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Appendix A

CALIBRATION OF ROTAMETER

Rotameter reading (%)	Volumetric flow rate* of air X 10^2 (m^3/sec)
0	0.0000
10	0.0750
20	0.1667
30	0.2778
40	0.4167
50	0.6000
60	0.7867
70	1.0000
80	1.2566
90	1.6755
100	2.5127

*Calibrate at room temperature and atmospheric pressure

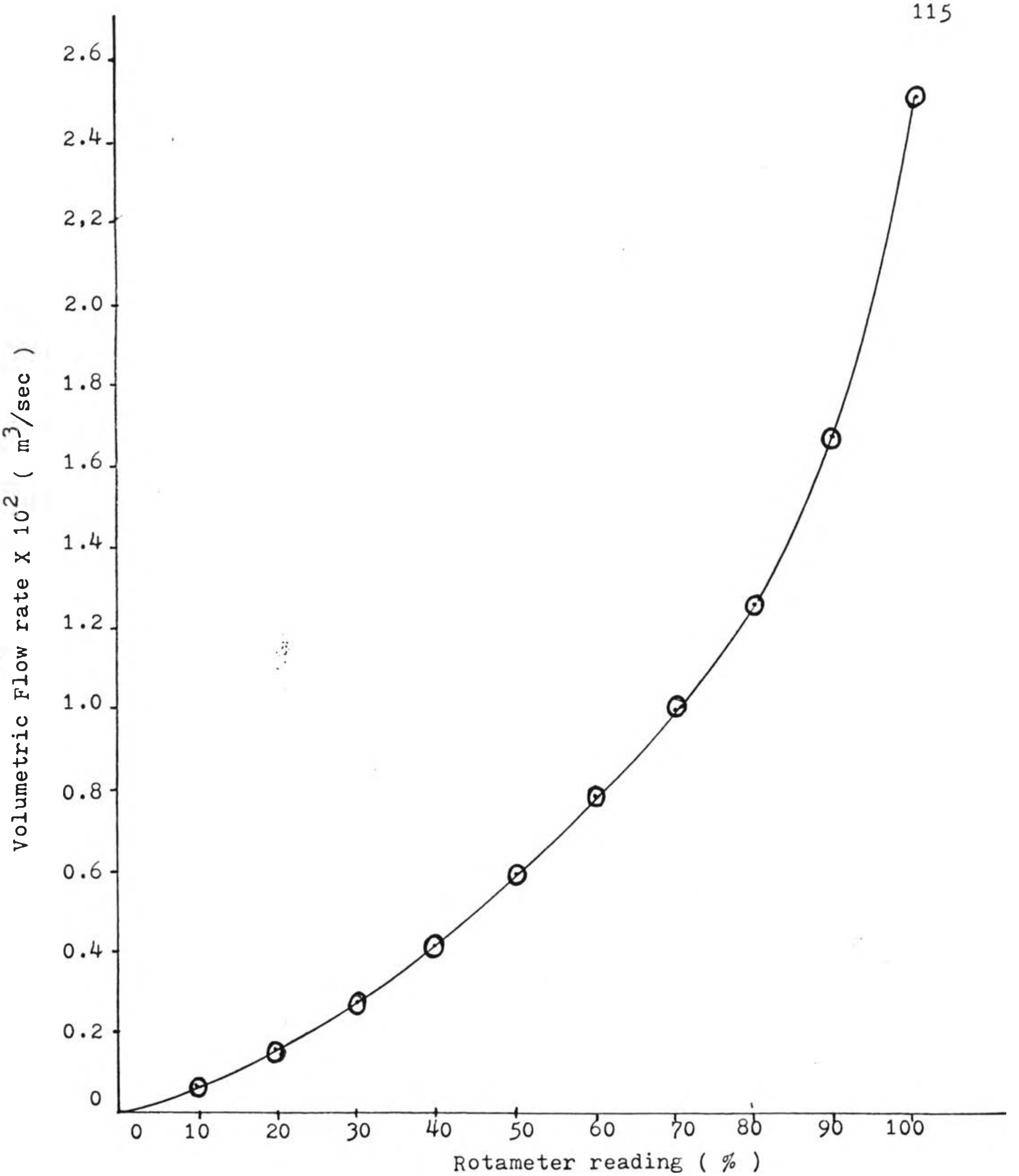


Figure A-A Calibration curve of rotameter

Appendix B

DETERMINATION OF MINIMUM FLUIDIZING CONDITIONS

Part I: Experimental Data

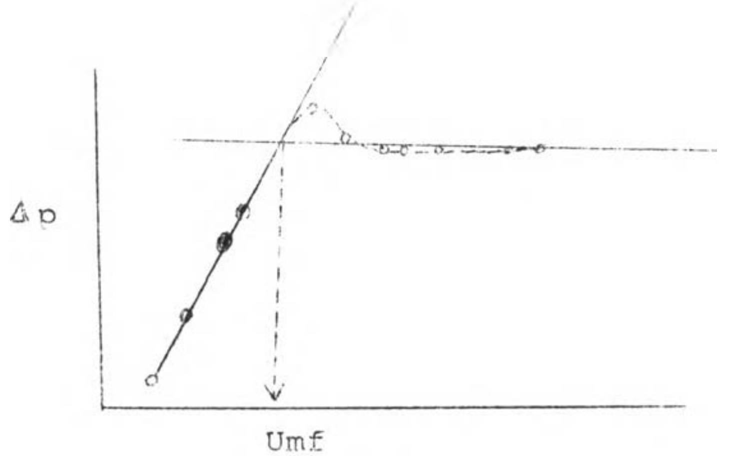
$Q_o \times 10^2$ * (m^3/sec)	Uo* (m/sec)	Δp ($cm.H_2O$)				
		Lm= 6.7 cm	Lm= 11.0cm	Lm= 15cm	Lm= 21 cm	Lm= 26.7 cm
0.0750	0.0955	0.5	0.4	0.5	0.8	0.9
0.1667	0.2123	1.5	1.0	1.6	2.3	2.9
0.2778	0.3537	3.0	2.0	2.9	4.4	5.5
0.4167	0.5306	4.0	3.1	4.5	7.4	8.5
0.6000	0.7640	4.0	4.3	6.5	9.9	12.0
0.7867	1.0017	4.0	6.0	7.3	11.6	14.1
1.0000	1.2733	4.0	6.2	7.5	11.5	14.0
1.2566	1.5999	4.0	6.0	7.5	11.5	14.0
1.6755	2.1333	4.0	6.0	7.5	11.5	14.0
2.5127	3.1993	4.0	6.0	7.5	11.5	14.0

* Investigated at room temperature and atmospheric pressure

Part II: Determination of minimum fluidizing velocity

1. By experimental method

From the plotting of Δp versus Uo in Figure 5-1; the two straight lines, when Δp vary with Uo (fixed bed) and Δp is constant, are drawn. The superficial velocity at the point of intersection is the minimum fluidizing velocity (Umf). This method of determination is shown below.



