Chapter V

EXPERIMENTAL RESULTS

5.1 Minimum Fluidizing Velocity Determination

From the experimental data shown in Appendix B, Pressure drop across bed (Δp) was plotted versus velocity at different height of bed as shown in Figure 5-1. The experimental and theoretical minimum fluidizing velocity (Umf) are compared in Table 5-1.

Table 5-1 Comparison of experimental and theoretical minimum fluidizing velocities

Lm (cm.)	Experimental Umf (m/sec)	Theoretical Umf (m/sec)
6.7	0.43	0.737
11.0	0.94	0.737
15.0	0.78	0.737
21.0	0.72	0.737
26.7	0.77	0.737

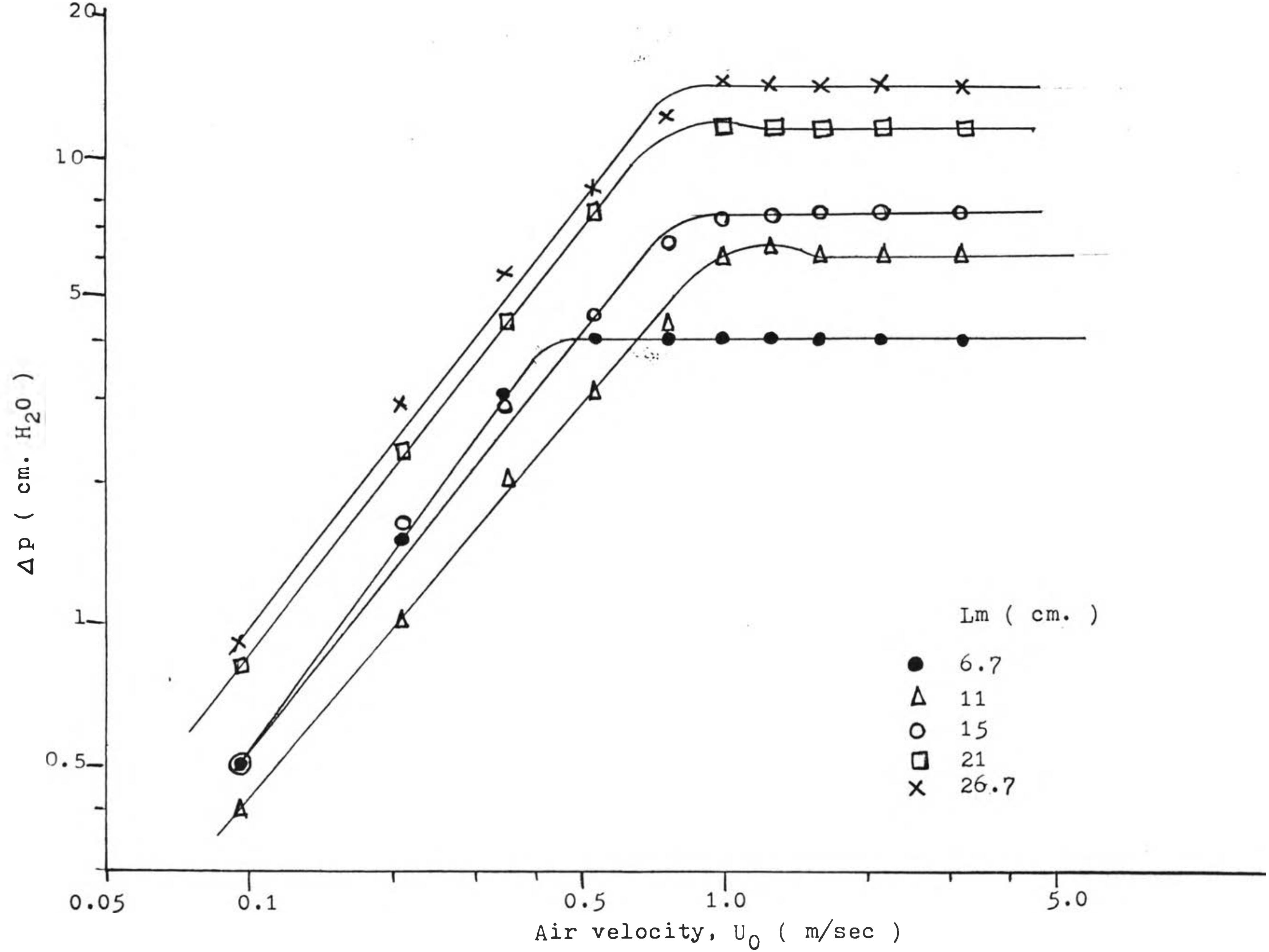


Fig. 5-1 Pressure drop vs. Air Velocity at different height of bed
(under the room temperature, atm. pressure)

5.2 The periods of drying (Batch operation)

From the experimental data, the rate of drying (dM/dt=R) was calculated. The correlation of time (t), moisture content (M), and the rate of drying are shown in Tables 5-2 to 5-11. The plots of M vs. t, R vs. M, R vs. Mav, and R vs. t. when air flow rate was fixed and temperature of air inlet was fixed are compared in Figures 5-2 to 5-9

5.2.1 Fixed air flow rate ($Q_o = 1.3297 \times 10^{-2}$ m^3/sec at S.T.P.)

Table 5-2 The rate of drying when Tgi = 80 °C

Time, t (min)	Moisture, M (% db)	Average M (% db)	Rate of drying, R ($\frac{gm.H_2O\ evaporate}{gm.dry\ solid.hr.}$)
0	57.1886		
4	45.2765	51.2326	1.7868
8	40.5529	42.9147	0.7085
12	35.9807	38.2668	0.6855
16	31.6902	33.8355	0.6436
20	28.5972	30.1437	0.4639
24	25.5528	27.0750	0.4567
	Tempering		
After tempering	24.9617		
2'	21.6677	23.3147	0.9882
4'	20.6894	21.1786	0.2935
6'	19.3672	20.0283	0.3966
8'	18.7836	19.0754	0.1751

Table 5-3 The rate of drying when Tgi = 100 °C

Time, t (min)	Moisture, M (% db)	Average, M (% db)	Rate of drying, R $\left(\frac{gm.H_2O\ evaporate}{gm.dry\ solid.hr}\right)$
0	59.3354		
2	51.6940	55.5147	2.2924
4	44.7545	48.2243	2.0819
6	41.1345	42.9445	1.0860
8	37.1691	39.1518	1.1896
10	32.7824	34.9758	1.3160
	Tempering		
After tempering	32.4770		
2'	25.5671	29.0221	2.0730
4'	24.5491	25.0581	0.3054
6'	22.4476	23.4984	0.6305
8'	19.9029	21.1753	0.7634

Table 5-4 The rate of drying when Tgi = 120°C

Time, t (min)	Moisture, M (% db)	Average, M (% db)	Rate of drying, R ($\frac{gm.H_2O\ evaporate}{gm.dry\ solid.hr}$)
0	57.1886		
2	49.1760	53.1823	2.4038
4	43.5743	46.3752	1.6805
6	38.2142	40.8943	1.6080
8	33.4745	35.8444	1.4219
10	30.1748	31.8247	0.9899
12	26.7604	28.4676	1.0243
	Tempering		
After tempering	25.3095		
2'	22.0477	23.6786	0.9785
4'	19.3363	20.6920	0.8134
6'	16.8853	18.1108	0.7353

Table 5-5 The rate of drying when Tgi = 143 ^{o}C

Time, t (min)	Moisture, M (% db)	Average, M (% db)	Rate of drying, R $(\frac{gm.H_2O\ evaporat...}{gm.dry\ solid.hr})$
0	59.3354		
2	47.7994	53.5674	3.4608
4	40.7726	44.2860	2.1080
6	31.0480	35.9103	2.9174
	Tempering		
After tempering	30.6061		
2'	23.4134	27.0098	2.1578
4'	20.2856	21.8495	0.9383
6'	16.0459	18.1658	1.2719

