Computer Applications in Food Technology

Use of Spreadsheets in Graphical, Statistical, and Process Analyses

R. Paul Singh

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Preface

During the past decade, the academic community has expressed considerable interest in enhancing the computer literacy of undergraduate students. The Institute of Food Technologists (IFT) has provided a strong endorsement for the use of computers in food science education. The minimum standards for degrees in food science, as suggested by IFT, "require the students to use computers in the solution of problems, the collection and analysis of data, the control of processes, in addition to word processing." Currently, in most food science curricula offered in the United States, the computer applications in food science are limited to writing reports using word processors, plotting experimental data, or using statistical software. There is little or no use of computers in problem solving, data collection and analysis, or the control of processes. This deficiency is partly due to the lack of appropriate study materials. This book is written to address this need by illustrating the use of spreadsheets in teaching computer applications in food science and technology.

Spreadsheets, with their advent in the business arena, have now become pervasive in most industrial organizations. While initially spreadsheets were mainly suited for business and marketing oriented analysis, the new versions of spreadsheet programs allow sophisticated analysis appropriate to fields such as food science. Interestingly, many of the important features of computer programming, such as logic, structured reasoning, and analysis, can be taught using spreadsheets, without spending time on programming per se. Thus, spreadsheets are ideally suited for food science students, who usually do not have an extensive mathematical background. Furthermore, spreadsheets allow statistical and graphical analysis of experimental data. The "what-if" scenarios are useful in studying the influence of process variables on the final output. This feature lets spreadsheets mimic laboratory experiments and control of process equipment. Therefore, spreadsheets are a useful tool for enhancing students' learning of physical concepts.

The self-guiding style of this book is aimed at food science students as well as practitioners in the food industry.

The contents of the book review general steps in using spreadsheets with examples drawn from food science. The book contains more than 50 solved comprehensive problems representing key areas of food science, namely food microbiology, food chemistry, sensory evaluation, statistical quality control, and food engineering. Each problem is presented with the required equations and detailed steps to obtain the solution with a spreadsheet. Helpful tips in using spreadsheets are provided throughout the text. Although the examples are written using *Excel 5.0 for Macintosh*, the close similarity to *Excel 5.0 for Windows* allows the reader to easily use either software package.

Instructors in a variety of courses in food science and technology may consider using this book as a secondary text. Students should be encouraged to create their own spreadsheet templates for later use. Using the solved comprehensive problems as a guide, additional problems may be developed. A repository of problems suitable for spreadsheets is available on the World Wide Web (www.engr.ucdavis.edu/~rpsingh).

Some of the material written in this book has been used in teaching courses in food processing/engineering at the University of California, Davis. Student evaluations on the use of spreadsheets have been extremely positive. The students noted that they were able to better comprehend the principles being taught in the classroom when spreadsheet analysis was used. In addition, they expressed the satisfaction of learning a new skill that they will use in their work environment after graduation.

Industry practitioners will find useful templates of major food processes including properties of steam, refrigerants, and air–water vapors. A computer disk available with this book contains a large database on the composition of over 2,400 foods and templates of selected industrial processes.

I am indebted to a number of my current and former graduate students who have assisted me in teaching food engineering principles to students majoring in food science. They provided numerous ideas that were incorporated in this book. I am grateful to Professor John R. Whitaker and Professor Jean–Xavier Guinard for their review of parts of this book and suggestions.

R. Paul Singh

Chapter ONE

A Primer on Using Spreadsheets

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1.1 Using a Mouse in Spreadsheets

Use of a mouse expedites spreadsheet tasks. In computer jargon, some of the commonly used actions performed with a mouse are as follows:

Pointing with a mouse:

- position the mouse pointer so that the tip of the arrow on the screen is on a desired item.

Clicking with a mouse:

- first point the mouse to the desired item,
- then press the mouse button once and release it.

Clicking with a mouse is done to make a cell active, to locate the insertion point on the formula bar, and to activate a toolbar button. If you are using Excel for Windows, use the left mouse button unless noted otherwise.

Double-clicking with a mouse:

- first point the mouse to the desired item,
- then press the mouse button twice rapidly.