2. By theoretical method

From eq.(2-4)

$$\frac{1.75}{\phi s \varepsilon mf^3}\left(\frac{dp\ Umf\ \rho g}{\mu g}\right)^2 + \frac{150(1-\varepsilon mf)}{\phi s^2 .\ \varepsilon mf^3}\left(\frac{dpUmf.\ \rho g}{\mu g}\right) = \frac{dp^3 \rho g(\rho s - \rho g)}{\mu g^2} g$$

when εmf = εm of random packed bed = 0.488

ϕs = 0.68

dp = 3.477×10^{-3} m

ρg = 1.1650 kg/m^3 (at room temp.30°C, 1 atm)

$\mu_g = 2 \times 10^{-5}$ kg/m.sec

$\rho_s = 1.1798$ kg/m^3

Therefore, the minimum fluidizing velocity calculated = 0.737 m/sec.

Appendix C

EXPERIMENTAL DATA

Part I: Batch Operation

Drying conditions:

Relative humidity	75 - 80 %
Room temperature	29 - 30 ^{o}C
Bed weight	1 kg
Bed depth	18.5 cm.

a) Fixed air inlet flow rate (1.3297 X 10^{-2} m^{3}/sec at S.T.P)

1. Temperature of air inlet = 80 ^{o}C

   Temperature of air in bed : 55, 57, 65, 70 ^{o}C

t (min)	M (% d.b.)
0	57.1886
4	45.2765
8	40.5529
12	35.9807
16	31.6902
20	28.5972
24	25.5528
Tempering	

t (min)	M (% d.b.)
After tempering	24.9617
2'	21.6677
4'	20.6894
6'	19.3672
8'	18.7836

2. Temperature of air inlet = 100 °C

Temperature of air in bed : 87,88,89,90,92,93,94 °C

t (min)	M (% d.b.)
0	59.3354
2	51.6940
4	44.7545
6	41.1345
8	37.1691
10	32.7824
Tempering	
After tempering	32.4770
2'	25.5671
4'	24.5491
6'	22.4476
8'	19.9029

