
16 Spreadsheet Applications

16.1 INTRODUCTION

General purpose spreadsheet software can be used effectively for engineering calculations. For example, Microsoft Excel with Visual Basic for Applications is an effective tool for process design. Spreadsheets offer sufficient process model “hospitality.” They are connected easily and online with charts and graphic objects, resulting in powerful and easy-to-use graphical interfaces. Excel also supports mathematical and statistical tools. For instance, Solver is an excellent tool for solving sets of equations and performing optimization. Databases are effectively and easily accessed. In addition, Visual Basic for Applications offers a powerful object-oriented programming language capable of constructing commercial graphics interfaces.

Our book *Food Process Design* (Maroulis and Saravacos, 2003) presents a systematic approach to solve engineering problems in a spreadsheet environment. In particular, it shows integrated procedures for robust process design by analyzing the following topics:

- Modeling and spreadsheets
- Analyzing the Solver
- Sensitivity analysis using Excel tables
- Controls and Dialog boxes to input data
- Graphics to get results
- Databases
- Visual Basic as a programming language

In the present book, a more simplified concept is adopted. It is a step from classic hand calculations toward more sophisticated spreadsheet calculations.

The following topics are introduced and applied to problems similar to those of the previous chapters of this book.

- Name variables
- Insert data
- Insert equations using names
- Use “Goal Seek” to solve an equation
- Automate using Visual Basic
- Assign a macro to a button
- Use Excel tables
- Use Excel charts
- Use the scroll bars

- Construct a simple database
- Use Combo Boxes
- Use matrix operations
- Use Solver

16.2 SHELL AND TUBES HEAT EXCHANGER

In this example, the following Excel operations are introduced:

- Name variables (Ctrl + Shift + F3)
- Insert data
- Insert equations using names

16.2.1 PROBLEM FORMULATION

Calculate the appropriate shell and tube heat exchanger for a tomato paste heating process using the available heating steam.

The design specifications are

$F = 1 \text{ kg/s}$	Feed flow rate
$T_1 = 50^\circ\text{C}$	Feed temperature
$T_2 = 100^\circ\text{C}$	Target temperature
$T_s = 120^\circ\text{C}$	Steam temperature

The required data of the tomato paste and the heating steam are

$\rho = 1130 \text{ kg/m}^3$	Fluid density
$\lambda = 0.55 \text{ W/(m K)}$	Fluid thermal conductivity
$\eta = 0.27 \text{ Pa s}$	Fluid apparent viscosity
$C_p = 3.50 \text{ kJ/(kg K)}$	Specific heat
$\Delta H_s = 2200 \text{ kJ/kg}$	Latent heat of steam condensation

The following design variables are also assumed:

$u = 1 \text{ m/s}$	Fluid velocity in tubes
$d = 0.01 \text{ m}$	Tube diameter
$dx = 5 \text{ mm}$	Tube thickness
$n = 4$	Number of passes in tubes

16.2.2 PROBLEM SOLUTION

The thermal load is calculated by the equation

$$Q = FC_p(T_2 - T_1)$$

The required steam flow rate Q is calculated by the equation

$$Q = F_s \Delta H_s$$

The mean temperature difference ΔT_m

$$\Delta T_m = \frac{(T_s - T_1) - (T_s - T_2)}{\ln[(T_s - T_1)/(T_s - T_2)]}$$

The total number of tubes N

$$u = \frac{F}{\rho(N/n)(\pi d^2/4)}$$

The surface heat transfer coefficient outside tubes h_o

$$h_o = 2750 \left(\frac{Nd}{F_s} \right)^{1/3}$$

The Pr number

$$Pr = \frac{C_p \eta}{\lambda}$$

The Re number

$$Re = \frac{\rho d u}{\eta}$$

The Nu number

$$Nu = 1.86 \left(Re Pr \frac{d}{L} \right)^{1/3} \left(\frac{\eta}{\eta_w} \right)^{0.14}$$

