would seem than an increase in inlet pressure would give better atomization, exposing more fluid surface (because of finer particle size) to the evacuated atmosphere, which in turn should lead to higher deaeration. It is therefore assumed that the slopes as shown on Figures 5 and 6, rather than Figure 4, are correct.

2) Change of Absolute Pressure (Vacuum):

In all cases it is evident that as the absolute pressure in the evacuated space decreases (i.e., vacuum increases) the percent deaeration increases, being highest when the vacuum reading is 29.5 in. Hg. Generally, the increase between 15.0 in. Hg. and 29.5 in. Hg. is very substantial, while at 3.0 in. Hg. very little deaeration is obtained.

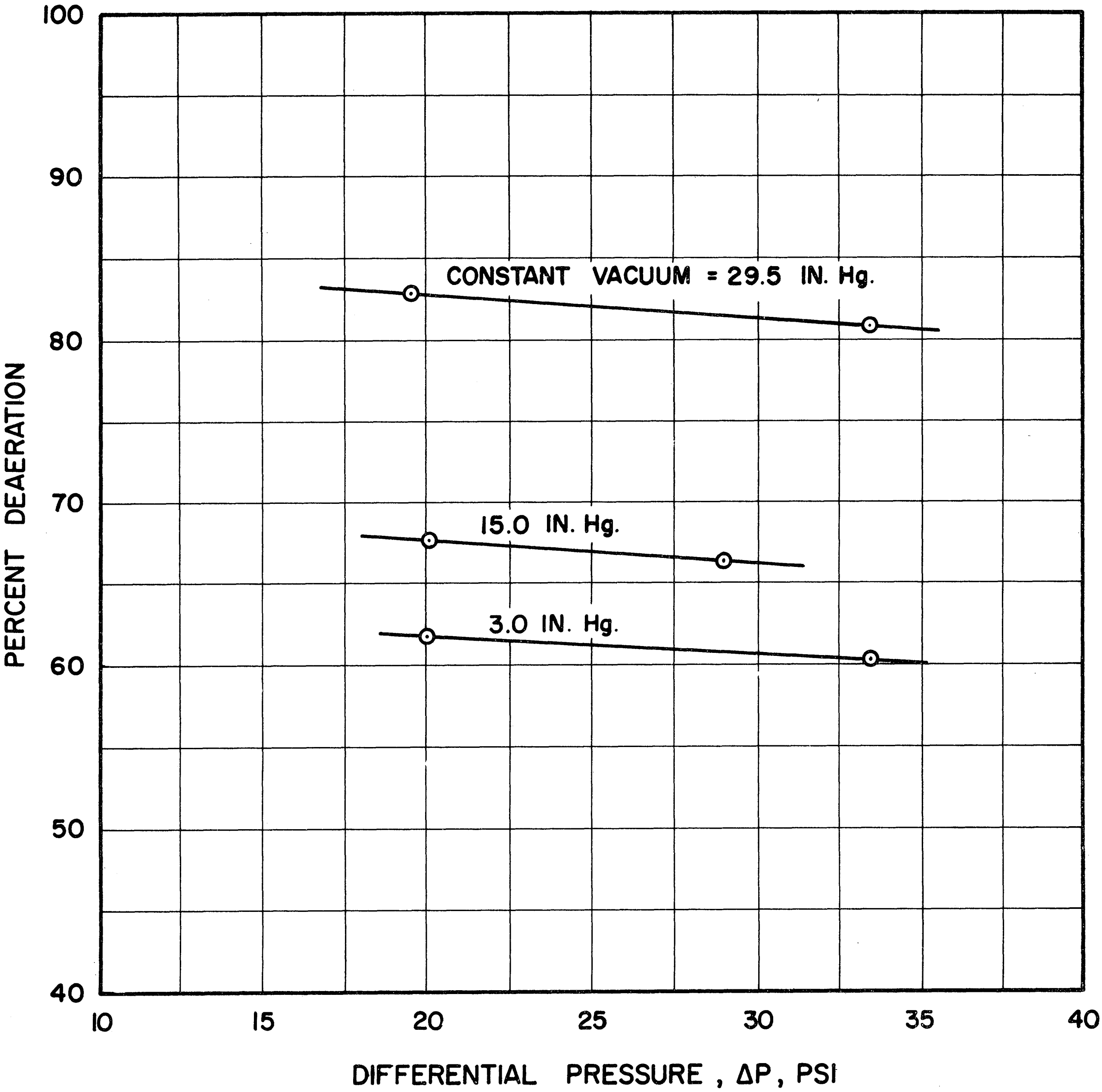

Figure 4. Percent Deaeration vs Differential Pressure
6" Diameter Deaerator, without Rashig Rings.