Table 5-6 The rate of drying when Tgi = 160°C

Time, t (min)	Moisture, M (% db)	Average, M (% db)	Rate of drying, R $\left(\frac{gm.H_2O\ evaporate}{gm.dry\ solid.hr}\right)$
0	59.4181		
2	43.8228	51.6205	4.6786
4	36.2295	40.0262	2.2780
6	27.9468	32.0882	2.4848
	Tempering		
After tempering	26.8574		
2'	20.9133	23.8854	1.7832
4'	16.4127	18.6630	1.3502

Table 5-7 The rate of drying when Tgi = 185 °C

Time, t (min)	Moisture, M (% db)	Average, M (% db)	Rate of drying, R $\left(\frac{gm.H_2O\ evaporate}{gm.dry\ solid.hr}\right)$
0	59.4181		
2	42.6822	51.0502	5.0208
4	34.7558	38.7190	2.3779
6	25.8485	30.3022	2.6722
	Tempering		
After tempering	24.0407		
2'	17.1452	20.5929	2.0687

5.2.2 Fixed air inlet temperature ($T_{gi} = 100^{o}C$)

Table 5-8 The rate of drying when $Q_o = 1.9941 \times 10^{-2}$ m^3/sec (at S.T.P)

Time, t (min)	Moisture,M (% db)	Average.M (% db)	Rate of drying,R $\left(\frac{gm.H_2O\ evaporated}{gm.dry\ solid.hr}\right)$
0	60.8424		
2	47.5721	54.2073	3.9811
4	41.8026	44.6874	1.7309
6	38.9258	40.3642	0.8630
8	34.9111	36.9185	1.2044
10	31.2456	33.0784	1.0997
	Tempering		
After tempering	29.5381		
2'	25.3069	27.4225	1.2694
4'	21.8499	23.5784	1.0371
6'	19.7596	20.8048	0.6271
8'	17.7970	18.7783	0.5888

Table 5-9 The rate of drying when Qo = 1.8283×10^{-2} m^3/sec (at S.T.P)

Time, t (min)	Moisture, M (% db)	Average.M (% db)	Rate of drying,R $\left(\frac{gm.H_2O\ evaporate}{gm.dry\ solid.hr}\right)$
0	60.8424		
2	55.2953	58.0689	1.6641
4	48.7891	52.0422	1.9519
6	44.0847	46.4369	1.4113
8	40.3445	42.2146	1.1221
10	35.4962	37.9204	1.4545
	Tempering		
After tempering	33.0271		
2'	30.9893	32.0082	0.6113
4'	27.0655	29.0274	1.1771
6'	24.3129	25.6892	0.8258
8'	21.5837	22.9483	0.8188

Table 5-10 The rate of drying when $Qo = 1.5790 \times 10^{-2}$ m^3/sec (at S.T.P)

Time, t (min)	Moisture,M (% db)	Average.M (% db)	Rate of drying,R $\left(\frac{gm.H_2O\ evaporate}{gm.dry\ solid.hr}\right)$
0	54.6843		
2	48.1621	51.4232	1.9567
4	42.3726	45.2674	1.7369
6	38.8201	40.5964	1.0658
8	36.1453	37.4827	0.8024
10	33.2318	34.6886	0.8741
	Tempering		
After tempering	32.0628		
2'	28.5345	30.2987	1.0585
4'	26.2221	27.3783	0.6937
6'	24.1820	25.2021	0.6120
8'	22.0866	23.1343	0.6286

Table 5-11 The rate of drying when Qo =1.0804 X 10^{-2} m^3/sec (at S.T.P)

Time, t (min)	Moisture,M (% db)	Average.M (% db)	Rate of drying,R ($\frac{gm.H_2O\ evaporate}{gm.dry\ solid.hr}$)
0	54.6843		
2	49.1539	51.9191	1.6591
4	44.0591	46.6065	1.5284
6	40.2858	42.1725	1.1320
8	37.4934	38.8896	0.8377
10	34.0870	35.7902	1.0219
	Tempering		
After tempering	32.0946		
2'	28.8604	30.4775	0.9703
4'	26.2376	27.543	0.7868
6'	24.6892	25.4634	0.4645
8'	22.6678	23.6785	0.6064