The surface heat transfer coefficient inside tubes h_i

$$Nu = \frac{h_i d}{\lambda}$$

The overall heat transfer coefficient U

$$\frac{1}{U} = \frac{1}{h_i} + \frac{1}{h_o}$$

A	Variable	TextName	ExcelName	C	D	E	F
1					Value	Units	Equation
2	Feed flow rate	F	F		1	kg/s	
3	Feed temperature	T_1	T1		50	°C	
4	Target temperature	T_2	T2		100	°C	
5	Steam temperature	T_s	Ts		120	°C	
6	Fluid specific heat	C_p	Cp		3.50	kJ/kgC	
7	Latent heat of steam condensation	ΔH_s	dHs		2200	kJ/kg	
8	Fluid density	ρ	p_		1130	Kg/m ³	
9	Fluid thermal conductivity	λ	k_		0.55	W/mK	
10	Fluid apparent viscosity	η	n_		0.27	Pa s	
11	Fluid velocity in tubes	u	u		1.00	m/s	
12	Tube diameter	d	d		0.01	m	
13	Tube thickness	δx	dx		5	mm	
14	Number of passes in tubes	n	m		4	—	
16	Thermal load	Q	Q		175	kW	$:=F * C_p * (T_2 - T_1)$
17	Steam flow rate	F_s	Fs		0.08	kg/s	$:=Q / dHs$
18	Mean temperature difference	ΔT_m	dTm		40	°C	$:=((T_s - T_1) - (T_s - T_2)) / LN(((T_s - T_1) / (T_s - T_2)))$
19	Total number of tubes	N	M		45	—	$:=F / p_ / (u / m) / (3.14 * d^2 / 4)$
20	Surface heat transfer coefficient outside tubes	h_o	ho		4.90	kW/m ² K	$:=2.75 * (M * d / F_s) ^ (1/3)$
21	Pr Number	Pr	Pr		1718	—	$:=C_p * n_ / k_ * 1000$
22	Re Number	Re	Re		42	—	$:=u * p_ * d / n_$
23	Nu Number	Nu	Nu		9.28	—	$:=1.86 * (Re * Pr * d / 10) ^ (1/3) * 1.2$
24	Surface heat transfer coefficient inside tubes	h_i	hi		0.51	kW/m ² K	$:=Nu * k_ / d / 1000$
25	Overall heat transfer coefficient	U	U		0.46	kW/m ² K	$:=1 / (1 / h_o + 1 / h_i)$
27	Heat transfer area	A	A		9.48	m ²	$:=Q / U / dTm$
28	Shell diameter	D	D		0.20	m	$:=d + 2 * dx / 1000) * (M / 0.319) ^ (1/2.142)$
29	Tube length	L	L		6.70	m	$:=A / M / 3.14 / d$

FIGURE 16.1

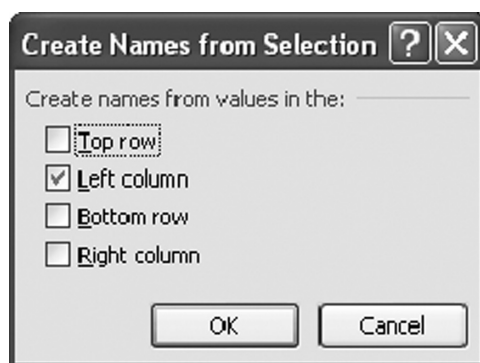


FIGURE 16.2

The total heat transfer area A

$$Q = AU\Delta T_m$$

The shell diameter D

$$N = 0.319 \left(\frac{D}{d} \right)^{2.142}$$

The tubes length L

$$A = N\pi dL$$

16.2.3 EXCEL IMPLEMENTATION

In an Excel spreadsheet and in the range A2:A29, type the names of the process variables incorporated in the previous solution as shown in Figure 16.1. The range A2:A14 is used for the data while the range A16:A29 for the results. In the next column and in the range B2:B29, type the symbols for these variables as used in the solution provided earlier.

In the range C2:C29, type the corresponding names in Excel. Use names similar to their symbols in the text if possible. In the range E2:E29, type the corresponding units.

By selecting the range C2:D29 and by simultaneously pressing the buttons Ctrl + Shift + F3, the names in column C are assigned to the cells of column D (Figure 16.2).

Enter the data for the given variables in the range D2:D14. Enter the equations according to the previous solution procedure into the range D16:D29. These equations are presented for information in the range F16:F29.

The problem has been solved. Any change of the data will change the result. The problem is solved with just 13 equations in the range D16:D29 by using 13 data in the range D2:D14. All other text in the spreadsheet is for information (Figure 16.1).

16.3 PSYCHROMETRIC CALCULATIONS

In this example, the following simple Excel calculations are introduced:

- Use the Goal Seek function to solve an equation
- Automate Using Simple Visual Basic
- Assign a macro to a button

16.3.1 PROBLEM FORMULATION

For an air/water mixture, when the following conditions are given:

$P = 1$ bar	Pressure
$T = 65^\circ\text{C}$	Temperature
$Y = 0.035$ kg/kg db	Total humidity (liquid + vapor)

Calculate the following properties:

P_d	bar	Dew pressure
P_s	bar	Vapor pressure at temperature T
P_w	bar	Vapor pressure at temperature T_w
T_b	$^\circ\text{C}$	Boiling temperature
T_d	$^\circ\text{C}$	Dew temperature
T_w	$^\circ\text{C}$	Wet bulb temperature
Y_L	kg/kg db	Humidity in liquid
Y_V	kg/kg db	Humidity in vapor
Y_s	kg/kg db	Saturation humidity at temperature T
Y_w	kg/kg db	Saturation humidity at temperature T_w
a_w	—	Water activity
H	kJ/kg db	Enthalpy of humid air
C_p	kJ/kg K db	Specific heat of humid air
ΔH_s	kJ/kg	Latent heat of condensation of water vapor at temperature T

Suppose that the following data are valid:

$m = 0.622$	Air/water molecular weight ratio
$C_{pA} = 1.00$ kJ/kg K	Specific heat of air
$C_{pV} = 1.90$ kJ/kg K	Specific heat of water vapor
$C_{pW} = 4.20$ kJ/kg K	Specific heat of liquid water
$\Delta H_0 = 2.50$ MJ/kg	Latent heat of water evaporation at 0°C
$a_1 = 1.19 \times 10^1$	Antoine equation constants for water
$a_2 = 3.99 \times 10^3$	
$a_3 = 2.34 \times 10^2$	

16.3.2 PROBLEM SOLUTION

A simple psychrometric model has been presented by Maroulis and Saravacos (2003) as follows:

$P_s = \exp [a_1 - a_2/(a_3 + T)]$	(E01)
$Y_s = m P_s/(P - P_s)$	(E02)
$Y_v = \min (Y, Y_s)$	(E03)
$Y_L = Y - Y_v$	(E04)
$Y_w = m a_w P_s/(P - a_w P_s)$	(E05)
$H = C_{pA} T + Y_v (\Delta H_0 + C_{pV} T) + Y_L C_{pL} T$	(E06)
$T_b = -a_3 + a_2/(a_1 - \ln P)$	(E07)
$T_d = a_2/(a_1 - \ln [Y P/(m + Y)]) - a_3$	(E08)
$P_d = \exp[a_1 - a_2/(a_3 + T)]$	(E09)
$P_w = \exp[a_1 - a_2/(a_3 + T_w)]$	(E10)
$Y_w = m P_w/(P - P_w)$	(E11)
$C_p = C_{pA} + Y_v C_{pV}$	(E12)
$\Delta H_S = \Delta H_0 - (C_{pL} - C_{pV}) T$	(E13)
$(Y_v - Y_w)/(T - T_w) = -C_p/\Delta H_S$	(E14)

Based on these equations, the following algorithm can be used:

(E01)	→	P_s	
(E02)	→	Y_s	
(E03)	→	Y_v	
(E04)	→	Y_L	
(E05)	→	a_w	
(E06)	→	H	
(E07)	→	T_b	
(E08)	→	T_d	
(E09)	→	P_d	
		T_w	Trial value ←
(E10)	→	P_w	
(E11)	→	Y_w	
(E12)	→	C_p	
(E13)	→	ΔH_S	
(E14)	→	T_w	Corrected value →

16.3.3 EXCEL IMPLEMENTATION

Using the same conventions as in the previous example, the following spreadsheet is constructed (Figure 16.3):

As the algorithm suggests, wet bulb temperature is calculated by trial and error, which means that we assign a trial value to cell D23 and examine the resulting cell

	A	B	C	D	E	F
1	Variable	Text	Excel Name	Value	Units	Equation
2	Antoine equation constant for water a1	a ₁	a1.	1.19E+01	—	
3	Antoine equation constant for water a2	a ₂	a2.	3.99E+03	—	
4	Antoine equation constant for water a3	a ₃	a3.	2.34E+02	—	
5	Air/water molecular weight ratio	m	m	0.622	—	
6	Latent heat of water evaporation at 0	ΔH ₀	dHo	2.50	kJ/kg	
7	Specific heat of liquid water	PW	Cp1	4.20	kJ/kg K	
8	Specific heat of water vapor	PV	Cpv	1.90	kJ/kg K	
9	Specific heat of air	PA	Cpa	1.00	kJ/kg K	
10	Pressure	P	P	1.0	bar	
11	Temperature	T	T	65.0	°C	
12	Total humidity (liquid + vapor)	Y	Y	0.035	kg/kg db	
13	Vapor pressure at temperature	P _s	Ps	0.25	bar	:=EXP(a1.-a2./a3.+T)
14	Saturation humidity at temperature	Y _s	Ys	0.206	kg/kg db	:=IF(m*Ps/(P-Ps)<0,10,m*Ps/(P-Ps))
16	Humidity in vapor	Y _v	Yv	0.035	kg/kg db	:=MIN(Y,Ys)
17	Humidity in liquid	Y _l	Yl	0.000	kg/kg db	:=Y-Yv
18	Water activity	a _w	aw	0.214	—	:= (P/Ps)/(1+m/Yv)
19	Enthalpy of humid air	H	H	156.8	kJ/kg db	:=Cpa*T+Y*(dHo*1000+Cpv*T)+Y*Cpl*T
20	Boiling temperature	T _b	Tb	99.9	°C	:=a2./(a1.-LN(P))-a3.
21	Dew pressure	P _d	Pd	4.7	Bar	:= (m/Y+1)*Ps
22	Dew temperature	T _d	Td	34.0	°C	:=a2./(a1.-LN(Y/P/(m+Y)))-a3.
23	Wet bulb temperature (trial value)	T _w	Tw	39.0	°C	
24	Vapor pressure at temperature	P _w	Pw	0.07	bar	:=EXP(a1.-a2./a3.+Tw)
25	Saturation humidity at temperature	Y _w	Yw	0.047	kJ/kg db	:=m*EXP(a1.-a2./(a3.+Tw))/(P-EXP(a1.-a2./(a3.+Tw)))
27	Specific heat of humid air	C _p	Cp	1.07	kJ/kgK db	:=Cpa+Y*Cpv
28	Condensation heat of water vapor at	ΔH _s	dH	2.35	kJ/kg	:= (dHo*1000-(Cpl-Cpv)*T)/1000
29	Wet bulb temperature (corrected value)	T _{wc}	Twc	39.0		:= T-(Yw-Yv)*dH/Cp*1000
30	Wet bulb temperature (corrected minus trial value)	dTw	dTw	9.57E-05		:= Twc-Tw

wbt

FIGURE 16.3

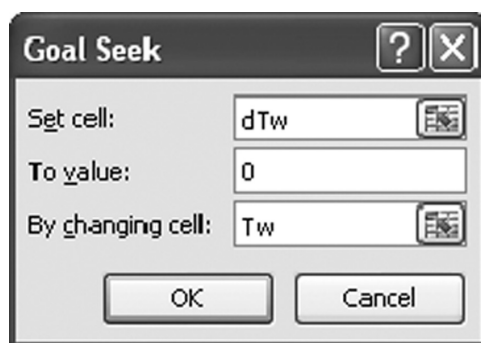


FIGURE 16.4

D29. We try different values in cell D23 until we obtain the same value in cell D29. The difference between the trial and corrected values is calculated in cell D30.