Double-clicking is done to select text for editing and to open an application or other items.

Dragging with a mouse:

- first point to an item,
- then move the mouse while keeping the mouse button pressed.

Dragging is done to choose menu commands or to select more than one cell at a time.

Selecting a cell with a mouse:

- first point at the cell
- then single-click on the cell.

1.2 Starting Excel

You can launch Excel either by double-clicking on the Excel program icon residing in a folder where Excel is stored (Fig. 1.1a) or by first clicking on the Excel program icon, then selecting the menu items, **File, Open** (Fig. 1.1b).

Figure 1.1a Double-clicking on the program icon to launch Excel.

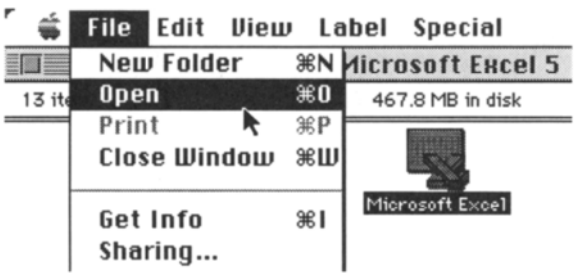


Figure 1.1b Use of the menu bar to launch Excel.

The first Excel screen will be similar to the one shown in Fig. 1.2. There may be some minor differences depending on your display monitor. We will refer to the descriptive items listed in Fig. 1.2 throughout this book.