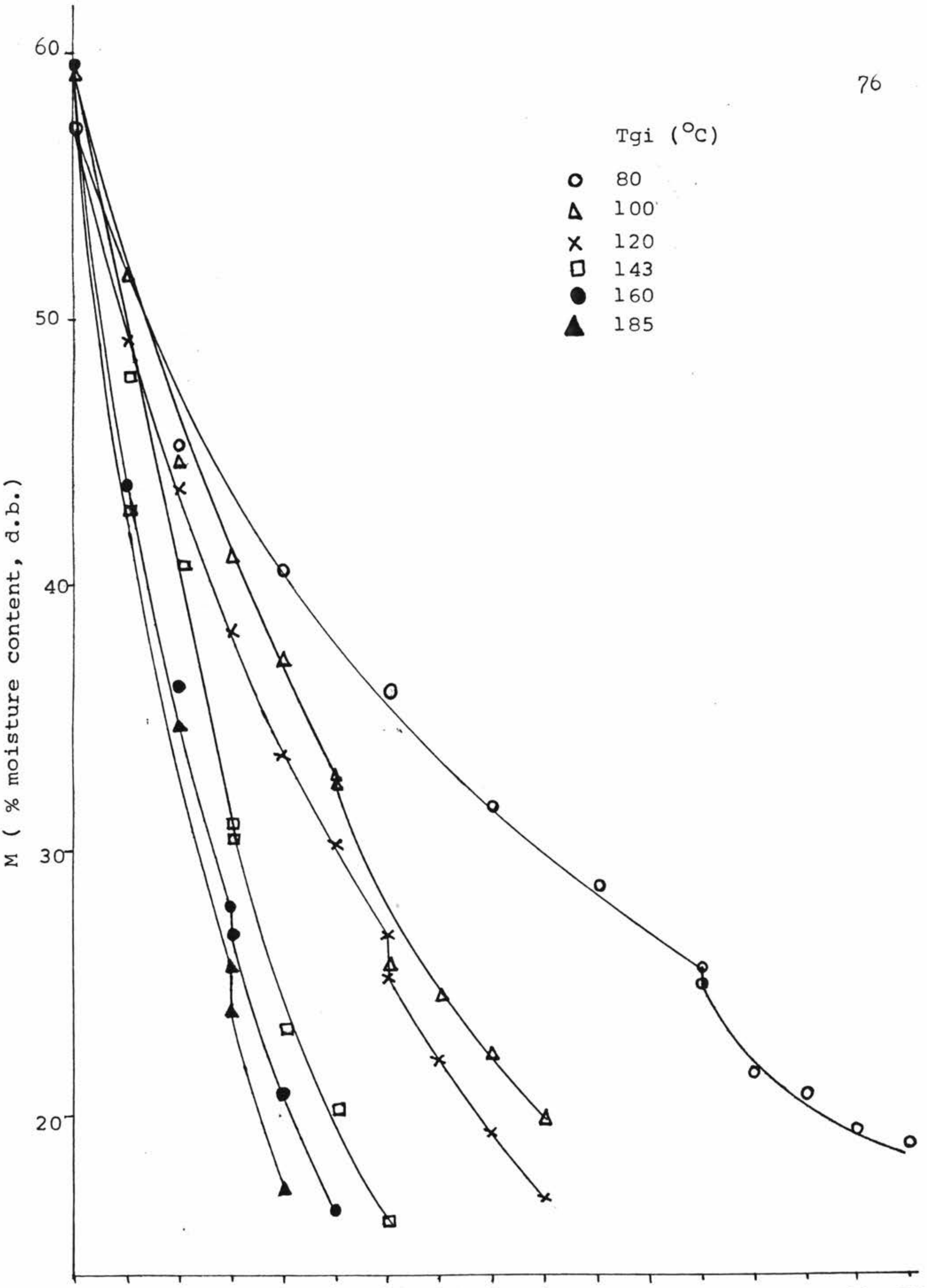


Figure 5-2 Moisture vs Time when air inlet flow rate

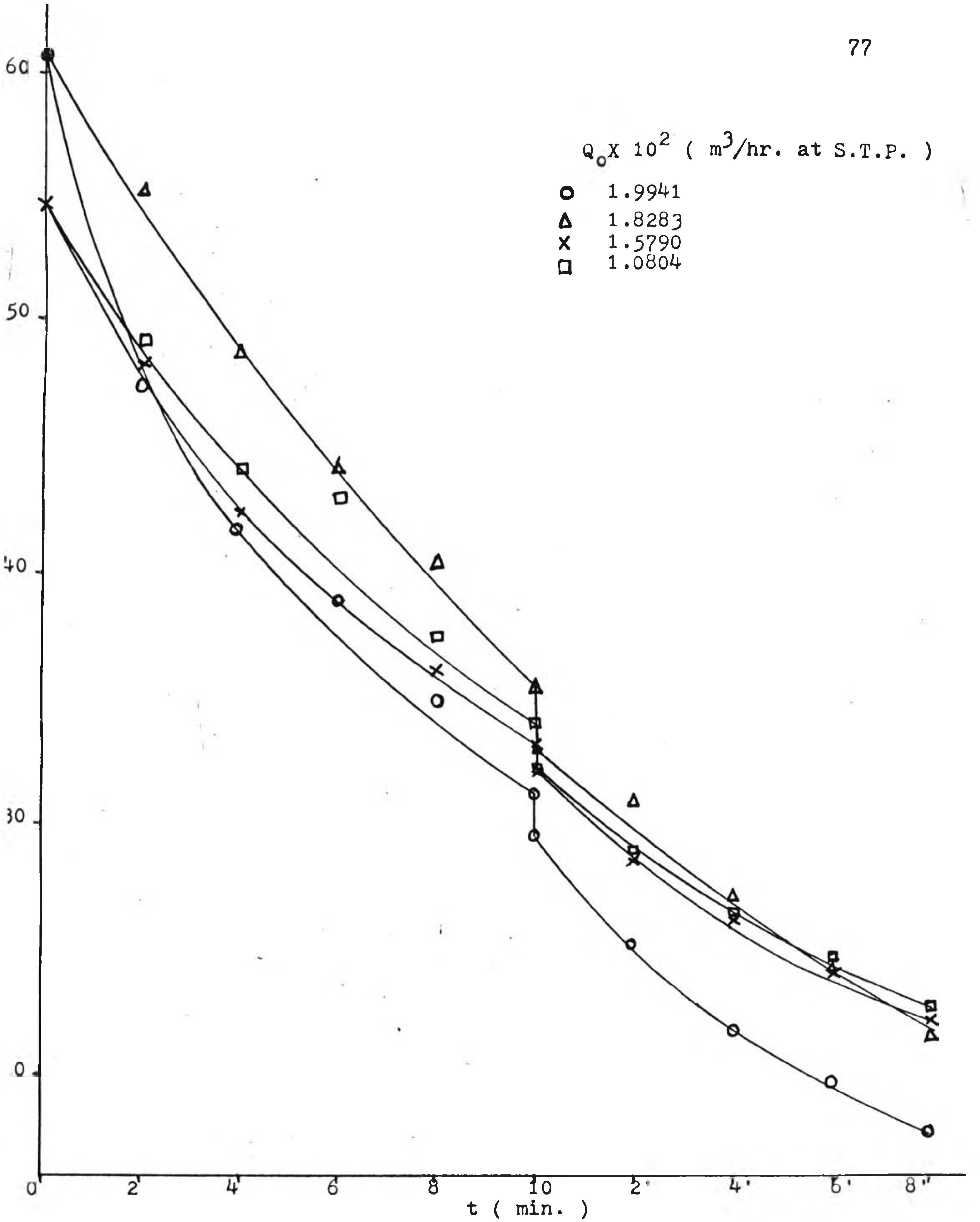


Figure 5-3 Moisture content vs. Time when air inlet temp. was fixed

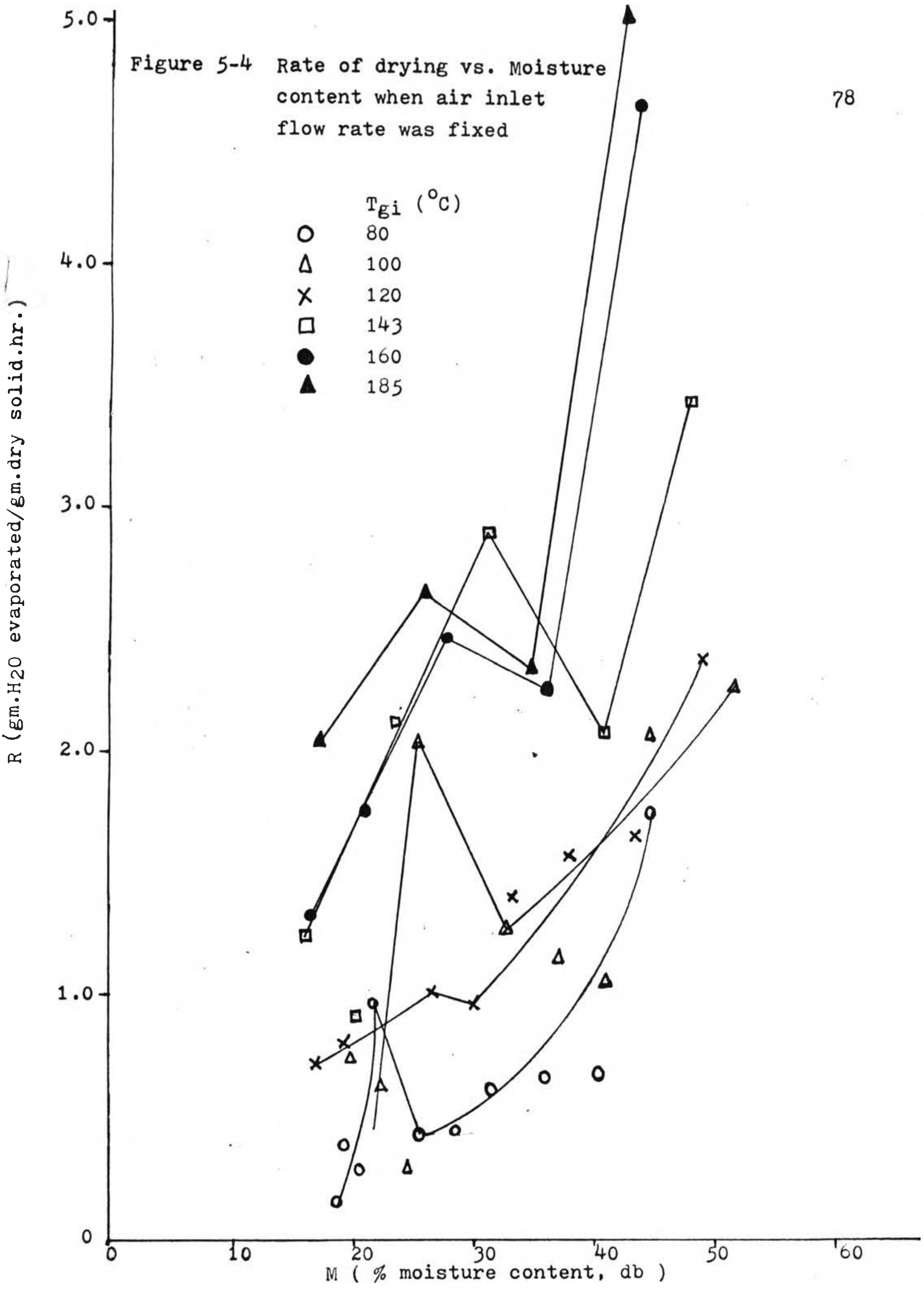


Figure 5-4 Rate of drying vs. Moisture content when air inlet flow rate was fixed
Tgi (°C)
80
100
120
143
160
185
5.0
4.0
3.0
2.0
1.0
0
0
10
20
30
40
50
60
R (gm.H2O evaporated/gm.dry solid.hr.)
M (% moisture content, db)