Alternatively, we can use the “Goal Seek” function of Excel to automatically set cell D30 to equal 0 by changing cell D23. Goal Seek can be found in the “Data” menu by selecting the “What-if Analysis” submenu (Figure 16.4).

Furthermore, we can automate the procedure as follows:

- From the “Developer” menu and the “Insert” submenu select a Button (Form Control) and insert it into the spreadsheet.
- By right clicking on the button, select “Edit text” and insert a caption e.g., wbt (Wet Bulb Temperature).
- By right clicking on the button, select “Assign Macro” (Figure 16.5) and then “Edit.”
- Type the following subroutine within the Visual Basic Editor.
 1. Sub wbd()
 2. Range(“Tw”).Value = Range(“Td”).Value
 3. Range(“wbt”).GoalSeek Goal: = 0#, ChangingCell:=Range(“Tw”)
 4. End Sub

The calculations are automatically happened every time the button “wbt” is clicking.

16.4 PSYCHROMETRIC CHART

In this example, the following Excel functions are introduced:

- Use a 2D Excel table
- Use an Excel chart

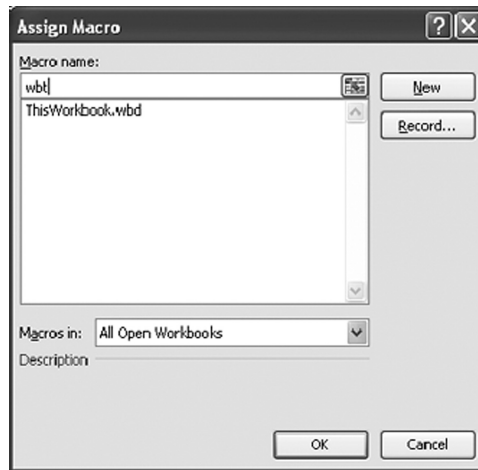


FIGURE 16.5

16.4.1 PROBLEM FORMULATION

Construct a psychrometric chart, i.e., plot the humidity in vapor Y_V (kg/kg db) versus the temperature T ($^{\circ}\text{C}$) for some constant values of water activity a_w ($-$) for an air water-vapor mixture at any pressure P (bar).

Suppose the following parameters are given:

$m = 0.622$	Water molecular weight ratio
$a_1 = 1.19 \times 10^1$	Antoine equation constants for water
$a_2 = 3.99 \times 10^3$	
$a_3 = 2.34 \times 10^2$	

16.4.2 PROBLEM SOLUTION

The humidity is calculated from the equation

$$Y_V = \frac{m a_w P_S}{(P - a_w P_S)}$$

where the vapor pressure is calculated by the Antoine equation

$$P_S = \exp \left[\frac{a_1 - a_2}{(a_3 + T)} \right]$$

Thus, for any given values of P , T , and a_w , the Y_V is obtained.

16.4.3 EXCEL IMPLEMENTATION

The solution just presented is provided in the following spreadsheet (Figure 16.6):

	I	J	K	L	M	N
1	Variable	Text Symbol	Excel Name	Value	Units	Equation
2	Antoine equation constant for water a1	a_1	a1.	1.19E+01	—	
3	Antoine equation constant for water a2	a_2	a2.	3.99E+03	—	
4	Antoine equation constant for water a3	a_3	a3.	2.34E+02	—	
5	Air/water molecular weight ratio	m	m	0.622	—	
6	Water activity	a_w	aw.	1.00	—	
7	Pressure	P	P.	1.00	bar	
8	Temperature	T	T.	65.00	°C	
9	Vapor pressure at temperature	P_s	Ps.	0.249	bar	:=EXP(a1.-a2./(a3.+T.))
10	Humidity in vapor	Y_v	Yv.	0.206	kg/kg db	:=m*aw.*Ps./(P.-aw.*Ps.)

FIGURE 16.6

A 2D Excel table is used to calculate the humidity for various values of temperature and water activity as follows (Figure 16.7):

1. In the range R4:R99, type the desired values for temperature and in the range S3:W3, the desired values for water activity.
2. In cell R3 insert the equation “=Yv.”
3. Select the range R3:W25, and from the menu “Data” and submenu “What-if Analysis” select “Data Table.” The Data Table dialogue will appear (Figure 16.8).
4. In Data Table Dialogue assign cell “T” for the Row Input Cell and cell “aw” for the Column Input Cell. The corresponding values for humidity are automatically filled in the range S4:W25 (Figure 16.7).

Select the range R3:W25 shown in Figure 16.7 and from the menu “Insert” select the “Scatter” diagram. The psychrometric chart in Figure 16.7 is constructed.

16.5 CALCULATIONS ON PSYCHROMETRIC CHART

In this example, the following Excel function is introduced:

- Use the scroll bar to change the values of a variable

16.5.1 PROBLEM FORMULATION

In the psychrometric chart of Example 3, select a point of given temperature and humidity (T, Y) and construct the corresponding dew point (T_d, Y), the saturated point (T, Y_s), and the wet bulb point (T_w, Y_w).