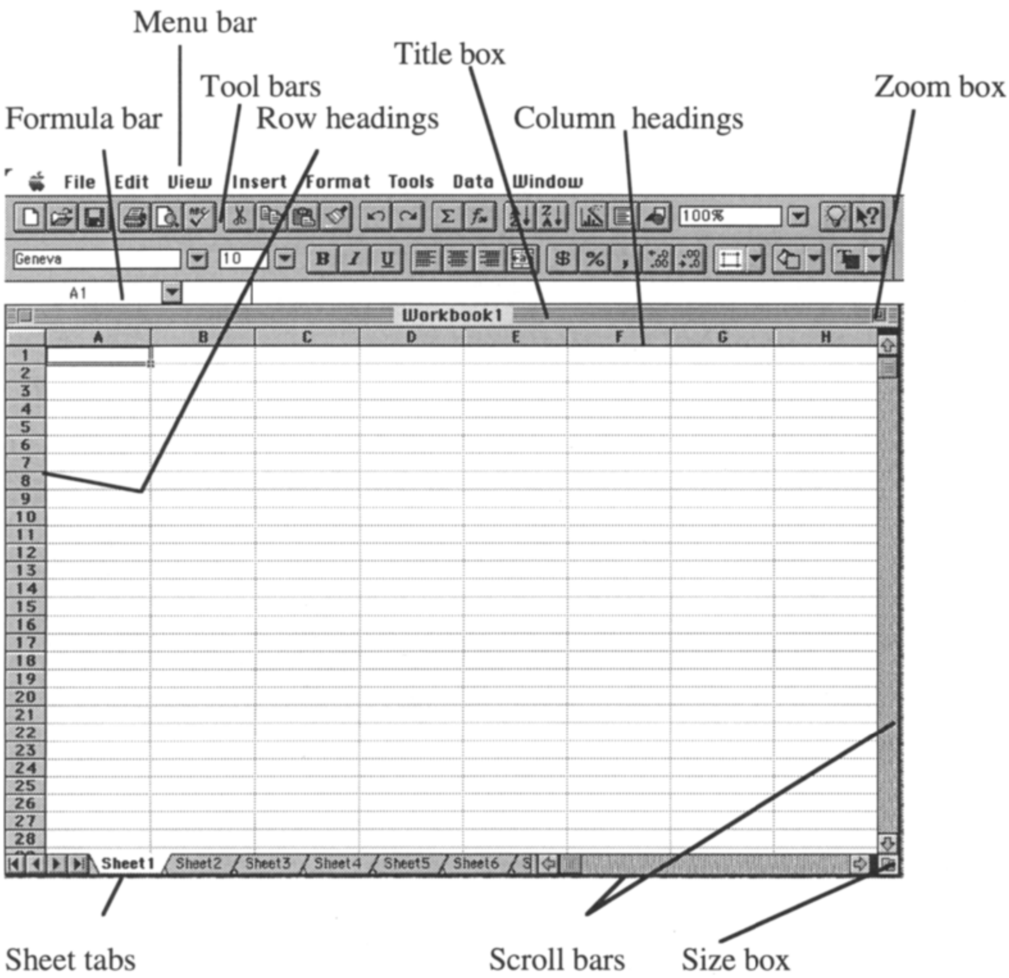


Figure 1.2 A sample spreadsheet.

Most of the features of Excel are similar to other Macintosh (or Windows) programs, for example, the close box, title bar, menu bar, mouse pointer, vertical scroll bar, horizontal scroll bar, and the size box. The row numbers are numerical and they appear along the left-hand side of the screen, whereas the column names are alphabetical and they are shown just under the title bar. The row numbers increase from 1 to 16,384, whereas the column names increase from A to IV, only rows 1 to 28 and columns A to H are shown in Fig. 1.2. You can scroll to other rows and columns of a worksheet by using scroll bars.

The intersection of a row and column is called a cell. The active cell has a highlighted border around it. In Fig. 1.2, cell A1 is the active cell. The cell reference area contains the column letter and row number of the active cell; e.g., A1 refers to the active cell located in column A and row 1.

Figure 1.3a **Standard** tool bar

Figure 1.3b **Formatting** tool bar.

You may tear a button containing an arrow from the toolbar. Just click on the button and drag it away from the toolbar. Position the button anywhere that is convenient on the screen.

The standard and formatting tool bars are shown in Fig. 1.3. However, Excel can display several other types of tool bars, as discussed later in Section 1.4. The name of the workbook is shown in the title bar in Fig. 1.2; this can be changed when we save the worksheet. In Excel, a spreadsheet is called a worksheet. If a project involves more than one worksheet, then several worksheets can be combined into a workbook. The name of the active worksheet is displayed as sheet tabs in the bottom part of the worksheet. In Fig. 1.2, Sheet1 is the name of the sheet.

1.3 Using Menus and Dialog Boxes

The worksheet operations are simplified by the use of menu items and dialog boxes. Menu items, such as **File** and **Edit**, appear in the menu bar. If you point to any menu item and press and hold the mouse button (this mouse operation is called pull-down), a drop-down menu will appear under the menu item. For example, under the menu item **Format**, the drop-down menu has several operations starting with **Cells...**, as shown in Fig. 1.4.

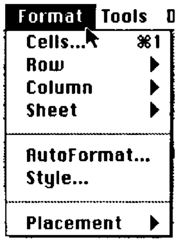


Figure 1.4 Pull-down menu items.

Some of the items in the menu bars are followed by ellipses (...). Selecting items with ellipses opens a dialog box with additional choices. Under the menu item **Format**, let us choose the **Cells**... command. This opens the dialog box, as shown in Fig. 1.5a.

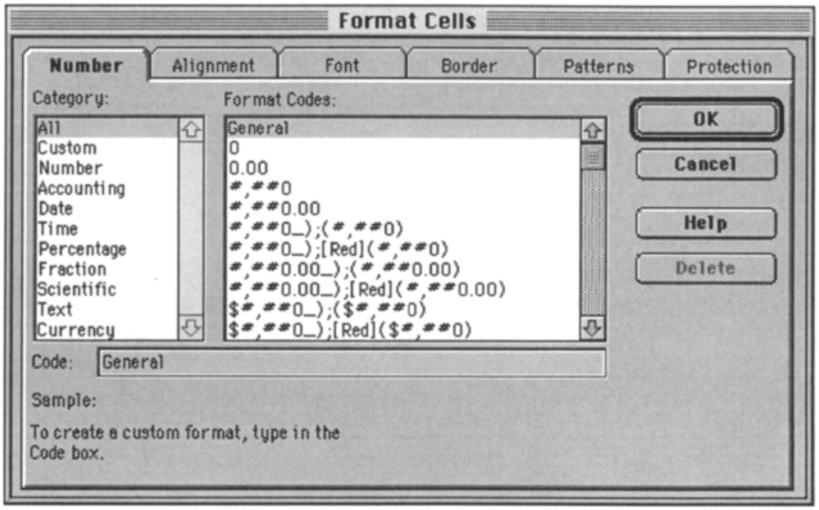


Figure 1.5a Dialog box with folders to format cells.

