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APPENDICES

APPENDIX A.

Table A. 1

Experimental Data and Results for Run No. A-1

Drying conditions

Temperature of hot air	=	80°C
Dry bulb temperature (ambient)	=	25°C
Wet bulb temperature (ambient)	=	20°C
Air flow rate	=	762 $Kg/hr.m^2$
Bed loading	=	20.9 $Kg.B.D.S./m^2$
Bed depth	=	10 cm.
X-area of the bed	=	0.0314 m^2.
Water content	=	61.5% (wet basis)
Bone dry solid	=	0.619 Kg
Chip size	=	Malaysian size

Time from Start (min.)	Wt.of Sample (Kg.)	Evaporated Water (Kg.)	Drying Rate (Kg.water/Kg dry solid.m^2 min.)	Water Content (Kg.water/Kg dry solid)
0	1.608	-	-	1.598
10	1.528	0.080	0.412	1.468
20	1.443	0.085	0.437	1.331
30	1.359	0.084	0.432	1.195
40	1.281	0.078	0.401	1.069
50	1.208	0.073	0.376	0.952
(1hr)60	1.138	0.070	0.360	0.838
70	1.074	0.064	0.329	0.735
80	1.015	0.059	0.304	0.640
90	0.904	0.051	0.262	0.557
100	0.916	0.048	0.247	0.480
110	0.872	0.044	0.226	0.409
(2hr)120	0.830	0.042	0.216	0.341
130	0.794	0.036	0.185	0.283
140	0.766	0.028	0.144	0.237
150	0.739	0.027	0.139	0.194
170	0.713	0.026	0.066	0.140
190	0.690	0.023	0.059	0.110

Table A. 2

Experimental Data and Results for Run. No. B-1

Drying conditions

Temperature of hot air = 80°C

Dry bulb temperature (ambient) = 30.5°C

Wet bulb temperature (ambient) = 25°C

Air flow rate = 2,096 $Kg/hr.m^2$

Bed loading = 32.1 Kg. $B.D.S./m^2$

Bed depth = 15 cm.

X-area of the bed = $0.0314m^2$

Water content = 60.5% (wet basis)

Bone dry solid = 0.971 Kg.

Chip size = 2x6x0.5 cm.

Time from Start (min.)	Wt.of Sample (Kg.)	Evaporated Water (Kg.)	Drying Rate (Kg.water/Kg dry $solid.m^2$ min)	Water Content (Kg.water/Kg dry solid)
0	2.458	-	-	1.531
15	2.218	0.240	0.525	1.284
30	2.001	0.217	0.474	1.060
45	1.809	0.192	0.420	0.862
(1hr)60	1.647	0.162	0.354	0.695
75	1.512	0.135	0.295	0.556
90	1.399	0.113	0.247	0.439
105	1.308	0.091	0.199	0.345
(2hr)120	1.233	0.075	0.164	0.268
135	1.174	0.059	0.129	0.207
150	1.130	0.044	0.096	0.162
165	1.097	0.033	0.072	0.128
(3hr)180	1.070	0.027	0.059	0.100
200	1.049	0.021	0.034	0.078
220	1.034	0.015	0.025	0.062

Table A. 3

Experimental Data and Results for Run. No. C-1

Drying conditions

Temperature of hot air	=	70°C
Dry bulb temperature (ambient)	=	28.8°C
Wet bulb temperature (ambient)	=	25°C
Air flow rate	=	4,038 Kg/hr.m^2
Bed loading	=	18.4 B.D.S/m^2
Bed depth	=	10 cm.
X-area of the bed	=	0.0163m^2
Water content	=	58%
Bone dry solid	=	0.281 Kg.
Chip size	=	2x6x0.3 cm.

Time from Start (min.)	Wt.of Sample (Kg.)	Evaporated Water (Kg.)	Drying Rate (Kg.water/Kg dry solid.m^2 min)	Water Content (Kg.water/Kg dry solid)
0	0.670	-	-	1.384
15	0.530	0.140	2.037	0.886
30	0.435	0.095	1.382	0.548
45	0.374	0.061	0.887	0.331
(1hr) 60	0.339	0.035	0.509	0.206
75	0.321	0.018	0.262	0.142
90	0.313	0.008	0.116	0.113
105	0.308	0.005	0.072	0.096
(2hr)120	0.306	0.002	0.029	0.089
140	0.304	0.002	0.021	0.081
160	0.3026	0.0014	0.015	0.076
(3hr)180	0.3015	0.0011	0.012	0.073
↓			↓	↓
5hr			approach zero	0.0590(We)