P	Q	R	S	T	U	V	W
1							
2							
3		Yv(T, aw)					
4		0.206	0.20	0.40	0.60	0.80	1.00
5		0	0.001	0.002	0.002	0.003	0.004
6		5	0.001	0.002	0.003	0.004	0.006
7		10	0.002	0.003	0.005	0.006	0.008
8		15	0.002	0.004	0.006	0.009	0.011
9		20	0.003	0.006	0.009	0.012	0.015
10		25	0.004	0.008	0.012	0.016	0.020
11		30	0.005	0.011	0.016	0.022	0.028
12		35	0.007	0.014	0.022	0.029	0.037
13		40	0.009	0.019	0.029	0.039	0.050
14		45	0.012	0.025	0.038	0.052	0.066
15		50	0.016	0.032	0.050	0.068	0.087
16		55	0.020	0.042	0.065	0.089	0.116
17		60	0.026	0.054	0.084	0.117	0.154
18		65	0.033	0.069	0.109	0.155	0.206
19		70	0.041	0.088	0.142	0.205	0.279
20		75	0.052	0.112	0.185	0.275	0.386
21		80	0.065	0.144	0.244	0.375	0.552
22		85	0.081	0.185	0.326	0.527	0.836
23		90	0.100	0.240	0.445	0.779	1.418
24		95	0.125	0.314	0.629	1.265	3.215
25		99	0.150	0.394	0.864	2.145	19.447
26							
27							

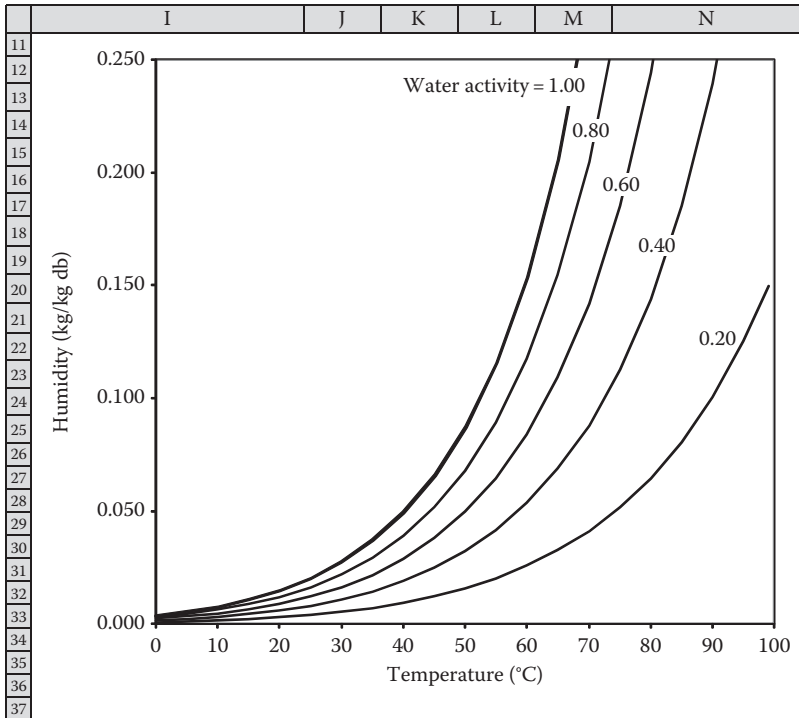


FIGURE 16.7

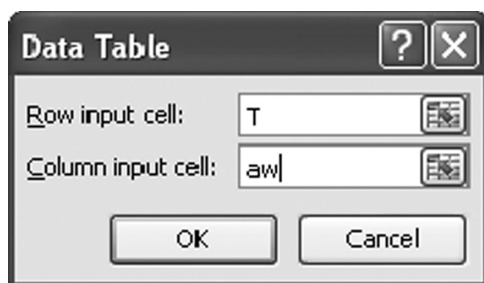


FIGURE 16.8

16.5.2 PROBLEM SOLUTION

When P , T , and Y are given, all the corresponding psychrometric properties are calculated according to Example 2.

Thus, if we combine Examples 2 and 3 in one spreadsheet, the problem is solved by plotting the results of Example 2 in the chart of Example 3.

16.5.3 EXCEL IMPLEMENTATION

In the range AC27:AD33, insert the equations presented in the range AH29:AI31. In the psychrometric chart insert two more curves, AC27:AD31 and AC32:AD33, and the icon appears in Figure 16.9.

If the values of cells T and Y change, the above points are moved in the chart and the new conditions appear. Obviously, the button “wb t ” described in Example 2 should be pressed (Figure 16.3).

More automation can be applied by using “scroll bars”:

From the “Developer” menu and the submenu “Insert” insert a “Scroll Bar.” By right clicking on the Scroll Bar select “Format Control” and select the temperature cell T (F11) for the “Cell Link” (Figure 16.10).

In order to automatically calculate the wet bulb temperature (without clicking the “wb t ” button) right click the scroll bar and select “Assign Macro.” Assign the macro “wb t ” to the scroll bar.

The Scroll Bar is now able to automatically change the temperature and move the point (T, Y) left or right. All other points (T_d, Y) , (T, Y_s) , and (T_w, Y_w) are automatically redrawn.

Scroll bar can also be inserted for pressure and/or humidity.