3. Temperature of air inlet = 120 °C

Temperature of air in bed : 80,90,91,95 °C

t (min)	M (% d.b.)
0	57.1886
2	49.1760
4	43.5743
6	38.2142
8	33.4745
10	30.1748
12	26.7604
Tempering	
After tempering	25.3095
2'	22.0477
4'	19.3363
6'	16.8853

4. Temperature of air inlet = 143 $^{\circ}C$

Temperature of air in bed : 114,115,120,121,122,123 $^{\circ}C$

t (min)	M (% d.b.)
0	59.3354
2	47.7994
4	40.7726
6	31.0480
Tempering	
After tempering	30.6061
2'	23.4134
4'	20.2856
6'	16.0459

5. Temperature of air inlet = 160 °C

Temperature of air in bed : 108,112,121,124 °C

t (min)	M (% d.b.)
0	59.4181
2	43.8228
4	36.2295
6	27.9468
Tempering	
After tempering	26.8574
2'	20.9133
4'	16.4127

6. Temperature of air inlet = 185 ^{o}C

Temperature of air in bed : 112,120,123,130,131 ^{o}C

t (min)	M (% d.b.)
0	59.4181
2	42.6822
4	34.7558
6	25.8485
Tempering	
After tempering	24.0407
2'	17.1452

b) <u>Fixed air inlet temperature (100 °C)</u>

1. Air inlet flow rate = 1.9941×10^{-2} m^3/sec at S.T.P.

t (min)	M (% d.b.)
0	60.8424
2	47.5721
4	41.8026
6	38.9258
8	34.9111
10	31.2456
Tempering	
After tempering	29.5381
2'	25.3069
4'	21.8499
6'	19.7596
8'	17.7970

2. Air inlet flow rate = $1.8283 \times 10^{-2}\ m^3$/sec at S.T.P.

t (min)	M (% d.b.)
0	60.8424
2	55.2953
4	48.7891
6	44.0847
8	40.3445
10	35.4962
Tempering	
After tempering	33.0271
2'	30.9893
4'	27.0655
6'	24.3129
8'	21.5837

3. Air inlet flow rate = $1.5790 \times 10^{-2}\ m^3$/sec at S.T.P.

t (min)	M (% d.b.)
0	54.6843
2	48.1621
4	42.3726
6	38.8201
8	36.1453
10	33.2318
Tempering	
After tempering	32.0628
2'	28.5345
4'	26.2221
6'	24.1820
8'	22.0866

4. Air inlet flow rate = 1.0804×10^{-2} m^3/sec at S.T.P.

t (min)	M (% d.b.)
0	54.6843
2	49.1539
4	44.0591
6	40.2858
8	37.4934
10	34.0870
Tempering	
After tempering	32.0946
2'	28.8604
4'	26.2376
6'	24.6892
8'	22.6678

Part II: Continuous Operation

Drying conditions:

Relative humidity	75-80 %
Room temperature	29-30^{o}C
Air inlet flow rate	1.5790X10^{-2}m^{3}/sec at S.T.P.
Air inlet temperature	183^{o}C
Pressure drop across bed (av.)	9.8 cm.H_2O

PX10^{3} (kg/sec)	Tg_b (^{o}C)	M (% d.b.)			
		starting	1st drying	After tempering	2nd drying
8.7753	121	62.1228	40.4662	39.4519	25.3842
7.6645	107	55.7700	36.4927	32.4442	19.8013
6.9980	103	57.8635	36.4327	31.1040	20.7409
6.4148	111	58.7637	33.3744	30.0501	17.0398
5.7483	109	58.2704	31.9333	26.6779	16.3417
5.4984	117	55.3635	25.6120	23.7267	13.5821
4.3821	103	58.8447	25.8487	23.1886	12.4752

Part III: Data from Milling

a) Batch operation (Fixed air inlet flow rate)

Tgi (°C)	% M after drying (d.b.)	% M before milling (d.b.)	Wt. of paddy (gm)	Wt. of brown rice (gm)	Wt. of rice (gm)	Wt. of head rice (gm)
Raw paddy	-	15.01	125	93.0	75.0	53.0
80	18.7836	12.54	125	96.0	94.5	91.0
100	19.9029	13.38	125	96.5	89.0	84.0
120	16.8853	12.35	125	95.5	90.9	84.5
143	16.0459	11.17	125	96.0	91.5	83.5
160	16.4127	12.54	125	96.0	89.8	80.5
185	17.1452	12.37	125	94.0	85.0	75.0

b) Batch operation (Fixed air inlet temperature)