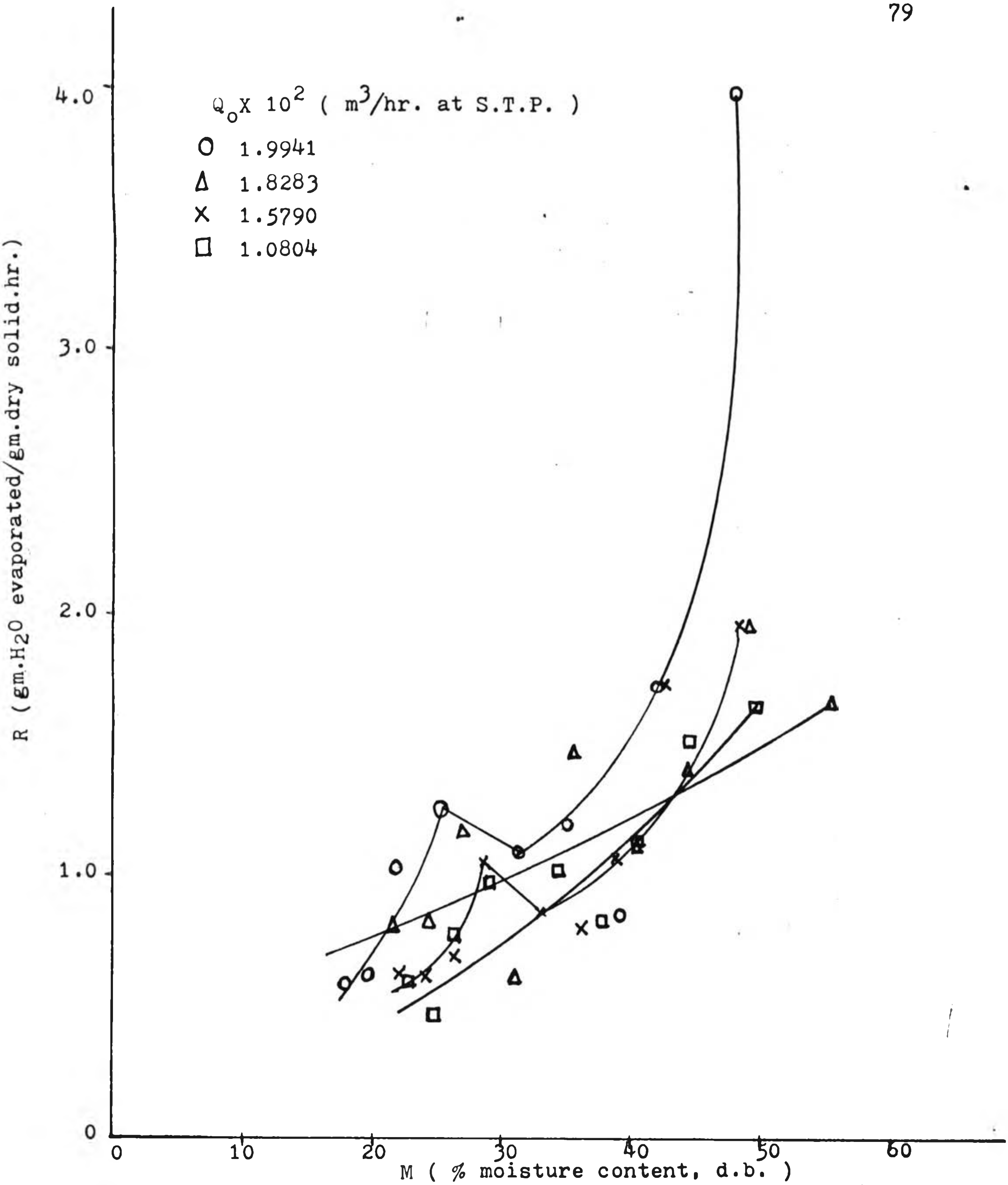
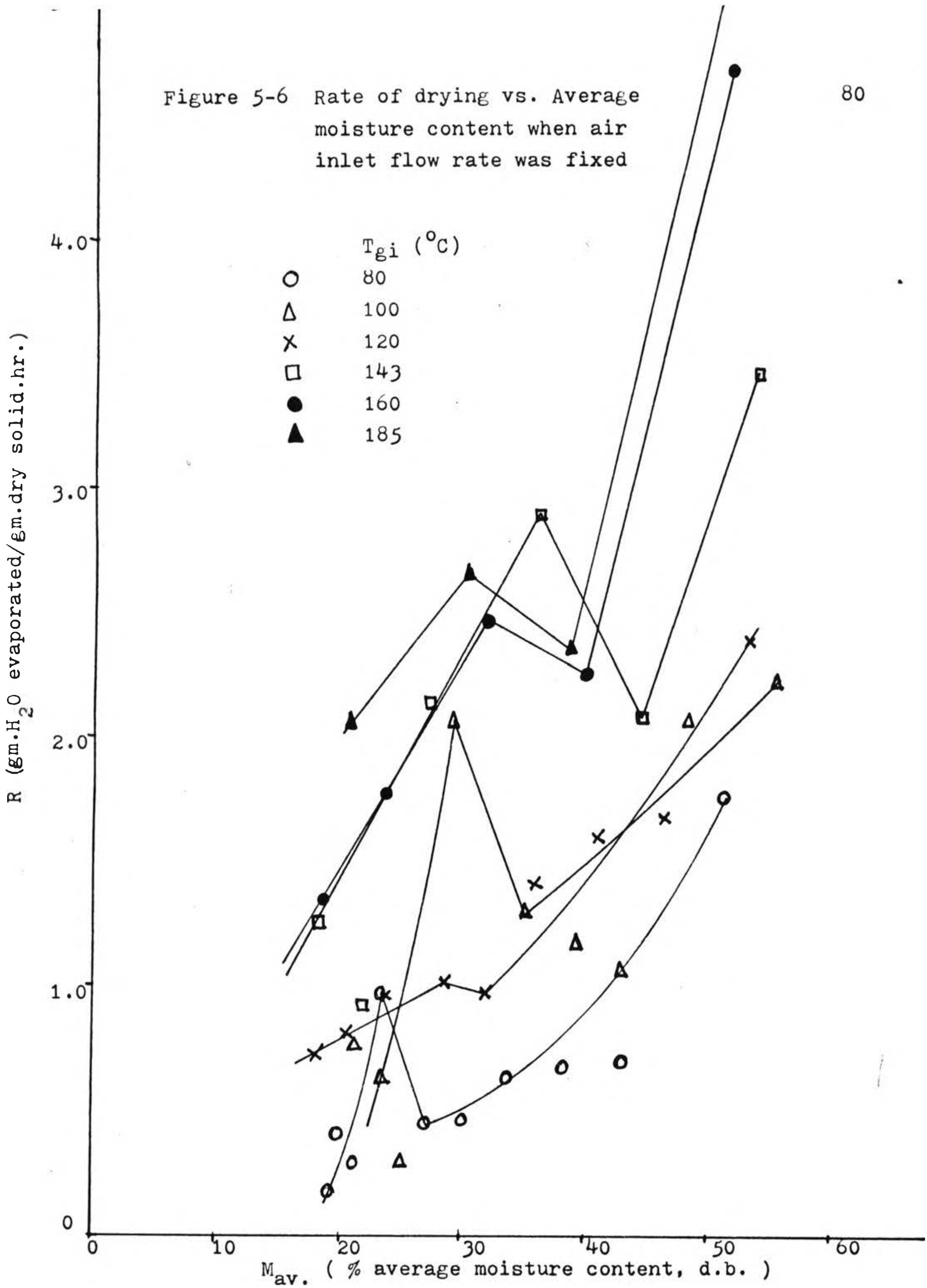


