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APPENDIX A

Experimental Data

Table A-1 Water content at the surface of the WAP-free sand column at the various conditions.

Conditions	Water content (% weight/dry weight)
50 °C, 25% RH	59.1
50 °C, 40% RH	58.9
40 °C, 25% RH	60.1
40 °C, 40% RH	58.4
30 °C, 25% RH	58.7
30 °C, 40% RH	59.2

Table A-2 Water content at the surface of sand column containing 0.2% WAP by weight at the various conditions.

Conditions	Water content (% weight/dry weight)
50 °C, 25% RH	56.2
50 °C, 40% RH	54.1
40 °C, 25% RH	58
40 °C, 40% RH	56.4
30 °C, 25% RH	60
30 °C, 40% RH	59.2

Table A-3 Water content at the surface of sand column containing 0.4% WAP by weight at the various conditions.

Conditions	Water content (% weight/dry weight)
50 °C, 25% RH	102.7
50 °C, 40% RH	99
40 °C, 25% RH	100.3
40 °C, 40% RH	102.8
30 °C, 25% RH	101.4
30 °C, 40% RH	101.9

Table A-4 Water content at the surface of sand column containing 0.5% WAP by weight at the various conditions.

Conditions	Water content (% weight/dry weight)
50 °C, 25% RH	120.2
50 °C, 40% RH	120.6
40 °C, 25% RH	128.2
40 °C, 40% RH	126.9
30 °C, 25% RH	122
30 °C, 40% RH	123.6

Table A-5 Water conten in the WAP-free column at depth inteval using ambient air condition :50 degree Celcius,25% RH (Data at 1 hour interval.)

Depth	Water content (% weight/dry weight)										
(cm)	0	1	2	3	4	5	6	7	8	9	10
0	59.1	3.8	2.03	1.78	1.4	0.58	0.01	0	0	0	0
10	59.1	12	8.35	7.66	6.1	5.26	6.06	2.02	0	0	0
20	59.1	20	13	11.7	11	6.18	4.71	3.46	1.8	0	0
30	59.1	35	24.6	23.6	20	20.2	18.6	15.7	9.2	4.74	1.54
40	59.1	59	49	37.5	28	23.5	22.3	20.8	16	10.2	10.1
50	59.1	56	58.2	56.4	47	32.5	28.4	23.5	22	10.1	22.5

Table A-6 Water conten in the WAP-free column at depth inteval using ambient air condition :50 degree Celcius,40% RH (Data at 1 hour interval.)

Depth	Water content (% weight/dry weight)										
(cm)	0	1	2	3	4	5	6	7	8	9	10
0	58.9	36	2.46	1.96	1.7	0.93	0.14	0.03	0	0	0
10	58.9	12	7.98	8.06	6.6	6.11	5.2	3.54	0.9	0	0
20	58.9	23	13.1	11.3	10	6.95	5.5	3.94	2.1	1.68	0.52
30	58.9	36	27	25.5	21	18.9	16.2	15.1	11	4.26	1.69
40	58.9	54	47.2	36.9	29	23.2	21.8	20.6	18	10.3	6.07
50	58.9	58	57.6	56.1	45	35.5	30.6	24.7	22	13.7	10.5

Table A-7 Water conten in the WAP-free column at depth inteval using ambient air condition :40 degree Celcius,25% RH (Data at 1 hour interval.)

Depth	Water content (% weight/dry weight)										
(cm)	0	1	2	3	4	5	6	7	8	9	10
0	60.1	4	2.67	1.94	1.2	0.8	0.33	0.7	0	0	0
10	60.1	15	9.52	7.4	7.1	5.95	4.16	3.11	1.9	0.37	0
20	60.1	19	16	12.6	11	7.58	5.24	3.48	2.1	0.99	0.16
30	60.1	37	26.4	23	21	18.9	18.6	15.5	12	6.38	3.62
40	60.1	56	48.3	38.2	31	25.4	23.9	19.1	13	10.8	11.5
50	60.1	63	59.3	56.1	47	33.4	29.8	23.4	19	12.2	15

Table A-8 Water conten in the WAP-free column at depth inteval using ambient air condition :40 degree Celcius,40% RH (Data at 1 hour interval.)