The dialog box contains groups of options that are listed under tab headings. Click on the tab heading to open the desired group of options. Within the dialog box, the options may be available as a list box, check boxes or radio buttons. For example, in the dialog box shown in Fig. 1.5a, there are six folders. The name of each folder, listed in the folder tab, indicates a group of actions that may be accessed. For example in Fig. 1.5a, the folder with commands to format numbers is in the active state.

If you want to exit a dialog box without making any selection, just click on the **Cancel** button. Otherwise, to select a desired item, either double-click on it or first highlight it followed by clicking on the **OK** button.

Let us make the **Font** folder active, by clicking on the **Font** tab. In the scrollable **list box** shown in Fig. 1.5b, select a font by scrolling to find the desired font and clicking on it.

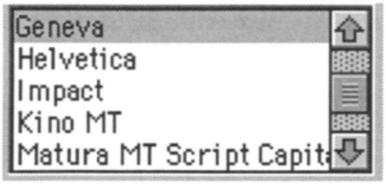


Figure 1.5b A scrollable list box for selecting a font.

You may also use the **Edit box** to directly type a desired font style in it (Fig 1.5c). First double-click inside the edit box, then type the desired font style.

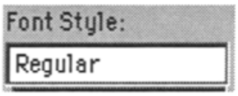


Figure 1.5c An edit box for font style.

To use the **pop-up menu**, pull down the pop-up menu and drag to the desired option and release the mouse button (Fig. 1.5d).

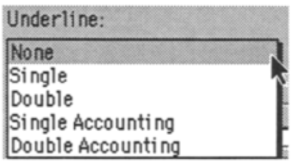


Figure 1.5d A pop-up menu.

Radio buttons are used to select one item from a group of available options. Click on any radio button to select it (Fig. 1.5e).

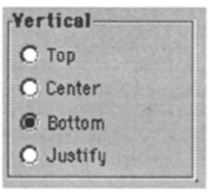


Figure 1.5e Radio buttons.

Check boxes are used to turn desired options on or off by clicking inside the check box (Fig. 1.5f). When a box is checked, the option is selected.

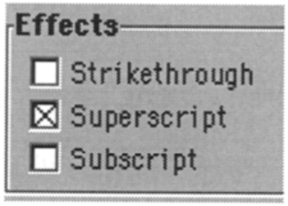


Figure 1.5f Check boxes.

Since the menu names cannot be extremely long (to conserve space on the monitor), some of the names are condensed by using an arrow key next to an item. For example, in Fig. 1.6, next to the item **Row** there is an arrow; if you drag on to **Row**, it will open a branched pull down menu, any of the menu items from the new menu bar may be selected by dragging on to the desired item, and releasing the mouse button.

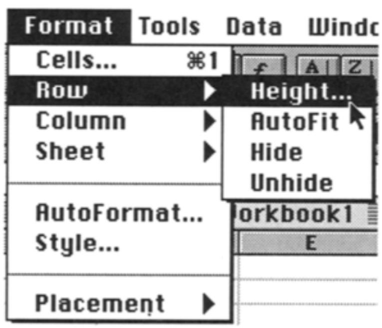


Figure 1.6 Use of branched pull-down menus.

Menu commands that are gray in color cannot be selected.

Some menu commands have a toggle mark before them. If the toggle mark is visible, then that command is turned on. Drag to the command and release the mouse button to switch the toggle on or off.

Menu commands may contain a shortcut procedure for using the keyboard. The key sequence is usually listed as a command key followed by a letter or number.