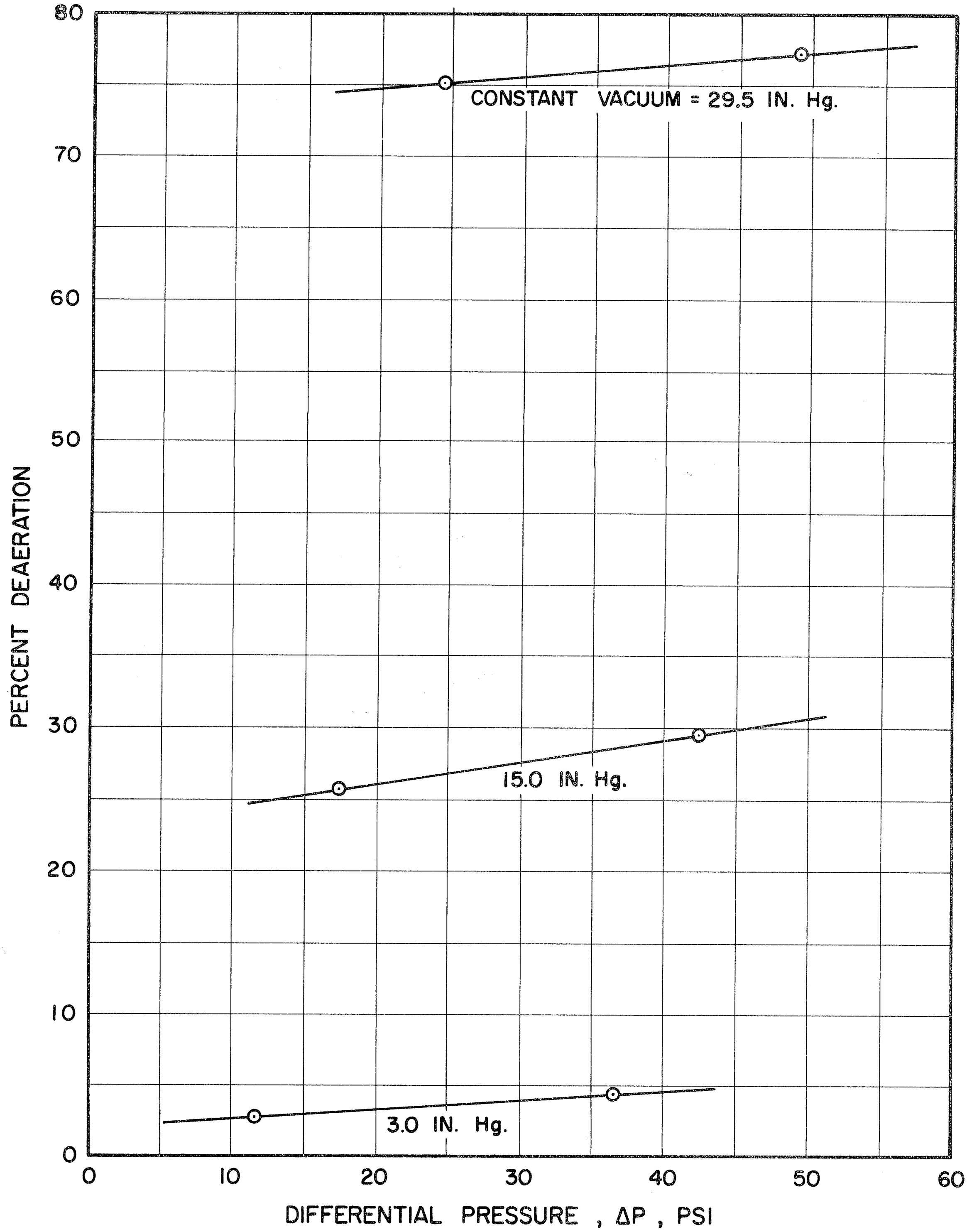

Figure 5. Percent Deaeration vs Differential Pressure
6" Diameter Deaerator, without Rashig Rings.