Figure 5-5 Rate of drying vs. Moisture content when air inlet temp. was fixed

Figure 5-6 Rate of drying vs. Average moisture content when air inlet flow rate was fixed



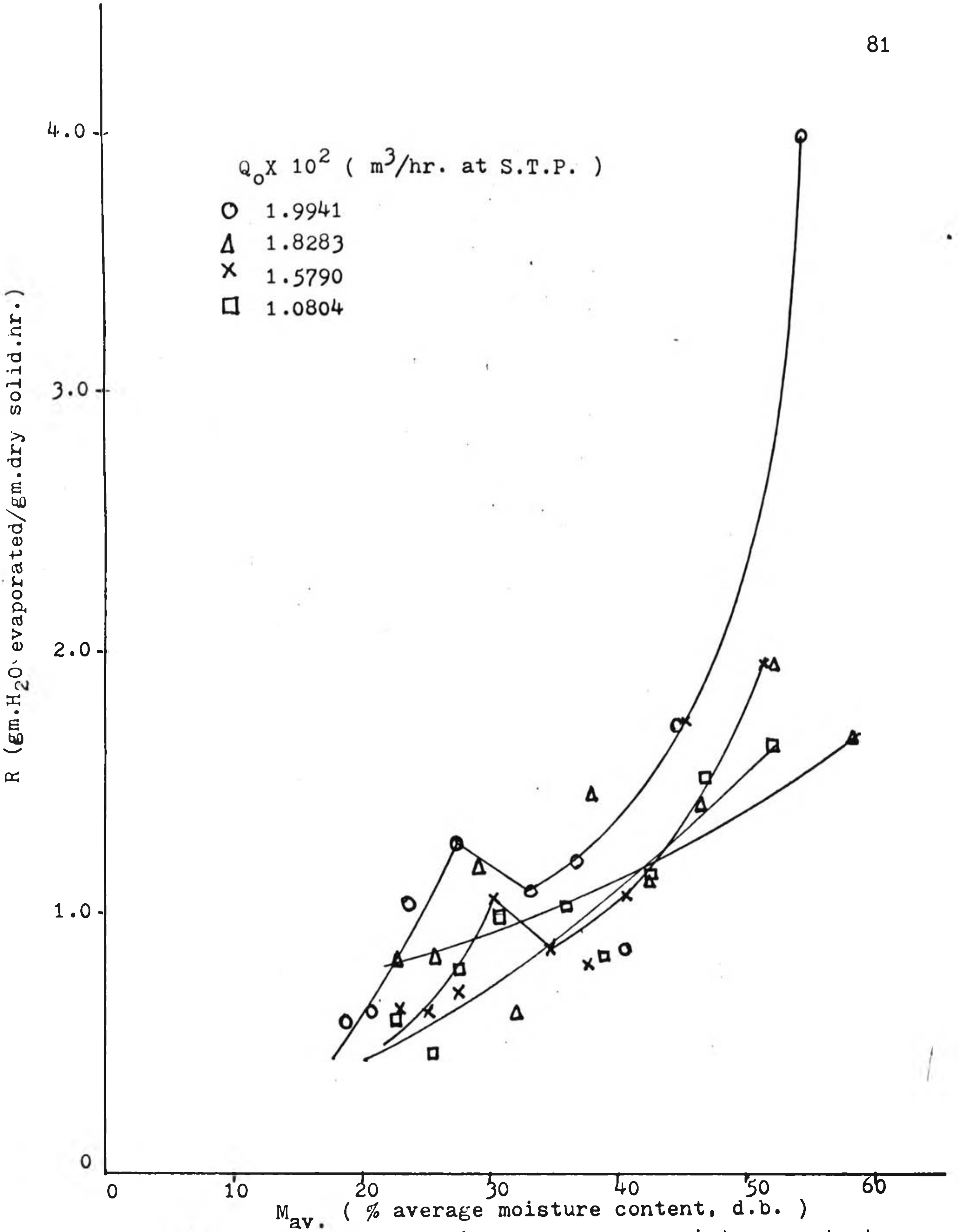
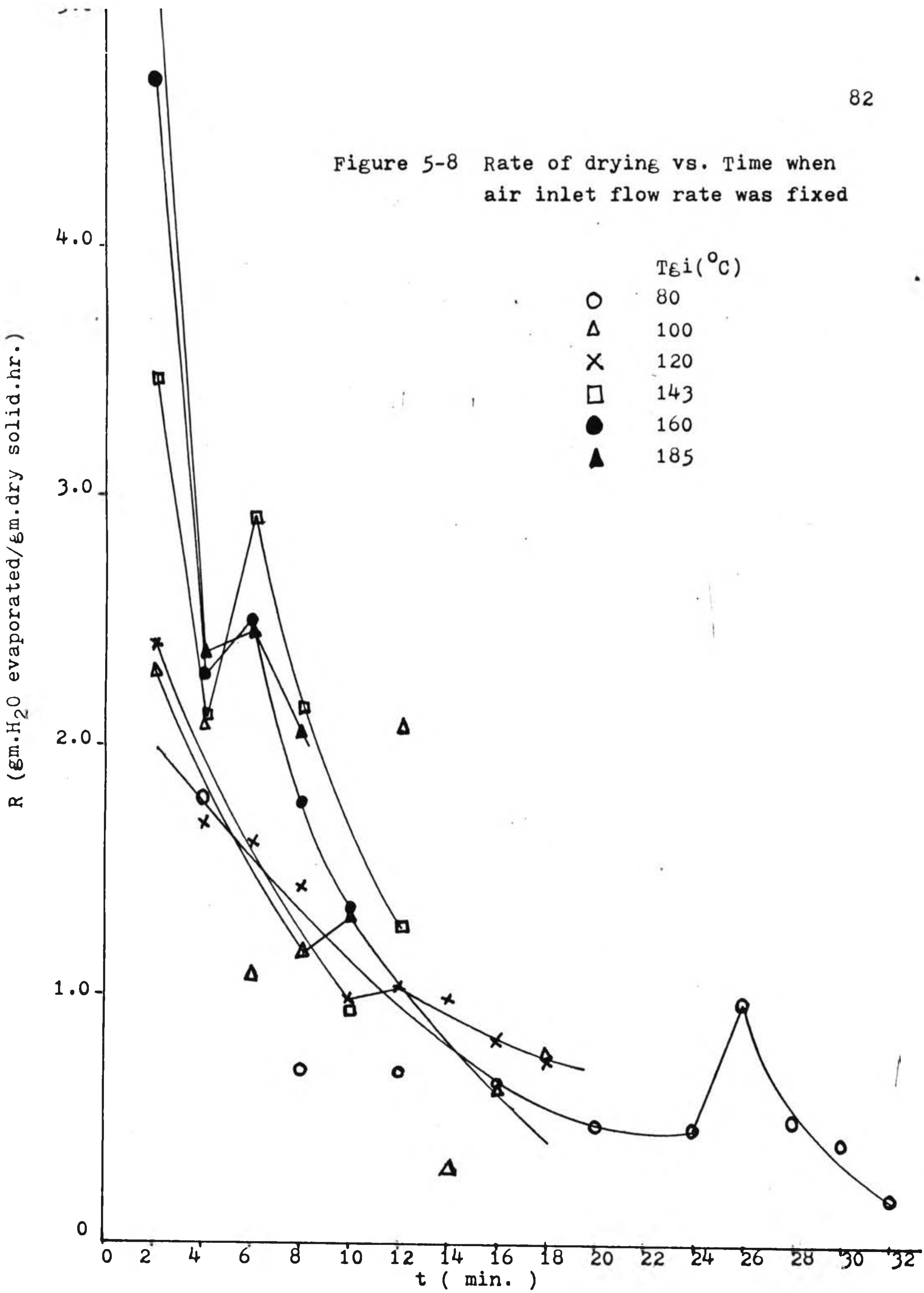


Figure 5-7 Rate of drying vs. Average moisture content when air inlet temp. was fixed