1.4 Use of Tool Bars

In addition to the menu and dialog boxes, tool bars offer short cut procedures to carry out various worksheet operations. The two tool bars that open by default, namely the Standard tool bar and the Formatting tool bar, were shown in Fig. 1.2. These tool bars contain icons that show what each item is supposed to do. If an icon is unfamiliar to you, just move the mouse pointer to the tool bar area; the pointer changes to an arrow. If the arrow tip is pointed on an icon, a small tool tip displays a description of what that button is supposed to do. For example, in Fig. 1.7, the third icon from the left-hand side on the Standard tool bar has a **Save** icon. If you just move the mouse pointer next to the **Save** icon, the tool tip displays *Save*, as seen in Fig. 1.7. By clicking on the **Save** icon, the active worksheet is saved on a disk. Although clicking on the **Save** icon directly saves the worksheet, clicking on other icons may first lead you to a dialog box to make an appropriate selection.

Figure 1.7 Tool tip for Save icon.

To open other tool bars:

- From the menu item **View**, choose **Tool bars...**.
- In the dialog box, click on check boxes for the desired tool bars.

Figures 1.8 and 1.9 are tool bars for Drawing and Chart, respectively.

Whenever you point to any button, an abbreviated description of what the button does is displayed in the status bar at the bottom of the screen. Similarly, when a command is to be executed, it is displayed in the status bar.

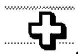
Figure 1.8 A Drawing toolbar.

Figure 1.9 A Chart toolbar.

1.5 Moving in a Worksheet

When entering text labels or data entries, you will need to move around in a worksheet to desired cell locations. There are several ways you can accomplish this task.

The first method is to

- move the hollow cross pointer, , to any cell in the worksheet on the screen and click; this will make that cell active, and the address of that cell will be shown in the cell reference area. For example, cell A3 is the active cell in Fig. 1.10.

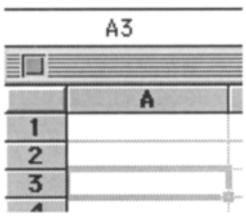
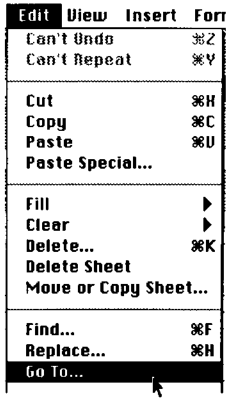


Figure 1.10 Moving to a cell A3.

The second method useful to move to some distant cell that is not currently visible on the monitor is to

- move the pointer into the cell reference area and click,

- delete any previous entry by using the **Delete** key, and
- type in the desired cell reference address. For example to move to cell BB10, move the pointer in the cell reference area, click, type BB10, and press the **Enter** key. You will notice that cell BB10 will be highlighted as an active cell.

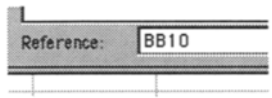


The third method to navigate in a worksheet is to

- use scroll bars, horizontal or vertical, to move to any desired area of the worksheet and then select the desired cell by clicking on it.

The fourth method involves the use of menu commands:

- From the menu choose **Edit**, **Go To...**. A dialog box will open.
- Enter the desired cell address such as BB10 and click **OK**.



1.6 Planning a Worksheet

Since the worksheet is an area on the screen where you may enter text labels and numerical data, and view the output as either numbers or a graph, it is always useful to first plan the structure of how you want your worksheet to appear on the screen or later in print. Although you can easily modify an existing worksheet by adding or deleting columns and rows, it is useful to develop a simple plan before starting.

For example, you probably want to give a title to your worksheet that should appear at the top. If you are solving a problem with a number of constant input values, then it would be desirable to have an area of the worksheet dedicated to list items that are given in a problem. If your worksheet is going to be in the form of a table, usually the independent variables, such as time in hours, months, or years, appear in columns and the dependent variables, such as vitamin concentration or temperature, are entered in rows. When later you print your worksheet, you may not want all of the worksheet to be printed; thus a proper grouping of items that will be in your final output report is useful. In the beginning, it is advisable to use a pencil and paper to develop a rough sketch of your planned worksheet. However, with experience, you will begin to develop a mental picture of the worksheet and you will start to develop the structure of a worksheet right on the screen. As you work through various examples in later chapters of this book, you will be able to practice with a number of different structures suitable for worksheets.