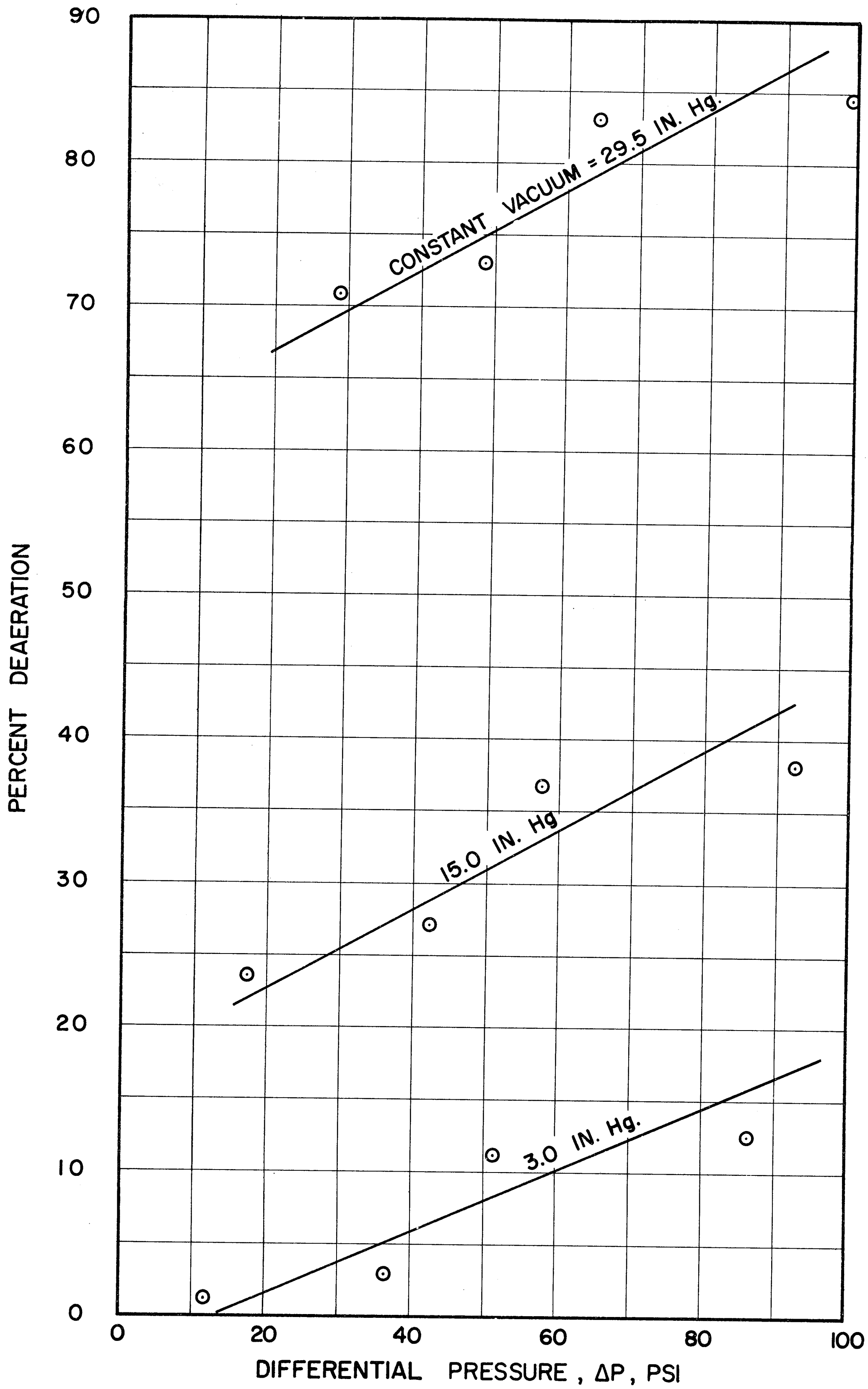

Figure 6. Percent Deaeration vs Differential Pressure 4" Diameter Deaerator, without Rashig Rings.