Depth	Water content (% weight/dry weight)										
(cm)	0	1	2	3	4	5	6	7	8	9	10
0	58.4	3.8	2.01	2.03	1.3	1.6	0.59	0.32	0	0	0
10	58.4	15	9.25	8.48	7.2	6.18	4.65	3.96	2.2	0.94	0
20	58.4	19	16.6	13.1	12	7.54	6.6	3.28	3	1.72	0.25
30	58.4	36	26.8	23.1	20	17.2	19	16.4	10	5062	4.88
40	58.4	56	48.1	38.5	30	27.7	26.9	20.2	14	12.1	10.6
50	58.4	58	58.3	56.5	49	35.1	30.2	24.2	20	12.3	10.4

Table A-9 Water conten in the WAP-free column at depth inteval using ambient air condition :30 degree Celcius,25% RH (Data at 1 hour interval.)

Depth	Water content (% weight/dry weight)										
(cm)	0	1	2	3	4	5	6	7	8	9	10
0	58.7	4.5	3.56	2.3	2.4	1.19	0.91	0.35	0	0	0
10	58.7	15	9.87	8.73	7.1	6.31	5.39	3.71	2.2	1.18	0.52
20	58.7	21	15.5	13.3	12	6.84	5.68	3.44	3.2	0.93	0.19
30	58.7	38	26.1	23.4	21	20.7	19.5	15.2	12	6.75	3.38
40	58.7	60	50.1	38.6	30	25.4	25.8	21.6	15	12.9	12.5
50	58.7	60	58.8	57.9	48	35.4	29	24.3	21	13	15.7

Table A-10 Water conten in the WAP-free column at depth inteval using ambient air condition :30 degree Celcius,40% RH (Data at 1 hour interval.)

Depth	Water content (% weight/dry weight)										
(cm)	0	1	2	3	4	5	6	7	8	9	10
0	59.2	3.8	3.12	2.23	1.9	1.09	1.23	0.6	0	0	0
10	59.2	14	9.11	8.32	6.2	5.63	5.01	3.26	2.2	1.2	0.75
20	59.2	20	15.9	13.1	11	6.4	5.16	4.23	3.5	1.83	1.43
30	59.2	37	27.5	25.7	20	19.6	17.9	15	12	5.81	4.72
40	59.2	56	49.6	42.1	30	27	25.6	20.5	17	13.6	12.6
50	59.2	60	55.5	54.9	51	46.2	30.4	25.6	22	13	10.4

Table A-11 Water content of sand column containing 0.2% WAP by weight at depth interval using ambient air condition :50 degree Celcius, 25% RH. (Data at 3 hours interval.)

Depth	Water content (% weight/dry weight)				
(cm)	0	3	6	9	12
0	56.18	39.84	16.06	15.81	14.02
10	56.18	41.84	37.62	22.86	16.14
20	56.18	46.73	40.41	33.44	20.93
30	56.18	52.68	42.96	39.20	38.89
40	56.18	54.52	49.88	44.48	39.38
50	56.18	69.61	51.62	46.26	39.54

Table A-12 Water content of sand column containing 0.2% WAP by weight at depth interval using ambient air condition :50 degree Celcius, 40% RH. (Data at 3 hours interval.)

Depth	Water content (% weight/dry weight)				
(cm)	0	3	6	9	12
0	54.14	37.73	20.51	16.38	14.21
10	54.14	42.61	39.05	20.39	17.23
20	54.14	45.86	40.85	30.57	21.68
30	54.14	52.78	40.82	39.36	40.63
40	54.14	54.87	45.07	44.23	38.45
50	54.14	53.61	52.11	45.98	39.47

Table A-13 Water content of sand column containing 0.2% WAP by weight at depth interval using ambient air condition :40 degree Celcius, 25% RH. (Data at 3 hours interval.)

Depth	Water content (% weight/dry weight)				
(cm)	0	3	6	9	12
0	57.99	43.49	31.52	20.03	11.86
10	57.99	39.94	45.84	20.17	18.58
20	57.99	49.06	46.49	35.24	23.91
30	57.99	53.88	52.85	42.44	31.15
40	57.99	50.16	57.85	52.07	40.71
50	57.99	60.54	63.99	53.49	45.39

Table A-14 Water content of sand column containing 0.2% WAP by weight at depth interval using ambient air condition :40 degree Celcius, 40% RH. (Data at 3 hours interval.)