1.7 Entering Text

Let us consider an example on how to develop a worksheet by entering some data and text labels. This example involves data taken in a frozen-pizza manufacturing plant on weights of pizza crust. Weights of pizza crust were obtained periodically as part of a quality control program. We will use data collected from three shifts as shown in Table 1.1. These data will be analyzed to develop some statistical information that will be used for quality control purposes.

Table 1.1 Data on weights of pizza crust for three shifts.

Sample No.	Shift 1	Shift 2	Shift 3
Sample1	162	166	160
Sample2	164	165	159
Sample3	158	163	160
Sample4	166	172	160
Sample5	164	158	161
Sample6	155	154	159
Sample7	170	166	163
Sample8	168	162	161

First, we want to type a title for our worksheet, *Quality Control in Pizza Crust Manufacturing—Weight of pizza crust (grams).*

From the menu, choose the items **File**, **New** to begin with a new worksheet. This will open a new worksheet. Cell A1 will be automatically highlighted. Start typing the title *Quality Control in Pizza Crust Manufacturing—Weight of pizza crust (grams).* As soon as you begin typing, you will notice that what you type starts to appear in cell A1 and also in the Formula bar (Fig. 1.11). Since what you type is much longer than the space allocated for cell A1, the text overflows into neighboring cells. This does not mean that text has been actually entered into neighboring cells. You can check this by clicking onto the cell reference area and typing B1. You will find that only the text that fits cell A1 is shown, the remaining has disappeared. The text is not partially erased, it is still there intact in cell A1; you just cannot see it. If you entered some text labels or numbers in cell B1, you would only see the partial text for cell A1. One way to display longer text than the space in the column is by changing the size of columns. We will use this feature later in this chapter.

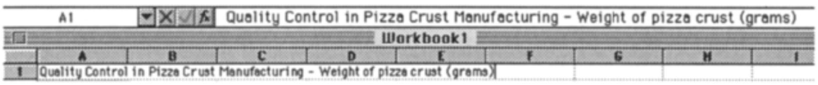


Figure 1.11 Typing text longer than cell width

We need to create row and column headings. Although, we can type in all the headings as shown in Table 1.1, we will use some of the built-in capabilities of Excel to simplify our task.

- In cell A3, type *Sample No.*
- In cell B3, type *Shift1*.
- Now instead of typing *Shift2* and *Shift3*, we will use the **AutoFill** feature. After typing *Shift1*, in cell B3, point at the bottom right-hand corner of cell B3, the cursor will change from a hollow cross, , to a solid cross, , as seen in Fig. 1.12.
- Drag the solid cross over cells C3 and D3. You will notice that Excel has entered Shift2 and Shift3 for us (Fig. 1.13). This is a very useful feature of Excel.

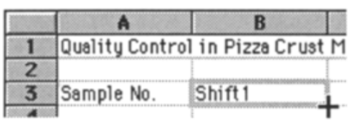


Figure 1.12 Using the **AutoFill** command, cursor changing to a solid cross.

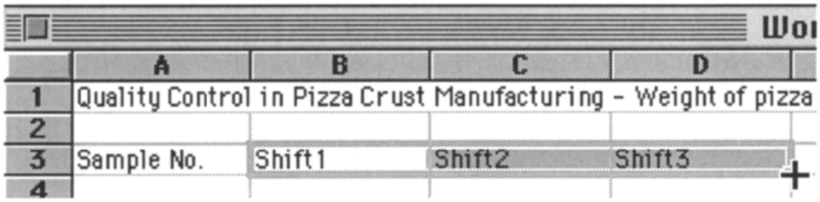


Figure 1.13 Using the **AutoFill** command, dragging the cursor on adjacent cells.

With the **AutoFill** feature you can enter dates, times, months, years, or any consecutively increasing numbers even when they are associated with some text, as in our example. If you wanted to have a decreasing number on the left-hand side, you could move the hollow cursor to the lower left-hand corner of the cell when it changed into a solid cursor and drag toward left, the numbers would be in decreasing order.