3) Change in Size (Diameter):

Comparison of Figures 5 and 6 shows that for the highest vacuum and similar flow rates, the 6" pipe shows an increase in deaeration of about 5% over the 4" pipe, and there is little significant change at reduced vacuum.

4) Change of Fluid Free Surface Area:

Comparison of Figures 4 and 5 shows that the use of Rashig rings, to increase the surface area and prolong the time that the fluid is in contact with the evacuated atmosphere, increases the percent deaeration (very substantially for the lower flow rates). At the higher vacuum (29.5 in. Hg.) however, the increase in deaeration is only about 7% - 8%.

CONCLUSIONS

From the results obtained it is concluded that:

1) The factor contributing most to the percent deaeration obtainable in such a simple unit is the degree of vacuum maintained in the evacuated space; the highest vacuum obtainable will give the greatest deaeration.
2) Increasing the flow rate also increases the deaeration factor over the range tested. For the equipment utilized in these tests a variation of the differential pressure across the nozzle from 30 to 80 psi results in an increase in percent deaeration of about 3% to 5%.
3) For the flow range specified (1.0 - 1.5 gpm), increasing the pipe diameter from 4" to 6" increases the percent deaeration by about 5%.

4) The use of Rashig rings increases the percent deaeration considerably with low vacuums, but at the highest vacuum obtainable the increase in deaeration is only about 7% - 8%.

In general, it is shown that at least 75% deaeration can be achieved in this simple unit with a single pass and starting with water saturated with air. With the addition of Rashig rings and larger pipe diameters, the effectiveness of such a unit could possibly be raised to above 85%.

APPENDIX

VAN SLYKE APPARATUS

The Van Slyke Apparatus is a device used to measure the total pressure of a known volume of air and water-vapor mixture, removed from a predetermined volume of water. The apparatus is shown schematically in Figure 7.

It is made entirely of glass, except for 1) the rubber hose connecting the flask "F" with valve 2, and 2) the thick-walled rubber hose connecting the main glass tube with the water jacket containing bulb "A" and the thermometer. Enough mercury is contained in the system to fill the glass tubing between valve 1 and valve 4, the flask "F" acting as a reservoir. A small, variable speed electric motor is used to agitate the water sample in the water-jacketed bulb "A".