Figure 5-8 Rate of drying vs. Time when air inlet flow rate was fixed



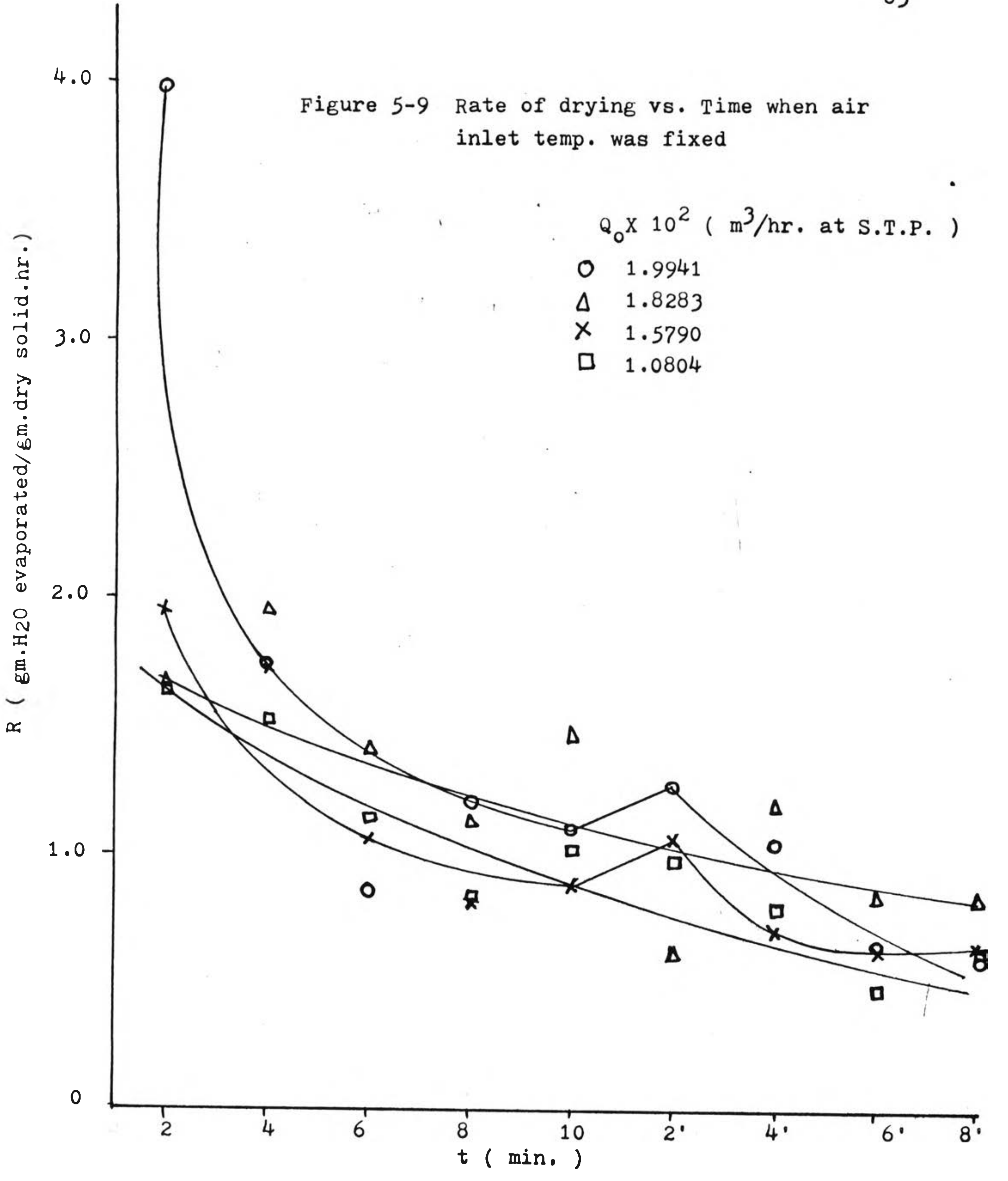


Figure 5-9 Rate of drying vs. Time when air inlet temp. was fixed

5.3 The Heat Balance

Heat balance around the fluidized bed was considered. The rate of heat transfer (q_h), heat transfer coefficient (h_p), Nusselt number (Nup), and Reynolds number (Rep) were determined. The results were obtained step by step as follows.

5.3.1 Rate of heat transfer and Temperature difference

From the experimental data and equation (2-7), the temperature differences for heat transfer and the rate of heat transfer were calculated. By plotting q_h against ΔT, As h_p is the slope. So, the heat transfer coefficients(h_p) were obtained from the plots. The results are shown in Tables 5-12, 5-13 and plotted in Figures 5-10, 5-11.

1. Batch operation when air inlet flow rate was fixed

($Qo = 1.3297 \times 10^{-2}\ m^3/sec$ at S.T.P)

Table 5-12 Rate of heat transfer and Temperature difference

Tgi = 80°C		Tgi = 100°C		Tgi = 120°C		Tgi = 143°C		Tgi = 160°C		Tgi = 185°C	
ΔT (°K)	$q_h \times 10^{-3}$ (J/sec)	ΔT (°K)	$q_h \times 10^{-3}$ (J/sec)	ΔT (°K)	$q_h \times 10^{-3}$ (J/sec)	ΔT (°K)	$q_h \times 10^{-3}$ (J/sec)	ΔT (°K)	$q_h \times 10^{-3}$ (J/sec)	ΔT (°K)	$q_h \times 10^{-3}$ (J/sec)
25	0.4498	13	0.2186	40	0.6559	29	0.4440	52	0.7834	73	1.0575
23	0.4139	12	0.2018	30	0.4919	28	0.4287	48	0.7231	65	0.9416
15	0.2699	11	0.1850	29	0.4755	23	0.3521	39	0.5875	62	0.8981
10	0.1799	10	0.1682	25	0.4099	22	0.3368	36	0.5423	55	0.7967
		8	0.1345			21	0.3215			54	0.7822
		7	0.1177			20	0.3062				
		6	0.1009								