Table A.4

Experimental Data and Results for Run No. C-6 (1)

Drying conditions

Temperature of hot air	=	55°C
Dry bulb temperature (ambient)	=	29°C
Wet bulb temperature (ambient)	=	24.5°C
Air flow rate	=	4,038 Kg/hr.m^2
Wt. of chip	=	4.0242 g.
Water content	=	60.81% (wet basis)
Bone dry solid	=	1.5599 g.
Chip size	=	2x6x0.3 cm.

Time from Start (min.)	Wt.of Sample (Kg.)	Evaporated water (Kg.)	Drying Rate (Kg.water/Kg. dry solid.m^2 min)	Water Content (Kg.water/Kg. dry solid)
0	4.0242	-	-	1.1740
15	3.4683	0.5559	1.4575	0.8682
30	2.9727	0.4956	1.2994	0.6059
45	2.6968	0.2759	0.7234	0.4569
(1hr) 60	2.4659	0.2309	0.6054	0.3321
75	2.3067	0.1592	0.4174	0.2461
90	2.2078	0.0989	0.2593	0.1927
105	2.1411	0.0667	0.1749	0.1572
(1hr)120	2.0885	0.0526	0.1379	0.1282
135	2.0529	0.0356	0.0933	0.1090
150	2.0361	0.0168	0.0440	0.0999
165	2.0240	0.0121	0.0317	0.0930
(3hr)180	2.0140	0.0100	0.0262	0.0880
↓			↓	↓
5hr			Approach zero	0.076 (We)

APPENDIX B.

Sample of Calculation

For run no. B-1

B.1 Determination of the water content

The water content of representative sample = 60.5% (wet basis)

Consequently, total water content in the bed of tapioca chips

= 0.605xWt. of tapioca used

= 0.605x2.458 Kg.

= 1.487 Kg.

Total bone dry solid = 2.458-1.487 Kg.

= 0.971 Kg.

∴ Water content = 1.487/0.971 Kg.Water/Kg.dry solid

= 1.531 Kg.Water/Kg.dry solid

At time = 15 min from initial

Weight of tapioca at this time = 2.218 Kg.

∴ Total water = 2.218-0.971 Kg.

= 1.247 Kg.

∴ Water content = 1.247/.971 Kg.water/Kg.dry solid

= 1.284 Kg.water/Kg.dry solid

B.2 Determination of the drying rate

$$\text{Drying rate} = \frac{\text{Weight of evaporated water}}{\text{Weight of bone dry solid x X-area x time interval}}$$

Wt. of evaporated water in is min. = 0.240 Kg.

Wt. of bone dry solid = 0.971 Kg.

X-area = 0.0314 m^2

∴ Drying rate at time = 15 min.= 0.240/0.971x0.0314x15 Kg water/Kg dry solid. $m.^2 min.$

= 0.525 Kg.water/Kg dry solid $m^2.min.$

Wt. of evaporated water at time = 30 min. from start.

= 0.217 Kg.

∴ Drying rate at time = 30 min = 0.217/0.971x0.0314x15 Kg.water/Kg dry solid $m^2.min.$

= 0.474 Kg water/Kg dry solid. $m^2.min.$

B.3 Determination of the enthalpy of the hot air with reference to 30°C

Dry bulb temperature (ambient) = 30°C

Temperature of hot air = 80°C

Air flow rate = 1100 l/min (2,096 $Kg/hr.m^2$)

Finding the mass flowrate of the air

At 1 atm pressure, $V_1 = V_2T_1/T_2$ (V = volume)

Assume that the air behaved Ideal gas and was 1 gm-mole.

The volume of 1 gm-mole of air (1atm, 0°C) = 22.414 lit.

So, V_1 = 22.414 (273.16+30)/273.16

= 24.8756 lit.

Density of air at 0°C, 1 atm = 1.2929 gm/lit.

(CPP, 5th.ed., Table C)

But the mass of air was constant.

∴ $D_1V_1 = D_2V_2$

$\therefore$ Air density at 30°C, 1atm = $\frac{\text{(Dat 0°C,1atm)(Vat 0°C,1atm)}}{\text{Vat 30C,1atm}}$

= 1.2929x22.414/24.8756 gm/lit.