16.6 ISOTHERMS

In this example, the following Excel functions are introduced:

- Construct a simple properties database
- Use a Combo Box to present data from a database

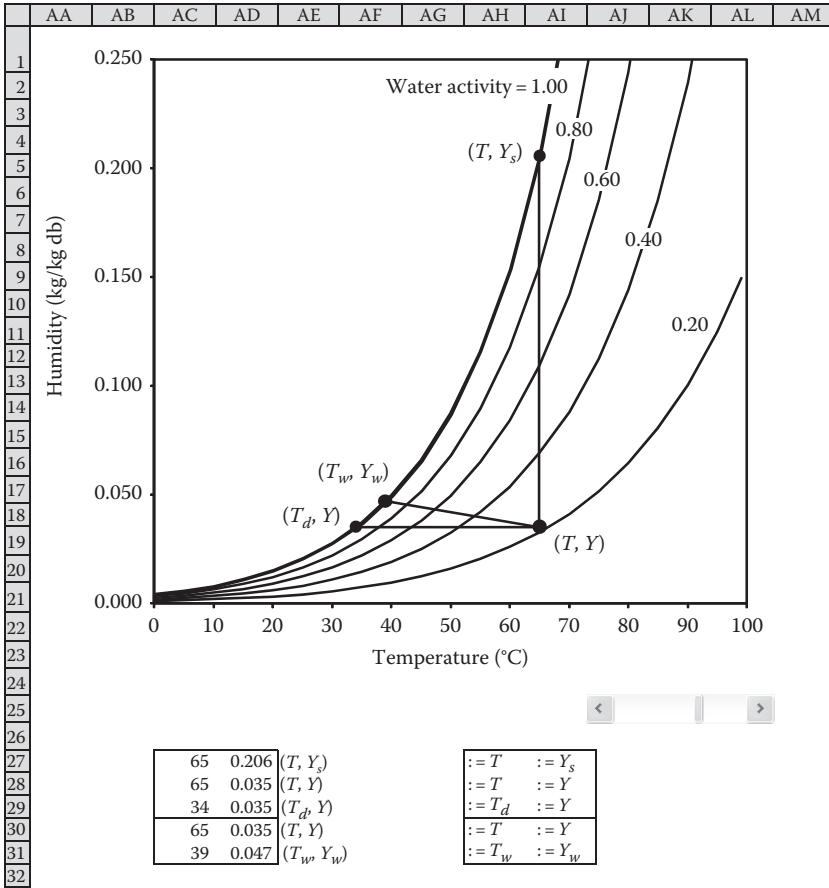


FIGURE 16.9

16.6.1 PROBLEM FORMULATION

The equilibrium material moisture content X_e depends on air temperature, T and water activity, a_w .

Various empirical or semitheoretical models have been proposed in the literature, but a modified Oswin model seems to be the most appropriate in process design calculations:

$$X_e = b_1 \exp \left[\frac{b_2}{(273 + T)} \right] \left[\frac{a_w}{(1 - a_w)} \right]^{b_3}$$

where b_1 , b_2 , and b_3 are adjustable empirical constants, depending on the material characteristics.

The purpose of this example is to construct a database in an Excel environment to incorporate the Oswin constants for some materials and by using the various Excel

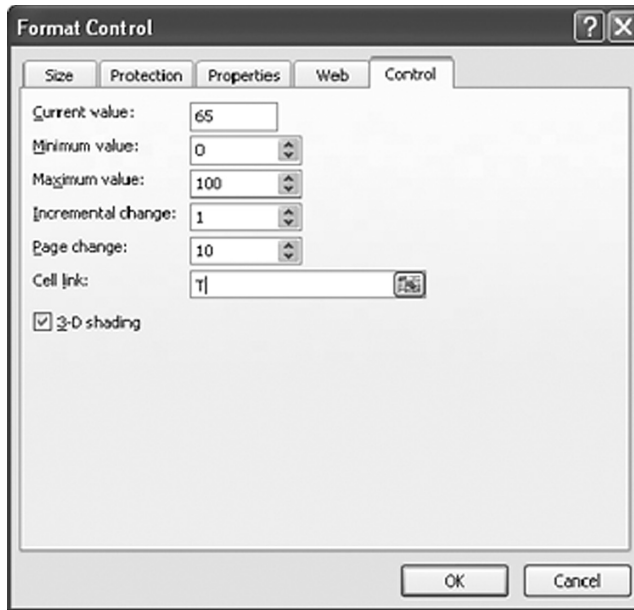


FIGURE 16.10

utilities to construct an environment in which the moisture isotherms for various materials will be examined automatically.

16.6.2 EXCEL IMPLEMENTATION

Retrieve some values for the Oswin constants from the literature (e.g., Maroulis and Saravacos 2003) and insert these values in to an Excel spreadsheet as shown in the range B2:E6 in Figure 16.11.

Insert initial data values for the variables as follows:

jMaterial	Material identification number
T	Temperature
Aw	Water activity

Insert the following equations for the following corresponding variable:

Name	:=INDEX(Material,jMaterial)
b1.	:=INDEX(Oswin1,jMaterial)
b2.	:=INDEX(Oswin2,jMaterial)
b3.	:=INDEX(Oswin3,jMaterial)
Xe	:=b1.*EXP(b2./(273 + T))*(aw/(1-aw))^b3.

The INDEX function selects a specific value from an array.