Depth	Water content (% weight/dry weight)				
(cm)	0	3	6	9	12
0	56.4	43.34	30.98	23.70	15.98
10	56.4	45.55	42.44	25.08	18.41
20	56.4	50.37	46.20	32.15	26.55
30	56.4	52.51	51.81	43.97	31.76
40	56.4	55.60	53.50	53.13	46.88
50	56.4	58.53	56.54	52.66	46.63

Table A-15 Water content of sand column containing 0.2% WAP by weight at depth interval using ambient air condition :30 degree Celcius, 25% RH. (Data at 3 hours interval.)

Depth (cm)	Water content (% weight/dry weight)				
	0	3	6	9	12
0	59.94	45.03	29.21	23.56	20.81
10	59.94	44.16	40.61	24.45	20.50
20	59.94	46.83	47.11	35.06	24.92
30	59.94	56.17	44.23	39.79	36.29
40	59.94	59.00	55.38	50.80	48.22
50	59.94	61.02	60.92	46.58	47.49

Table A-16 Water content of sand column containing 0.2% WAP by weight at depth interval using ambient air condition :30 degree Celcius, 40% RH. (Data at 3 hours interval.)

Depth (cm)	Water content (% weight/dry weight)				
	0	3	6	9	12
0	59.25	46.86	27.66	24.58	19.12
10	59.25	47.37	45.57	30.52	22.53
20	59.25	52.61	47.04	36.20	25.71
30	59.25	56.93	50.80	42.03	33.62
40	59.25	60.78	55.00	52.38	45.63
50	59.25	62.55	59.28	48.58	46.42

Table A-17 Water content of sand column containing 0.4% WAP by weight at depth interval using ambient air condition :50 degree Celcius, 25% RH. (Data at 3 hours interval.)

Depth (cm)	Water content (% weight/dry weight)				
	0	3	6	9	12
0	102.68	77.15	61.06	47.45	32.58
10	102.68	83.68	79.34	62.15	43.30
20	102.68	85.97	84.09	77.01	70.89
30	102.68	91.81	92.56	83.37	88.71
40	102.68	98.88	98.28	96.13	95.78
50	102.68	106.47	100.82	97.06	101.00

Table A-18 Water content of sand column containing 0.4% WAP by weight at depth interval using ambient air condition :50 degree Celcius, 40% RH. (Data at 3 hours interval.)

Depth (cm)	% WATER				
	0	3	6	9	12
0	99.04	78.33	63.28	45.04	30.36
10	99.04	84.74	79.59	61.23	48.38
20	99.04	90.19	88.39	74.51	69.81
30	99.04	96.12	90.56	85.63	80.67
40	99.04	98.54	95.22	93.67	94.76
50	99.04	102.57	97.33	96.77	95.90

Table A-19 Water content of sand column containing 0.4% WAP by weight at depth interval using ambient air condition :40 degree Celcius, 25% RH. (Data at 3 hours interval.)

Depth	Water content (% weight/dry weight)				
(cm)	0	3	6	9	12
0	100.34	80.85	71.19	56.00	35.00
10	100.34	84.01	84.29	73.21	44.15
20	100.34	91.65	88.05	75.70	68.71
30	100.34	96.23	92.32	85.32	87.33
40	100.34	99.73	97.05	89.29	93.76
50	100.34	105.74	97.21	98.07	97.85

Table A-20 Water content of sand column containing 0.4% WAP by weight at depth interval using ambient air condition :40 degree Celcius, 40% RH. (Data at 3 hours interval.)

Depth	Water content (% weight/dry weight)				
(cm)	0	3	6	9	12
0	102.80	80.91	67.96	56.14	33.84
10	102.80	83.82	79.44	73.34	50.75
20	102.80	92.74	88.02	76.41	70.24
30	102.80	96.02	93.42	85.78	88.71
40	102.80	98.38	99.90	90.88	95.14
50	102.80	103.53	100.27	97.40	97.04

Table A-21 Water content of sand column containing 0.4% WAP by weight at depth interval using ambient air condition :30 degree Celcius, 25% RH (Data at 3 hours interval.)