= 1.165 gm/lit.

The mass flow rate of air = (1100 lit/min)(1.165 gm/lit)

= 1281.5 gm/min.

The drying time taken for the chips to be dried from water content of 1.531 to 0.1 Kg.water/Kg.dry solid. was 180 min.

The enthalpy of the hot air = $MC_p\Delta T$

Where M = Mass of air used = 1281.5x180 gm

C_p = Heat capacity of air = 0.238 cal./gm° C

(Perry, chem. Eng. Hand book, Table 3-180,pp 3-134,5th.ed.)

ΔT = Hot air temp.- Initial temp.of air

= 80 - 30 = 50°C

Hence, the enthalpy of the hot air = 1281.5x180x0.238x50 cal.

= 2744.97 Kcal.

B.4 Determination of the useful heat for evaporation of the moisture

Useful heat = sensible heat + Latent heat

= $mC_p\Delta T + ml$

m = Mass of the water evaporated from the tapioca chips

= 1,388 gm.

C_p = Heat capacity of water

= 1 cal./gm°C (Perry,Chem.Eng.Hand book, 5th.ed, Fig. 3-11, pp. 3-129)

ΔT = 50°C

l = latent heat of vaporization of water at 80°C

=600.13 cal/gm.(Perry, Chem. Eng. Hand book, 5th.ed., Table 3-276, pp. 3-206)

.·. Useful heat = (1,388x1x50) + (1,388x600.13) cal.

= 902.38 Kcal.

B.5 Determination of thermal efficiency

% Thermal efficiency = Useful heat/air enthalpy x 100

= 902.38 x 100/2744.97

= 32.87 %

B.6 Comparison between the experimental and Theoretical value of the amount of evaporated water.

For run no. B-1

Ambient

Dry bulb temperature = 30°C (86°F)

Wet bulb temperature = 25°C (77°F)

From the Humidity chart of the air-water system (Fig. B-1)

.·. Humidity of the ambientair = 0.019 lb.H_2O/lb dry air

Outlet air

Average dry bulb temperarure = 60.2°C (140.4°F)

Average wet bulb temperature = 34.6°C (94.3°F)

From the Humidity chart

.·. Humidity of the outlet air = 0.025 lb.H_2O/lb dry air

.·. water evaporated (Theoretical) = 0.025-0.019 lbH_2O/lb.dry air

= 0.006 lbH_2O/lb.dry air

Total air used (θ = 220 min.) = 621.66 lb

Weight of dried air = 621.66/1.019 lb

= 610.1 lb

Total water evaporated from this run = 3.140 lb

$\therefore$ Water evaporated (Experimental) = 3.140/610.1 lbH_2O/lb.dry air

= <u>0.00515</u> lb.H_2O/lb.dry air

B.7 <u>Determination of the value of effective diffusivity (De)</u>

<u>For run no. C-4 (1)</u> from standard equation

$$\overline{W}\text{-We/Wo-We} = \frac{8}{\pi^2}\left[e^{-De\theta(\pi/2a)^2} + \frac{1}{9}e^{-9\,De\theta(\pi/2a)^2} + \frac{1}{25}e^{-25\,De\theta(\pi/2a)^2} + \ldots\ldots\right]$$

For long drying times this equation simplified to

$$\overline{W}\text{-We/Wo-We} = \frac{8}{\pi^2}e^{-De\theta(\pi/2a)^2}$$

Wo = The initial moisture content = 2.1309 g.water/g.dry solid

We = The final equilibrium water content = 0.05 g.water/g. dry solid

$\overline{W}$ = Average water content at time θ = 0.1 g.water/g.dry solid

θ = Drying time = 69 min. = 4,140 sec.

a = One half slab thickness = 0.15 cm.

De = Effective diffusion coefficient, cm^2/sec.