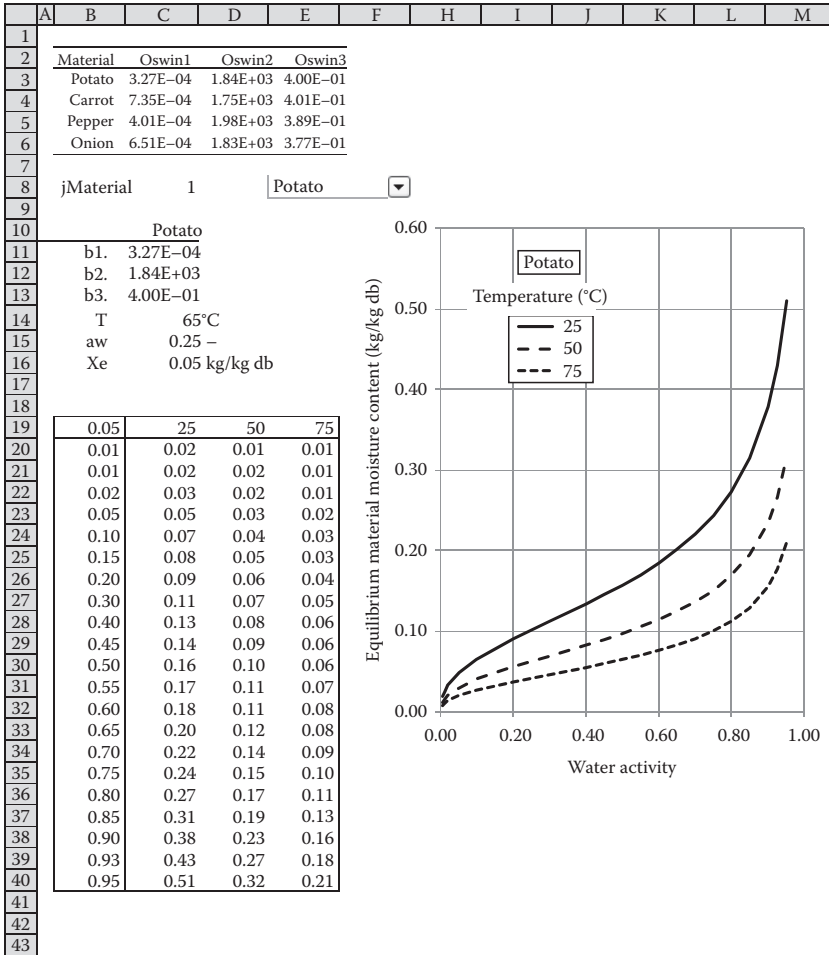


FIGURE 16.11

The following Excel names should be assigned in the following cells:

Name	Cell
aw	C15
b1.	C11
b2.	C12
b3.	C13
jMaterial	C8
Material	B3:B6
Oswin1	C3:C6
Oswin2	D3:D6
Oswin3	E3:E6
T	C14
Xe	C16

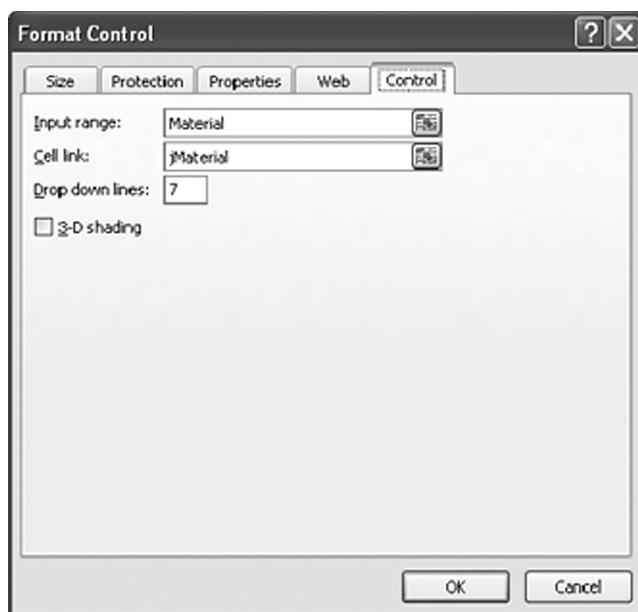


FIGURE 16.12

Insert a 2D Excel table using water activity values as the Column Input Cell and Temperature values as the Row Input Cell. The resulting table is shown in Figure 16.11.

Insert a Scatter Graph, as also shown in Figure 16.11, to graphically represent the results of the 2D Excel table.

Automate the material selection using a “Combo Box”:

- Insert a “Combo Box” from the menu “Developer” and submenu “Insert.”
- Right click on the Combo Box and select “Format Control.”
- In the “Format Control Dialogue,” assign the “Material” name to the “Input Range” and the “jMaterial” name to the “Cell Link” (Figure 16.12).

The spreadsheet is now fully automated:

By clicking the Combo Box, the available material appears in the Combo Box List, and when a material is selected from the list, the material isotherms are automatically plotted in the Chart (Figure 16.11).