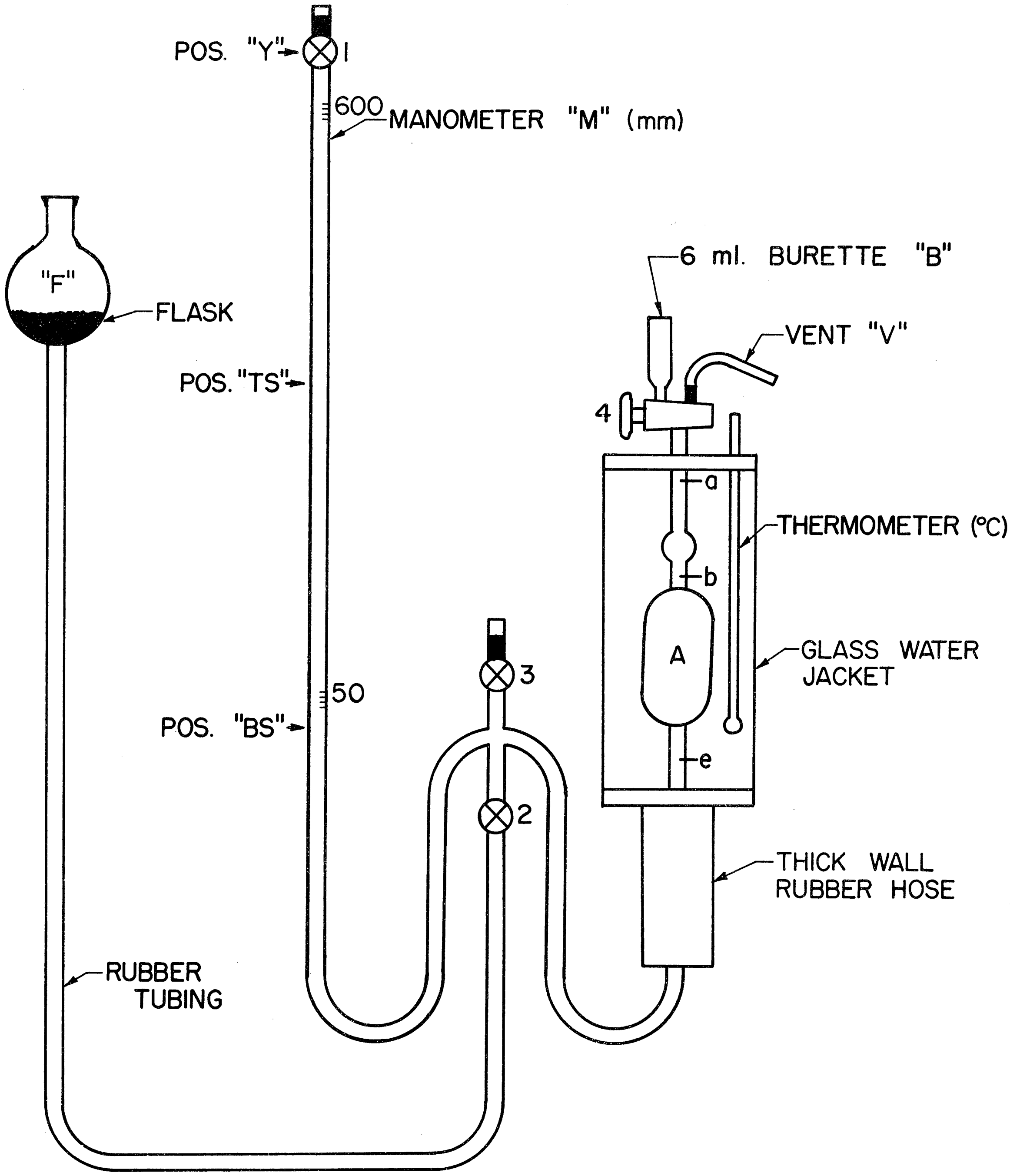

Figure 7. Van Slyke Apparatus Schematic.

A) Test Procedure:

Start: (Make sure all valves are closed)

1) Place flask "F" at position TS:

   a) OPEN valve 2 (slowly).

2) LOWER flask "F" to Position BS:

   a) OPEN valve 4 (slowly) to vent "V", allowing mercury trapped above valve 4 to drop into bulb "A" --- CLOSE valve 4.

   b) OPEN valve 4 (slowly) to 6 ml. burette "B", allowing water in "B" (from last test) to drop into bulb "A" --- CLOSE valve 4.

3) RAISE flask "F" to Position TS:

   a) OPEN valve 4 (slowly) to vent "V" and allow mercury level in bulb "A" to slowly rise until approximately 1/8" of mercury is showing in vent "V" --- CLOSE valve 4.

   NOTE: This procedure will drive all the water from the previous sample out of bulb "A", and the tubing between bulb "A" and valve 4.

   b) OPEN valve 1 (slowly) and allow the mercury trapped in the vent line above valve 1 to drop into manometer "M" --- CLOSE valve 1.

NOTE: At this point, always check the glass tubing just below valve 3 to ascertain that no air is trapped in this section; if air is present, open valve 3 very slowly (so as not to blow the mercury in the vent above valve 3 into your eyes) and allow the trapped air to escape to the atmosphere. About 1/8" of mercury should always be kept in the vent line above valve 3.

4) RAISE flask "F" to Position Y:

a) OPEN valve 1 (slowly), allowing the mercury level in manometer "M" to slowly rise, until it just shows (1/8") in the vent line above valve 1 --- CLOSE valve 1.

NOTE: If the mercury stops rising before it enters the vent, very slowly raise flask "F" to a slightly higher position, allowing the mercury level in the manometer to rise in a corresponding manner --- close valve 1 immediately the mercury shows in the vent line.