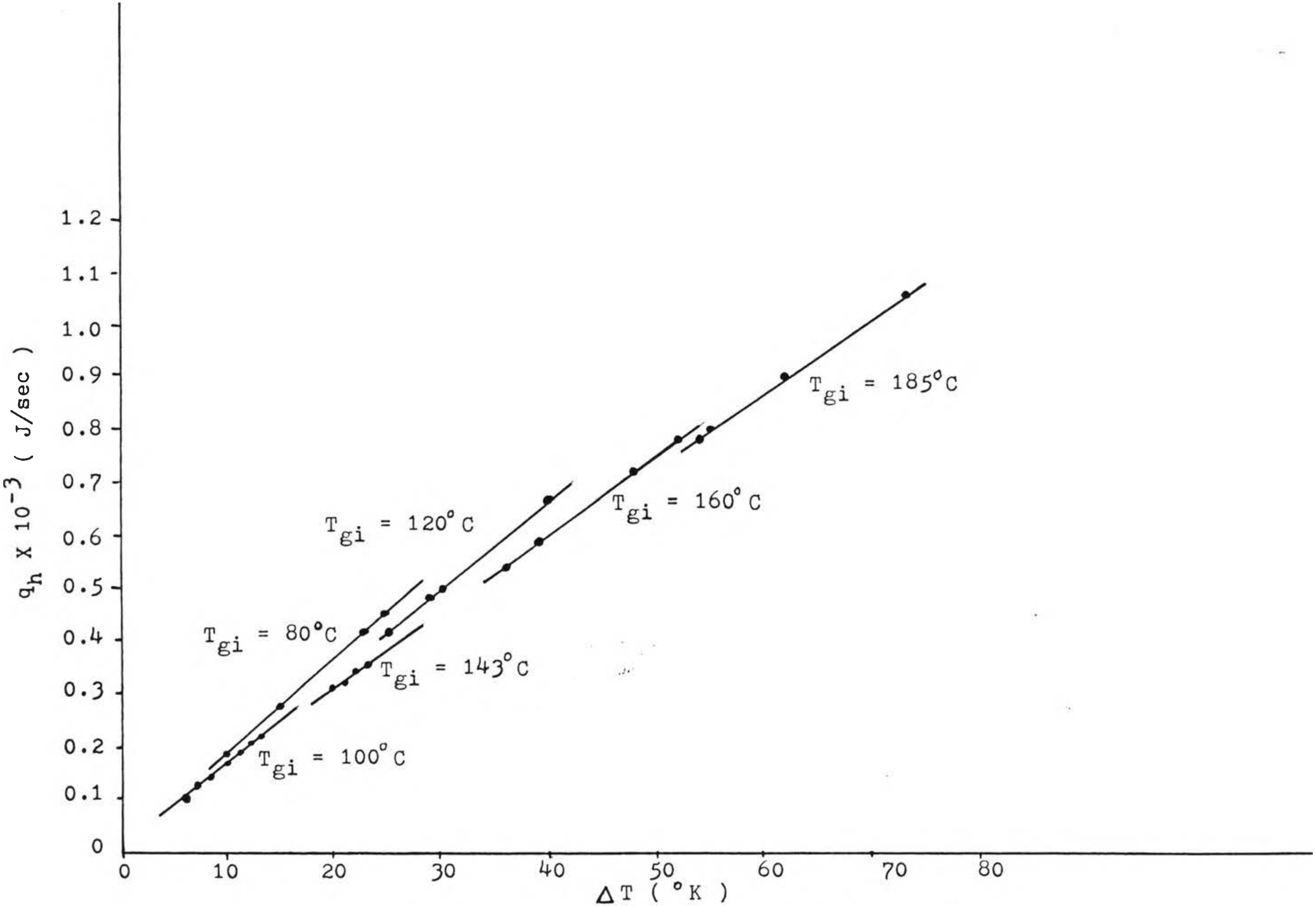


Figure 5-10 Rate of heat transfer vs. Temperature difference
(Batch operation)

2. Continuous operation when air inlet flow rate and temperature were fixed ($Qo = 1.5790 \times 10^{-2}$ m^3/sec at S.T.P)

Table 5-13 Rate of heat transfer and Temperature difference

$P \times 10^3$ (kg/sec)	$As \times 10^2$ (m^2/sec)	$q_h \times 10^{-3}$ (J/sec)	ΔT (^oK)
8.7753	2.0122	1.0863	62
7.6645	1.7575	1.3316	76
6.9980	1.6046	1.4017	80
6.4148	1.4709	1.2615	72
5.7483	1.3181	1.2966	74
5.4984	1.2608	1.1564	66
4.3821	1.0048	1.4017	80

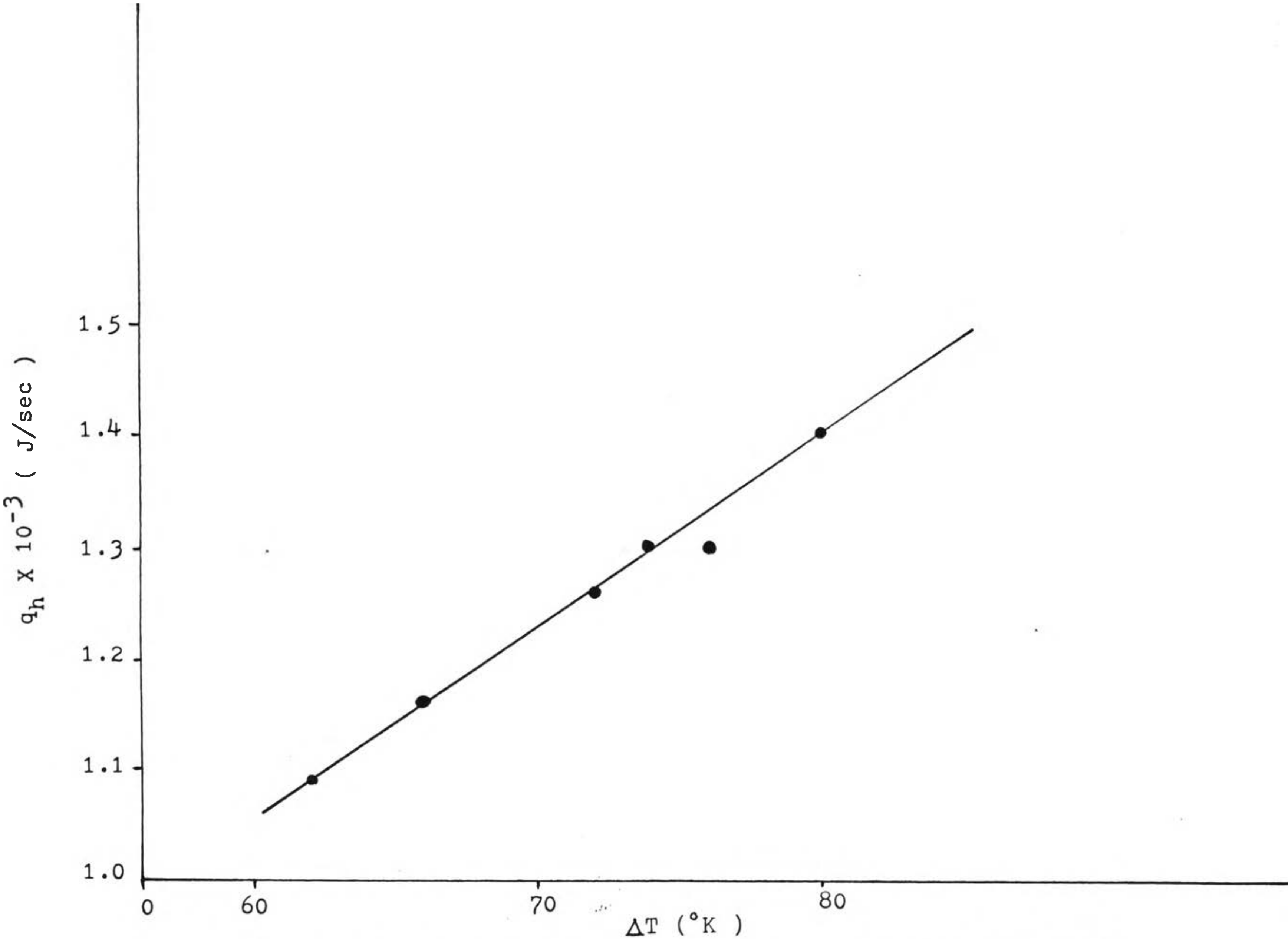


Figure 5-11 Rate of heat transfer vs. Temperature difference
(Continuous operation)

5.3.2 Heat transfer coefficient

Experimental heat transfer coefficients were determined from the slope of plotting of q_h versus ΔT. They are shown in Table 5-14 and 5-15.

Table 5-14 Experimental heat transfer coefficients for batch operation when air inlet flow rate was fixed at 1.3297 X 10^{-2} m^3/sec at S.T.P.

Tgi (^oC)	ρ_g (kg/m^3)	Cpg X 10^{-3} ($J/kg. ^oK$)	h_p ($J/sec.m^2.^oK$)
80	1.026	1.0467	7.8456
100	0.959	1.0467	7.3310
120	0.935	1.0467	7.1522
143	0.873	1.0467	6.6725
160	0.859	1.0467	6.5722
185	0.826	1.0467	6.3192

Table 5-15 Experimental heat transfer coefficients for continuous operation when air inlet flow rate was fixed at 1.5790 m^3/sec at S.T.P.

P X 10^3 (kg/sec)	h_D X 10^{-3} (J/sec.m^2.°K) (sec)
8.7753	0.8709
7.6645	0.9972
6.9980	1.0922
6.4148	1.1919
5.7483	1.3296
5.4984	1.3899
4.3821	1.7441

5.3.3 Nusselt number and Reynolds number

Nusselt and Reynolds numbers were determined from the experimental data. From the logarithmic plot of Nup against Rep, c and m are intercept and slope, respectively. So, at constant temperature of air inlet (batch operation), c and m were obtained from the plot. The results are shown in Table 5-16 and plotted in Figure 5-12.