π = 3.143

Substituting these values into the equation:

$$0.1-0.05/2.1309-.05 = 8/(3.143)^2 \exp -4,140\ De(3.143/0.3)^2$$

$$0.024 = 0.8098 \exp (-454,447\ De)$$

$$0.0296 = \exp (-454,447\ De)$$

$$De = \ln 33.8/454,447$$

$$= 7.74 \times 10^{-6}\ cm.^2/sec.$$

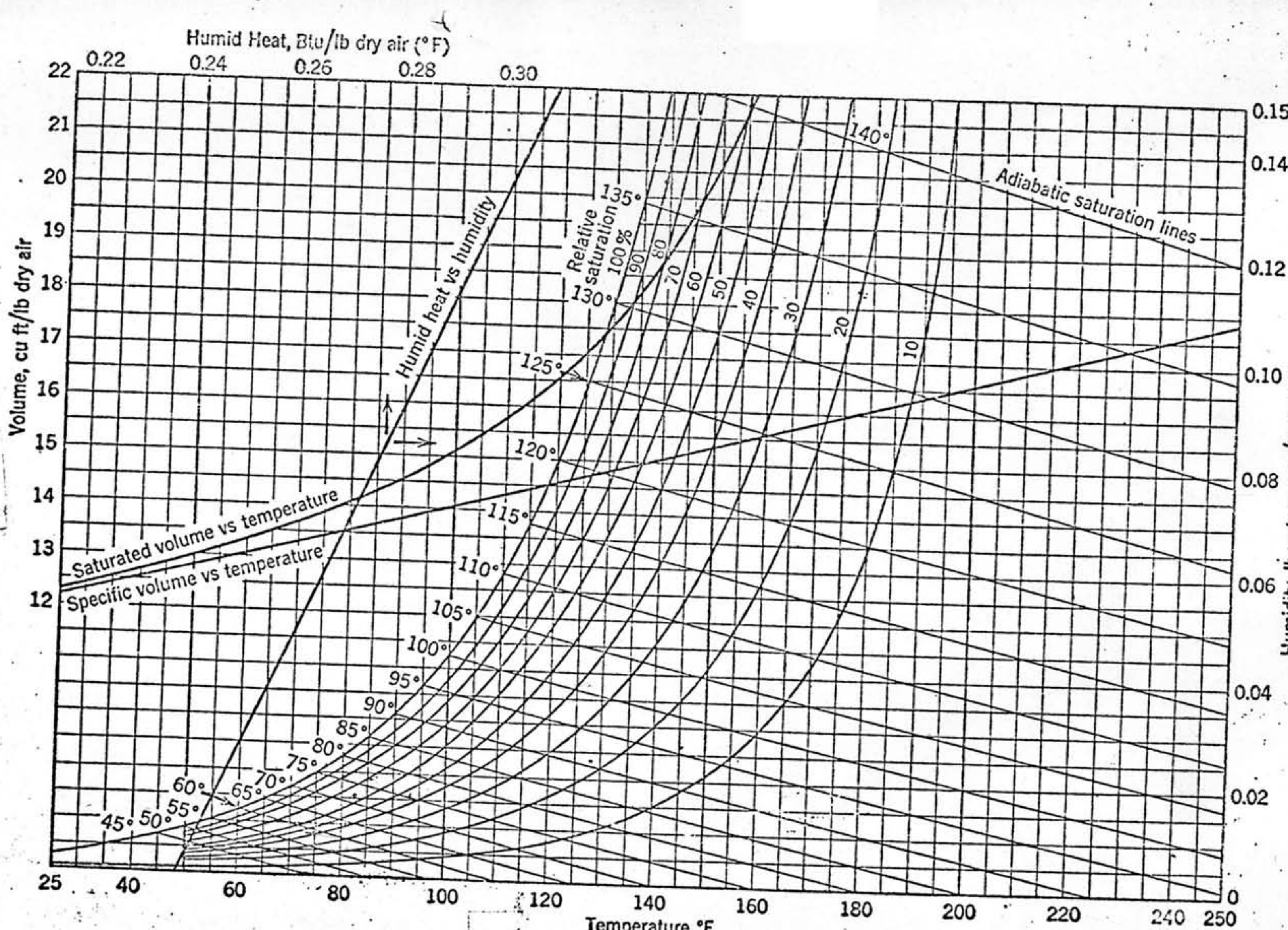

FIG. B.1 Humidity chart for the air-water system[23]

APPENDIX C.

Table C.1

Calibration of Orifice Meter

Air at 30°C, 760 mm Hg.