Depth	Water content (%weight/dry weight)				
(cm)	0	3	6	9	12
0	101.04	80.37	68.00	58.68	36.83
10	101.04	84.74	85.07	73.67	46.20
20	101.04	93.79	90.19	78.62	70.96
30	101.04	97.36	96.94	90.50	87.43
40	101.04	98.96	97.18	91.47	94.36
50	101.04	103.92	98.13	95.56	96.20

Table A-22 Water content of sand column containing 0.4% WAP by weight at depth interval using ambient air condition :30 degree Celcius, 40% RH. (Data at 3 hours interval.)

Depth	Water content (% weight/dry weight)				
(cm)	0	3	6	9	12
0	101.88	81.57	66.46	59.92	35.66
10	101.88	84.59	84.72	74.63	46.67
20	101.88	94.79	89.92	78.52	68.94
30	101.88	99.96	97.16	87.32	87.24
40	101.88	100.90	98.74	93.75	97.18
50	101.88	104.03	100.06	99.46	96.73

Table A-23 Water content of sand column containing 0.5% WAP by weight at depth interval using ambient air condition :50 degree Celcius, 25% RH. (Data at 3 hours interval.)

Depth	Water content (% weight/dry weight)				
(cm)	0	3	6	9	12
0	120.18	100.20	82.46	75.77	56.34
10	120.18	77.69	91.87	88.57	72.49
20	120.18	104.10	101.29	87.94	83.90
30	120.18	116.80	111.05	95.66	94.06
40	120.18	140.22	96.58	102.32	99.11
50	120.18	132.81	108.62	107.40	104.61

Table A-24 Water content of sand column containing 0.5% WAP by weight at depth interval using ambient air condition :50 degree Celcius, 40% RH. (Data at 3 hours interval.)

Depth	Water content (% weight/dry weight)				
(cm)	0	3	6	9	12
0	120.55	101.85	84.22	75.11	59.44
10	120.55	103.72	96.08	89.61	74.71
20	120.55	106.73	99.75	90.59	86.90
30	120.55	111.97	103.34	95.62	89.53
40	120.55	120.63	113.38	108.41	97.00
50	120.55	125.14	114.46	107.69	106.65

Table A-25 Water content of sand column containing 0.5% WAP by weight at depth interval using ambient air condition :40 degree Celcius, 25% RH. (Data at 3 hours interval.)

Depth	Water content (% weight/dry weight)				
(cm)	0	3	6	9	12
0	128.21	102.66	88.46	69.67	60.98
10	128.21	103.37	92.44	87.50	73.91
20	128.21	108.01	97.19	90.03	81.58
30	128.21	111.77	112.67	98.42	95.01
40	128.21	117.10	115.29	107.83	101.40
50	128.21	129.79	120.18	118.21	120.80

Table A-26 Water content of sand column containing 0.5% WAP by weight at depth interval using ambient air condition :40 degree Celcius, 40% RH (Data at 3 hours interval.)

Depth	Water content (% weight/dry weight)				
(cm)	0	3	6	9	12
0	126.88	102.06	87.82	74.10	62.60
10	126.88	104.28	96.86	89.79	74.37
20	126.88	108.74	97.73	92.03	86.66
30	126.88	110.86	110.65	98.51	96.58
40	126.88	120.87	116.18	108.43	100.27
50	126.88	127.31	121.98	116.54	116.32

Table A-27 Water content of sand column containing 0.5% WAP by weight at depth interval using ambient air condition :30 degree Celcius, 25% RH (Data at 3 hours interval.)

Depth	Water content (% weight/dry weight)				
(cm)	0	3	6	9	12
0	122.03	102.35	87.78	74.30	61.86
10	122.03	103.57	94.93	88.32	75.41
20	122.03	110.58	97.90	91.85	82.02
30	122.03	117.91	115.85	99.65	90.33
40	122.03	125.09	118.03	106.74	99.01
50	122.03	130.91	122.71	117.93	116.27

Table A-28 Water content of sand column containing 0.5% WAP by weight at depth interval using ambient air condition :30 degree Celcius, 40% RH (Data at 3 hours interval.)