$QoX10^2$ at STP. (m^3/sec)	%M after drying (d.b.)	%M before milling (d.b.)	Wt.of paddy (gm)	Wt.of brown rice (gm)	Wt.of rice (gm)	Wt.of head rice (gm)
Raw paddy	-	15.34	125	98.0	86.8	54.8
1.9941	17.7976	13.26	125	95.0	90.0	88.0
1.8283	21.5837	13.61	125	95.0	90.0	88.5
1.5790	22.0866	13.67	125	98.5	93.5	91.8
1.0804	22.6678	14.53	125	98.5	93.5	92.3

c) Continuous operation (Fixed air inlet flow rate and Temperature)

P X 10^3 (kg/sec)	%M after drying (d.b.)	%M before milling (d.b.)	Wt.of paddy (gm)	Wt.of brown rice (gm)	Wt.of rice (gm)	Wt.of head rice (gm)
Raw paddy	-	15.34	125	92.5	82.5	55.0
8.7753	25.3842	12.46	125	92.5	91.0	87.0
7.6645	19.8013	12.30	125	93.5	87.0	81.5
6.9980	20.7409	12.32	125	93.0	88.0	83.0
6.4148	17.0398	11.86	125	95.0	88.5	79.5
5.7483	16.3417	11.54	125	93.0	87.5	82.5
5.4984	13.5821	11.11	125	93.5	83.0	79.5
4.3821	12.4752	11.05	125	90.5	82.5	78.0

Appendix D

SAMPLE OF CALCULATION

Part I. Experimental run (Sample shown here is for exp. run no. 1)

1. The rate of heat transfer (q_h)

From equation (2-7),

$$q_h = Qo.\rho g.Cpg.(Tgi-Tgb)$$

Where Qo = volumetric air inlet flow rate at Tgb

ρg = density of air at Tgb

Cpg = specific heat of air at Tgb

a) For batch operation (Fixed air inlet flow rate)

$$Qo = 1.6755 \times 10^{-2} \ m^3/sec$$

$$\rho g = 1.026 \ kg/m^3$$

$$Cpg = 0.25 \ Cal/gm.^{\circ}C = 1.0467 \times 10^3 \ Joule/kg.^{\circ}K$$

Therefore, the rate of heat transfer

$$= (1.6755 \times 10^{-2})(1.026)(1.0467 \times 10^3)(80-55)$$

$$= 0.4498 \times 10^3 \ Joule/sec$$

b) For continuous operation (Fixed air inlet flow rate and temperature)

$$Qo = 1.9897 \times 10^{-2} \ m^3/sec$$

$$\rho g = 0.8413 \ kg/m^3$$

$$Cpg = 1.0467 \times 10^3 \ Joule/kg.^{o}K$$

Therefore, the rate of heat transfer

$$= (1.9897X10^{-2})(0.8413)(1.0467X10^{3})(183-121)$$

$$= 1.0863 \times 10^3 \ Joule/sec$$

2. The heat transfer coefficient (h_p)

From overall heat balance around the fluidized bed, negected heat lost to surroundings,

$$q_h = h_p . As(Tgi-Tgb)$$

Therefore; by plotting q_h vs. ΔT, the slope of the straight lin equaled to h_p.As

The experimental heat transfer coefficient

$$= \frac{slope}{As}$$

$$= \frac{(17.99)}{(2.2930)}$$

$$= 7.8456 \ Joule/sec.m^2.^{o}K.$$
(for batch drying)

$$= \frac{(17.525)}{(2.0122 \times 10^{-2})}$$

$$= 0.8707 \times 10^3 \ (J/sec.m^2.^{o}K)(sec)$$
(for continuous drying)

3. <u>To find empirical contents (c,m) of equation (2-5) for batch operation</u> (Fixed air inlet temperature)

From eq.(2-5)

$$Nup = c.Rep^{m}$$

$$\log Nup = \log c + m.\log Rep$$

$$Nup = \frac{h_p.d_p}{k_g}$$

$$k_g = 1.695 \text{ Btu/ft.hr.}^{\circ}\text{F} = 2.9340 \text{ Joule/sec.m.}^{\circ}\text{F}$$ (at Tgb)

$$Rep = \frac{dp.Uo.\rho g}{\mu g}$$

$$\mu g = 0.0206 \text{ centipoise} = 2.06 \times 10^{-5} \text{ kg/m.sec}$$ (at Tgb)

$$\rho g = 0.9846 \text{ kg/m}^3$$ (at Tgb)