Table 5-16 Nusselt number and Reynolds number

$Qo \times 10^2$ at STP (m^3/sec)	$Qo \times 10^2$ at Tgb (m^3/sec)	Uo (m/sec)	Rep X 10^{-2}	h_p (J/sec.m^2.^oK)	Nup X 10^2
1.9941	2.5127	3.1993	5.3168	11.2932	1.3383
1.8283	2.3038	2.9333	4.8748	10.3543	1.2271
1.5790	1.9897	2.5334	4.2102	8.9426	1.0598
1.3297	1.6755	2.1333	3.5453	7.5305	0.8924
1.0804	1.3614	1.7334	2.8807	6.1188	0.7251

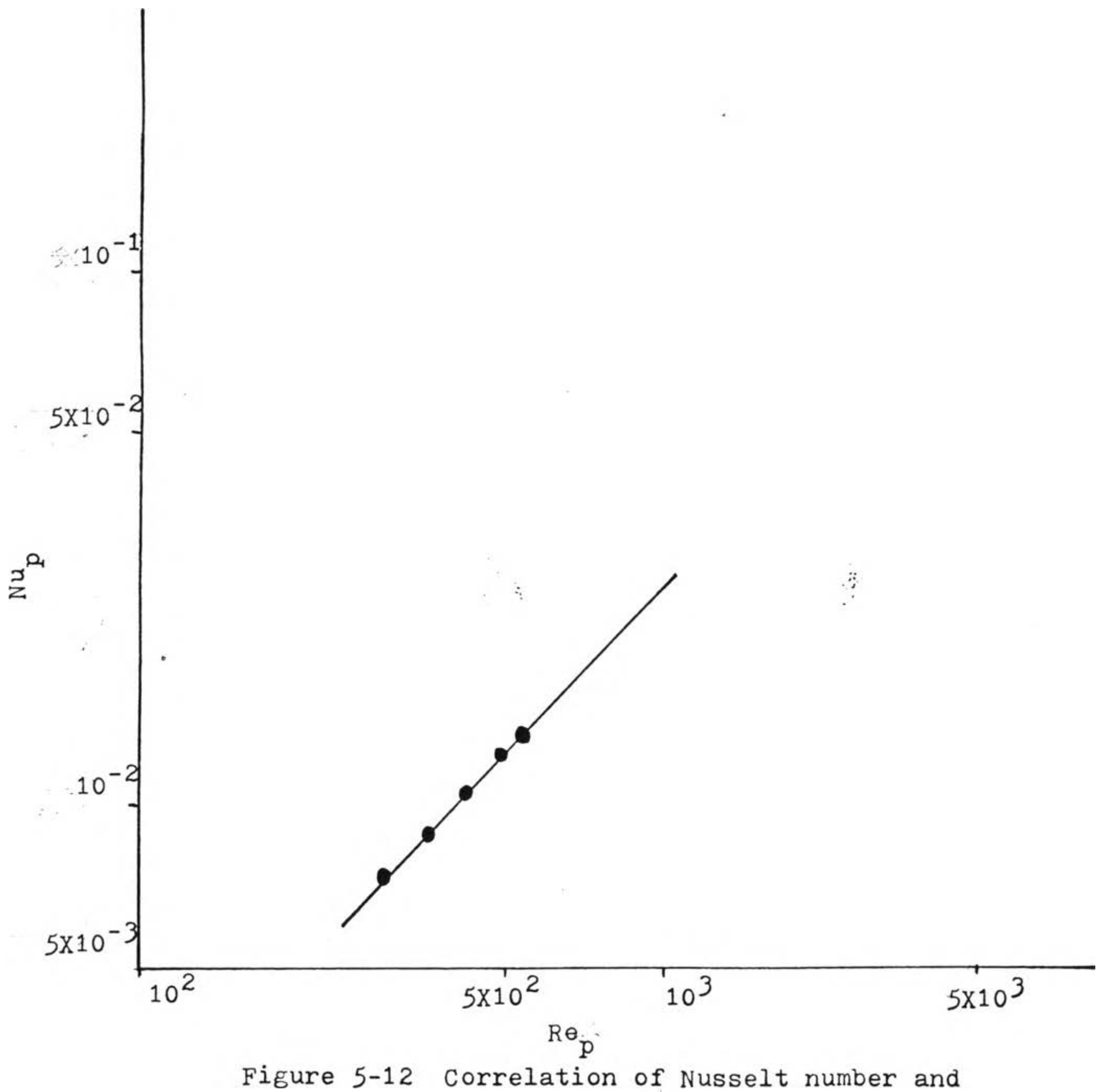


Figure 5-12 Correlation of Nusselt number and Reynolds number

5.4 Results of Milling

The results of milling: % husk, % bran, % broken rice, and % head rice were noted after milling. The comparisons are shown in Tables 5-17, 5-18, and 5-19.

Table 5-17 Results of Milling for Batch operation when air flow rate was fixed

Tgi (°C)	% M after drying (d.b.)	% M before milling (d.b.)	100%			
			Husk (%)	Bran (%)	Broken rice (%)	Head rice (%)
Raw paddy	-	15.01	25.6	14.40	17.60	42.4
80	18.7836	12.54	23.2	1.20	2.80	72.8
100	19.9029	13.38	22.8	6.00	4.00	67.2
120	16.8853	12.35	23.6	3.68	5.12	67.6
143	16.0459	11.17	23.2	3.60	6.40	66.8
160	16.4127	12.54	23.2	4.96	7.44	64.4
185	17.1452	12.37	24.8	7.20	8.00	60.0

Table 5-18 Results of Milling for Batch operation when air inlet temp. was fixed

Qo X 10^2 at STP. (m^3/sec)	% M after drying (d.b.)	% M before milling (d.b.)	100%			
			Husk (%)	Bran (%)	Broken rice (%)	Head rice (%)
Raw paddy	-	15.34	21.60	8.96	25.60	43.84
1.9941	17.7976	13.26	24.00	4.0	1.60	70.40
1.8283	21.5837	13.61	24.00	4.0	1.20	70.80
1.5790	22.0866	13.67	21.20	4.0	1.36	73.44
1.0804	22.6678	14.53	21.20	4.0	0.96	73.84

Table 5-19 Results of Milling for Continuous operation when air flow rate and inlet temp. were fixed.

$P \times 10^3$ (kg/sec)	%M after drying (d.b.)	%M before milling (d.b.)	100% Husk (%)	Bran (%)	Broken rice (%)	Head rice (%)
Raw paddy	-	15.34	26.0	8.0	22.0	44.0
8.7753	25.3842	12.46	26.0	1.2	3.2	69.6
7.6645	19.8013	12.30	25.2	5.2	4.4	65.2
6.9980	20.7409	12.32	25.6	4.0	4.0	66.4
6.4148	17.0398	11.86	24.0	5.2	7.2	63.6
5.7483	16.3417	11.54	25.6	4.4	4.0	66.0
5.4984	13.5821	11.11	25.2	8.4	2.8	63.6
4.3821	12.4752	11.05	27.6	6.4	3.6	62.4

5.5 Determination of Physical Properties of Bed

All physical properties of bed which were necessary for using in calculation were determined from the experimental data. The results are shown in Table 5-20

Table 5-20 Determination of Physical Properties of Bed

Physical Properties	Value
Void fraction (εm)	0.488
Sphericity (ϕs)	0.68
Diameter of sphere having the volume of paddy (dp)	3.477×10^{-3} m
Density of raw paddy (ρs)	1.1798×10^{3} kg/m^{3}
Density of wet parboiled paddy (ρs)	1.1067×10^{3} kg/m^{3}
Bed surface area (As)	
for batch drying	2.2930 m^{2}
for continuous drying	2.2930 P m^{2}/sec