16.7 FITTING RHEOLOGICAL DATA FOR CHOCOLATE

In this example, the following Excel functions are introduced:

- Use matrix operations (Alt + Ctrl + Shift + ok)
- Excel Solver

16.7.1 PROBLEM FORMULATION

Analyze the rheological data on chocolate at 40°C, obtained in the COST 90 European project (Prentice and Huber 1983), using the Casson model:

$$\tau = (\tau_0^{1/2} + K_c \gamma^{1/2})^2$$

where

τ (Pa) is the shear stress

γ (1/s) is the shear rate

τ_0 and K_c are the Casson constants

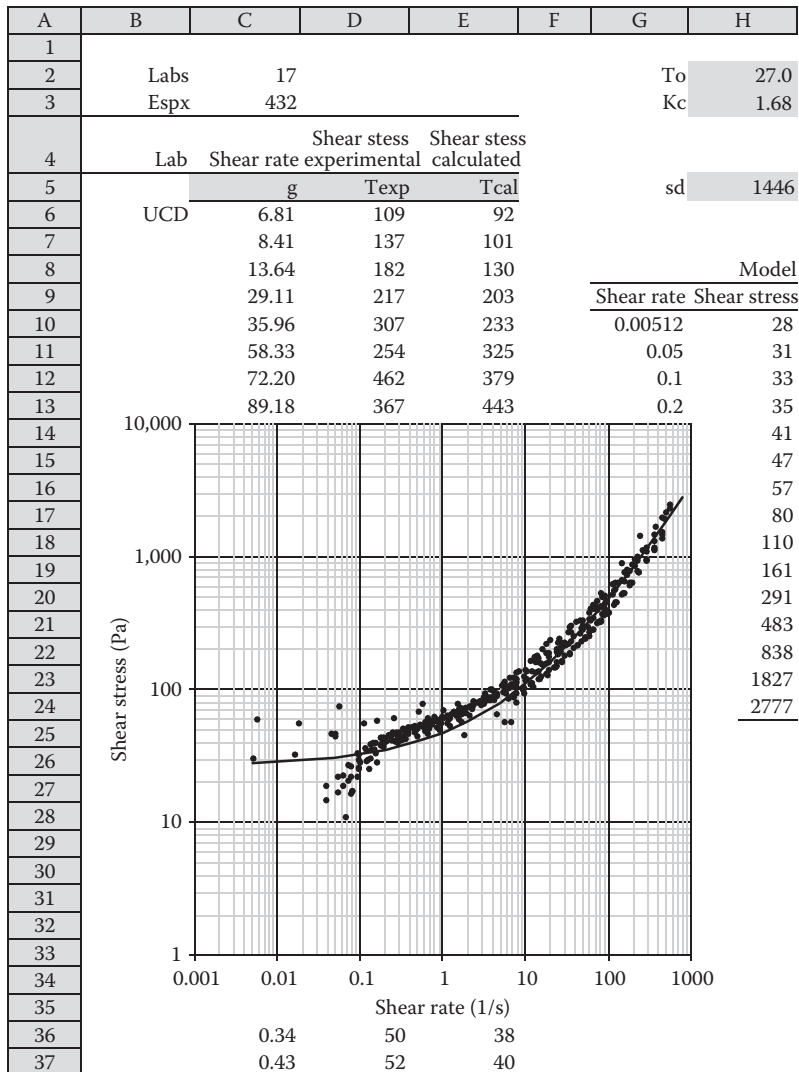


FIGURE 16.13

16.7.2 EXCEL IMPLEMENTATION

In the spreadsheet in the Figure 16.13, 423 experimental data from 17 different laboratories are introduced in the range C6:D428.

Initial values for the Gasson constants are also introduced in the range H2:H3.

In the range E6:E428, the calculated values using the Gasson model are introduced using the equation:= (To^0.5 + Kc*g^0.5)^2 in each cell.

The following Excel names should be assigned in the following cells:

Name	Cell
g	C6:C428
Kc	H3
sd	H5
Tcal	E6:E428
Texp	D6:D428
To	H2

The standard deviation between the experimental and calculated values is estimated in cell H5 by using the equation:

$$:=\{\text{SQRT}(\text{SUM}((\text{Texp}-\text{Tcal})^2))\}$$

Since Texp and Tcal are arrays, the mathematical operation in the cell refers to the matrix operation.

This is denoted by pressing Alt + Ctrl + Shift simultaneously when ok is clicked to end the equation editing. If the brackets {} exist in the equation, the matrix operation has been accepted.

A comparison between the experimental and calculated values can be obtained by introducing the appropriate chart.

Curve fitting means finding the best values for the parameters To and Kc to minimize the standard deviation sd between the experimental and calculated values.

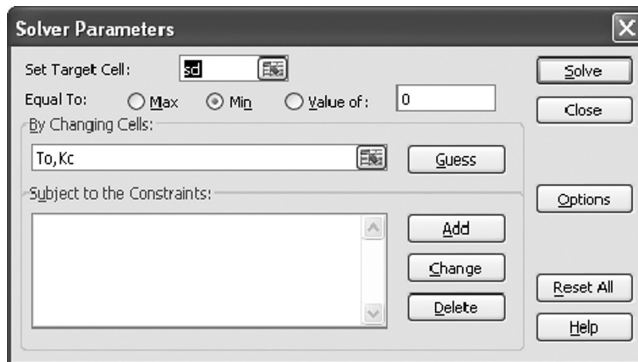


FIGURE 16.14

This operation can be performed using the Excel Solver:

- From the menu “Data” select “solver” and the Solver Parameters Dialogue will appear (Figure 16.14).
- Select the “min” operation, insert the variable “sd” in the “Set Target Cell” parameter, and the variables “To; Kc” in the “By Changing Cells” parameter.
- By pressing the button “Solve”, the optimization procedure is executed, and after some iteration, the optimal parameter estimates are obtained.

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