The system should now be completely filled with mercury from valve 1 to valve 4 --- check to make sure that no air (or water) is trapped under valves 1, 3, or 4. If air or water is found, secure all valves and repeat procedure from Step 1.

Testing Sample:

5) LOWER flask "F" to Position BS:

a) Fill burette "B", with sample water, to 6 ml. mark.

NOTE: This operation is very critical --- extreme care must be exercised to avoid carrying air bubbles into the water in the burette while filling. If any air bubbles are noticed, tap the burette gently to dislodge them and bring them to the surface.

b) OPEN valve 4 (slowly) to burette "B" and allow the sample water level in the burette to drop to the 1 ml. mark on the burette --- CLOSE valve 4.

c) Repeat steps a) and b) above until 20 ml. of sample water has been measured off into bulb "A".

NOTE: After the 20 ml. of sample water has been measured off into bulb "A", check the tubing below valve 4 very carefully for the presence of entrapped air. If any air is noticed, 1) raise flask "F" to position TS, 2) open valve 4 (slowly) to the burette "B" and allow the air to vent back into the burette (some water may come with it), 3) close valve 4 and lower flask "F" back down to position BS, 4) open valve 4 (slowly) to burette "B" and allow the water level in the burette to drop to the 1 ml. mark again, 5) close valve 4.

6) LOWER flask "F" slowly towards the floor, allowing the mercury level in bulb "B" to slowly drop to a point about 1" above the mark "e" --- CLOSE valve 2.

7) RAISE flask "F" to position TS:

a) Start shaker motor and agitate water sample in bulb "A" for 5 minutes.

b) OPEN valve 2 (slowly), allowing water level in bulb "A" to slowly rise to mark "b" --- CLOSE valve 2.

NOTE: Make sure there is no water trapped in the section between marks "a" and "b". If water is trapped: close valve 2, and procede again from step 6 onward.

c) READ, 1) mercury level in manometer "M", and 2) temperature of thermometer.

B) Sample Calculations:

Nomenclature:

V_s = 20 cc. = predetermined volume of sample water

V_a = 2 cc. = known volume of air component in air + water-vapor mixture at partial pressure "P_a" and temperature "t"

V_{ac} = volume of air component "V_a", corrected to standard atmospheric pressure "P"

P = 1 atmosphere = standard atmospheric pressure = 760 mm. Hg.

P_m = total pressure of air plus water-vapor mixture

P_v = water-vapor pressure, at temperature "t".

P_a = partial pressure of air component of mixture

t = temperature of air plus water-vapor mixture

1) For Tap Water:

P_m = 147 mm. Hg. t = 68°F

(1) From Steam Tables:

P_v = 0.690 in. Hg. = (0.69)(25.4) mm. Hg.

(2) $P_a = P_m - P_v$

$= 147 - (.69)(25.4) = 129.5$ mm. Hg.

(3) $V_a = 2$ cc.

$$V_{ac} = V_a\left(\frac{P_a}{P}\right) = 2\left(\frac{129.5}{760}\right) = 0.34 \text{ cc.}$$

(4) $$\% \text{ Air (by volume)} = \frac{V_{ac}}{V_s} \times 100 = \frac{(.34)(100)}{20} = 1.7\%$$

2) <u>For Deaerated Water</u>:

$P_m = 47$ mm. Hg. $t = 68°F$

(1) From Steam Tables:

$P_v = (.69)(25.4)$ mm. Hg.

(2) $P_a = P_m - P_v = 47 - 17.5 = 29.5$ mm. Hg.

(3) $V_a = 2$ cc.

$$V_{ac} = V_a\left(\frac{P_a}{P}\right) = \frac{(2)(29.5)}{760} = 0.0776 \text{ cc.}$$

(4) $$\% \text{ Air (by volume)} = \frac{V_{ac}}{V_s} \times 100 = \frac{(.0776)(100)}{20} = .388\%$$

(5) $$\% \text{ Deaeration} = \frac{1.7 - 0.388}{1.7} = 0.772 = 77.2\%$$

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