Therefore, the Nusselt number $= \dfrac{(11.2932)(3.477\times10^{-3})}{(2.9340)}$

$= 1.3383\times10^{-2}$

and the Reynolds number $= \dfrac{(3.477\times10^{-3})(3.1993)(0.9846)}{(2.06\times10^{-5})}$

$= 5.3168\times10^{2}$

Plotting Nup vs. Rep on logarithmic graph

m = Slope of the straight line = 1.0000

Intercept of the straight line = log c

$c = 0.2517\times10^{-4}$

Therefore, $Nup = 0.2517\times10^{-4} \cdot Rep^{1.0}$

Part II: Determination of Physical Properties of Bed

1. Determination of void fraction (ϵ_m) and sphericity (ϕ_s) of raw paddy

Volume of water before mixing	= 50	c.c.
Volume of raw paddy and void	= 21.5	c.c.
Volume after mixing	= 61	c.c.

Therefore, the void fraction of packed bed $= \dfrac{(50+21.5)-(61)}{(21.5)}$

$= 0.488$

From the reference no.(12) p.66 Figure 1, at Normal packing line when $\epsilon_m = 0.488$

Therefore, the sphericity = 0.68

2. Determination of diameter of sphere having the volume of paddy (dp)

Volume of raw paddy and void	= 21.5	c.c.
amount of raw paddy	= 500	particles

Total volume of paddy $= (500)\left(\dfrac{\pi\, dp^3}{6}\right) = (21.5)(1-0.488)$

Therefore, $dp = \left[\dfrac{(21.5)(1-0.488)(6)}{(500)(\pi)}\right]^{1/3}$

$= 0.3477$ cm

$= 3.477 \times 10^{-3}$ m.

3. Determination of the density of paddy (ρ_s)

wt. of raw paddy = 12.9873 gm.

vol. of raw paddy = 21.5 c.c.

Therefore, the density of raw paddy

$$= \frac{(12.9873)}{(21.5)(1-0.488)}$$

$$= 1.1798 \text{ gm/c.c.}$$

$$= 1.1798 \times 10^3 \text{ kg/m}^3$$

and the density of wet parboiled paddy

$$= \frac{(28.3329)}{(50)(1-0.488)}$$

$$= 1.1067 \times 10^3 \text{ kg/m}^3$$

4. Determination of bed surface area (As)

From the reference no.(12) p.66 equation (4)

$$\text{Specific surface} = a' = \left(\frac{\text{surface of particles}}{\text{volume of particles}}\right) = \frac{6}{\phi_s . d_p}$$

$$\text{the surface of bed (or particles)} = (\text{volume of bed}) \left(\frac{6}{\phi_s . d_p}\right)$$

a) For batch drying (assume the bed weigh is constant = 1 kg/batch)

Therefore, the bed surface area

$$= \frac{(1)}{(1.1067 \times 10^3)} \cdot \frac{(6)}{(0.68)(3.477 \times 10^{-3})}$$

$$= 2.2930 \text{ m}^2$$

b) For continuous drying

$$As = \frac{p}{\rho_s} \cdot \left(\frac{6}{\phi_s . d_p}\right)$$

From run no.1 ; production rate = 8.7753×10^{-3} kg/sec

Therefore, the bed surface area = $\frac{(8.7753 \times 10^{-3})}{(1.1067 \times 10^{3})} \cdot \frac{(6)}{(0.68)(3.477\times 10}$

$= 2.0122 \times 10^{-2}$ m^2/sec

Part III: Drying Properties Determination

1. Determination of moisture content (M)

wt. of paddy before drying in oven = 37.2021 gm.

wt. of paddy after drying in oven = 24.4312 gm.

wt. of plastic bag and elastic = 2.1 gm.

Therefore, % moisture content (dry basis) = $\frac{\text{wt.of moisture}}{\text{wt.of dry paddy}} \times 100$

$= \frac{(37.2021-24.4312)}{(24.4312-2.1)} \times 100$

$= 57.1886$

2. Determination of rate of drying (R)

moisture content at time 0 min = 0.571886 gm.water/gm.dry paddy

moisture content at time 4 min = 0.452765 gm.water/gm.dry paddy

Therefore, the rate of drying = $\frac{\text{wt.of moisture evaporated}}{\text{time}}$

$= \frac{(0.571886-0.452765)}{(4)}$

$= 0.0298 \frac{\text{gm.}H_2O\text{ evaporated}}{\text{gm.dry paddy.min}}$

$= 1.7868 \frac{\text{gm.}H_2O\text{ evaporated}}{\text{gm.dry paddy.hr}}$

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