Depth	Water content (% weight/dry weight)				
(cm)	0	3	6	9	12
0	123.59	102.84	88.93	78.70	63.76
10	123.59	104.10	95.29	89.62	75.98
20	123.59	109.71	98.80	93.55	86.88
30	123.59	116.97	109.14	102.00	92.14
40	123.59	125.47	117.17	106.34	99.26
50	123.59	129.05	125.66	120.33	116.48

APPENDIX B

Computer Program

This program is written in C-language for calculating the diffusion equation (equation in Chapter II) using Crank-Nicolson method. The steps of calculation are as follow:

1. call in the initial and boundary condition.

2. call in constant "a" for diffusion coefficient.

3. assume the concentration profile at time interval t = 0+Δt and calculate diffusion coefficient.

4. create a concentration profile at various points along the column every 3 hours for a total of 12 hours.

5.calculate the absolute error from the difference between the experimental data and the data from the computer program.

The program listing is on the next page.

```
# include <conio.h>
# include <stdio.h>
# include <math.h>
# include <stdlib.h>
float A,T,deltaT,delphi,er,Err,error,net_err;
float M[51],MW1[51],DR[51],BIGM[51],F[51],MW2[51],DELM[51],MT[6];
int kk,kkk;

main()
    {

    int i;
    clrscr();
    T = 0; kk = 0;error = 0;
    calla();
    calldelt();
    in_con();
step1:  b_con();
    er = 100; kkk =0;
    assumm();
    do {
    dif_co();
    calbigm();
    calf();
    cnequat();
    c_right();
    c_kkk();
    recaleq();
    }
    while (er>0.01||er<-0.01);
    nextdata();
    expdata();
    recal();
    goto step1;
    }
        calla()
        {

        /*input the value of A constant value*/
        printf("\n Please put the value of A:");
        scanf ("%f",&A) ;
        }

        calldelt()
        {

        /*input delta T and delta phi */
        printf("\n Please put the value of deltaT and deltaphi:");
        scanf ("%f",&deltaT);
        scanf ("%f",&delphi);
        printf ("\n %f  %f ",deltaT ,delphi);
        }
```

```
in_con()
{
int j; float mo;
/* input the initial condition */
printf ("\n initial mass fraction :");
scanf ("%f",&mo);
for (j = 0; j<=50 ; j++) M[j] = mo ;
datatable(M);
}

b_con()

{
/* input boundary condition*/
if (T<180) { MW1[0] = 102.68 - (102.68-77.15)*T/180;}
if (T>=180 && T<360)
           { MW1[0] = 77.15 - (77.15-61.06)*(T-180)/180;}
if (T>=360 && T<540)
           { MW1[0] = 61.06 - (61.06-47.45)*(T-360)/180;}
if (T>=540 && T<=720)
           { MW1[0] = 47.45 - (47.45-32.58)*(T-540)/180;}

}

assumm()
{
int i;
/* initially assume M[51] value at time zero+delta T*/
for (i = 1;i<=50 ; i++) MW1[i] = 0.999*M[i];
}

dif_co()
{
int j;
/* Crank nicolson calculation*/
/* call in value of diffusion coefficient DR(J)*/
/* Let DR(M) = AM+(1-A)*/
for (j = 0;j<=50 ;j++) DR[j] = A*M[j]+(1-A);
}

calbigm()
{
int j;
/* subprogram compute BIGM[j] */
for (j =0; j<=50 ;j++) BIGM[j] = DR[j]*deltaT/pow(delphi,2);
}
```

```
calf()
{
int j;
/* compute vector F[j] */
for (j = 1; j<=49 ;j++)
F[j]  =((1-BIGM[j])*M[j]+0.5*BIGM[j]*(M[j+1]+M[j-1]))/(1+BIGM[j])
F[0]  = F[1];
F[50] = F[49];
for (j = 0; j<=50 ;j++){
if(F[j]<0) F[j] = 0;
if(F[j]>1) F[j] = 1;}
}

cnequat()
{
int j;
/* compute Crank Nicolson Equation */
for (j =1; j<=49 ;j++){
MW2[j]  = F[j]+(0.5*BIGM[j]/(1+BIGM[j]))*(MW1[j+1]+MW1[j-1]);
MW1[j]  = MW2[j];
}
MW2[0]  = MW1[0];
MW2[50] = MW2[49];
MW1[50] = MW2[50];
}