ΔP Orifice Meter cm (H_2O)	Rotameter Air Flow Rate, lit/min.	ΔP, Orifice Meter cm. (H_2O)	Rotameter Air Flow Rate, lit/min.
1.5	197	13.3	747
2.6	265	13.8	755
3.1	299	14.2	771
3.7	328	14.6	775
4.2	385	15.1	779
4.9	404	15.6	809
5.5	438	16.3	816
5.9	450	16.7	823
6.2	462	17.2	846
6.8	490	17.7	850
7.3	511	18.2	863
7.8	535	18.7	874
8.0	543	19.0	884
8.6	559	19.6	896
9.1	610	20.0	911
9.7	640	20.7	918
10.3	642	21.3	931
10.8	645	21.8	939
11.3	686	22.5	957
11.9	696	22.8	961
12.6	726	23.2	974
12.9	739	24.8	1007

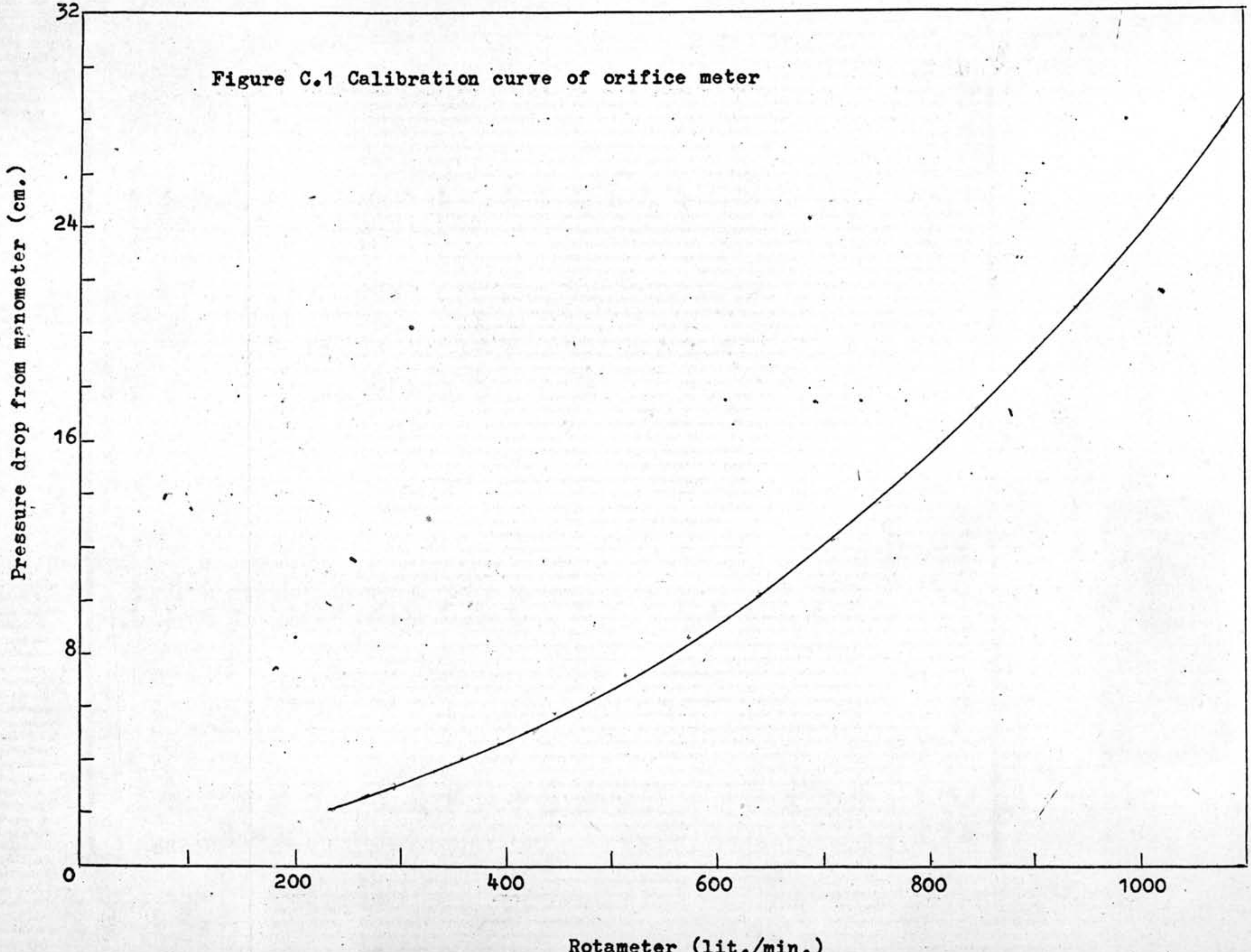

Figure C.1 Calibration curve of orifice meter

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