c_right()
{
float MW2EQN;

/* check accuracy of MW2[25] */
MW2EQN = F[25]+(0.5*BIGM[25]/(1+BIGM[25]))*(MW2[26]+MW2[24]);
er     = (MW2EQN - MW2[25])/(0.5*(MW2EQN+MW2[25]));
printf("\n %f  %f  %f",MW2EQN,MW2[25],er);
}

c_kkk()
{
/* check number of iteration */
kkk++;
if (kkk>11) { printf("\n program error ");
              exit(1);
            }
}

recaleq()
{
int j;
/* recalculate equation */
for (j = 0; j<=50 ;j++) MW1[j] = MW2[j];
}
```

```
nextdata()
{

/* continue with next data step */
int l;
T = T + deltaT;
kk = kk+1;
if (kk>220) exit(1);
if(T == 65.0) l=1;
if(T==125.0)l=2;
if(T==185.0)l=3;
if(T==365.0)l=4;
if(T==545.0)l=5;
if(T==725.0)l=6;
if(T> 725.0)l=7;
switch(l){
/*      case 1 : printf("\n moisture content at time 1 hr.\n");
                 datatable(MW2); getch();
                 break;
        case 2 : printf("\n moisture content at time 2 hrs.\n");
                 datatable(MW2); getch();
                 break;*/
        case 3 : printf("\n moisture content at time 3 hrs.\n");
                 datatable(MW2); getch();
                 break;
        case 4 : printf("\n moisture content at time 6 hrs.\n");
                 datatable(MW2); getch();
                 break;
        case 5 : printf("\n moisture content at time 9 hrs.\n");
                 datatable(MW2); getch();
                 break;
        case 6 : printf("\n moisture content at time 12 hrs.\n");
                 datatable(MW2); getch();
                 break;
        case 7 : net_err = error/24 ;
                 printf("\n net error : %f",net_err);getch();
                 printf("\n  ending of the program");
                 exit(1);
                 break;
      }

recal()
{

/* next step of iteration*/
int j;
for ( j=0 ; j<=50 ; j++){
     DELM[j] = MW2[j]-M[j];
     M[j]    = MW1[j];
     MW1[j]  = M[j] + DELM[j];
     }
}
```

```
datatable(float MW3[51])
{

int j,R,C;
j=0;
for (R=1 ; R<=11 ; R++)
{ for (C=1 ; C<=5 ; C++)
  { printf("%8.3f  ",MW3[j]);
    j++;
   }
 printf("\n");
 }
 }

 expdata()
 {

 int z,l ;

 float MT3[6]  = {77.15,83.68,85.97,91.81,98.88,106.47};
 float MT6[6]  = {61.06,79.34,84.09,92.56,98.28,100.82};
 float MT9[6]  = {47.45,62.15,77.01,83.37,96.13,97.06};
 float MT12[6] = {32.58,43.30,70.89,88.71,95.78,101.00};

 if(T==185.0)l=3;
 if(T==365.0)l=4;
 if(T==545.0)l=5;
 if(T==725.0)l=6;
 switch(l){
       case 3 :for(z = 0; z<=5 ;z++) MT[z] = MT3[z];
               calerror();     break;
       case 4 :for(z = 0; z<=5 ;z++) MT[z] = MT6[z];
               calerror();     break;
       case 5 :for(z = 0; z<=5 ;z++) MT[z] = MT9[z];
               calerror();     break;
       case 6 :for(z = 0; z<=5 ;z++) MT[z] = MT12[z];
               calerror();     break;
       }

}


calerror()
{

int y;
float E[6] ;
Err = 0;
for( y = 0 ; y<=5 ; y++ ) { E[y] = MT[y] - MW2[y*10];}
for( y = 0 ; y<=5 ; y++ ) { E[y] = (E[y]>=0)? E[y] : -E[y] ;}
for( y = 0 ; y<=5 ; y++ ) Err = Err + E[y] ;
printf("\n E for 1 loop : %f", Err);
error = error + Err;
printf("\n total error : %f", error);
}
```

AUTOBIOGRAPHY

Sinsupha Chuichulcherm was born on May 12,1966 in Bangkok, Thailand. She grauduated from Suksanaree school in 1984. She received her Bechelors' degree of Science in Biotechnology from Kasetsart University, Thailand, in 1988. She continued her Master's degree at Chulalongkorn University in 1990.