Let us use **AutoFill** to fill labels for sample numbers 1 to 8.

- In cell A4, type **Sample1**
- Move the cursor to the bottom right-hand corner of cell A4, then drag it down to cell A11; Excel will fill column A with sample numbers increasing from 1 to 8 (Fig. 1.14).

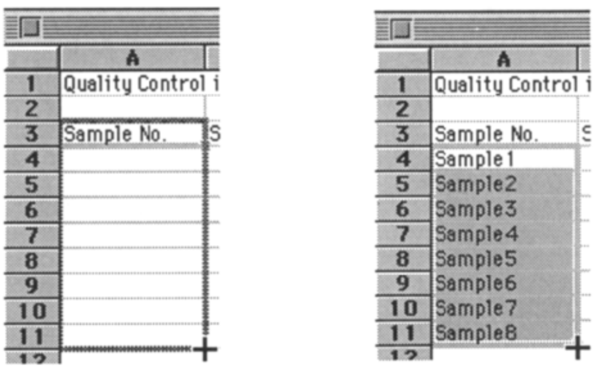


Figure 1.14 Using **AutoFill** to fill sample numbers in column A.

Workbook1

	A	B	C	D	E
1	Quality Control in Pizza Crust Manufacturing - Weight of pizza crust (grams)				
2					
3	Sample No.	Shift1	Shift2	Shift3	
4	Sample1	162	166	160	
5	Sample2	164	165	159	
6	Sample3	158	163	160	
7	Sample4	166	172	160	
8	Sample5	164	158	161	
9	Sample6	155	154	159	
10	Sample7	170	166	163	
11	Sample8	168	162	161	

Figure 1.15 Data typed in cells B4:D11.

If you enter 7-10 in a cell, Excel recognizes this as a date July 10. To enter a number as text, for example an inventory number, first type an apostrophe then the number, e.g., by entering '7-10, the cell entry will be displayed as well as printed as 7-10.

Type the given data from Table 1.1 in cells B4:D11. The worksheet will look like Fig. 1.15. The cells B4:D11 refer to a two-dimensional array in the worksheet, starting with cell B4 in the top left-hand corner to cell D11 in the bottom right-hand corner. The colon specifies the range. You can think of colon as the word "through", e.g., we typed data in cells B4 through D11.

1.8 Worksheet Calculations

Our first calculation involves determining the average of all the weight data for each shift. One method to calculate the average is to add each number for a given shift and then divide the sum by the number of observations. Another more elegant way is to calculate the average directly by using the built-in functions. Excel provides a number of mathematical and statistical functions that make calculations much easier to do. We will use both manual and built-in functions.

1.8a Manual Procedure for Calculations

Select cell B12, and type = (equals sign) in the cell. The equals sign means that the item to be entered in the cell is a formula. This sign is used whenever you want to enter a formula in a cell. If you do not type the equals sign as the first item in a cell, anything you enter in the cell is considered to be either a text label or numerical data.

Care must be exercised after you have typed = in a cell; if you click on any cell on the screen, its reference will be entered into the formula. If you make an error when typing a formula, press the **Delete** key or click the **Cancel** button, , on the formula bar to start over again.

	A	B
1	Quality Control in Pizza Crust	
2		
3	Sample No.	Shift1
4	Sample1	162
5	Sample2	164
6	Sample3	158
7	Sample4	166
8	Sample5	164
9	Sample6	155
10	Sample7	170
11	Sample8	168
12	Sum	=

Figure 1.16 To type a formula, first type an equals sign (=) in the cell.

Next, let us add all the numbers for Shift 1. There are several ways that we can add numbers. The manual procedure, in Excel for Macintosh, is to type = in cell B12, then click in cell B4, then cell B5, then cell B6, and so on, until cell B11 (as shown in Fig. 1.17). In Excel for Windows, type = in cell B12, then click in cell B4, type +, click in cell B5, type +, and so on, until cell B11. Then press **Enter**. The sum will appear in cell B12, as shown in Fig. 1.18. This is a cumbersome procedure.

B11 =B4+B5+B6+B7+B8+B9+B10+B11

Workbook1

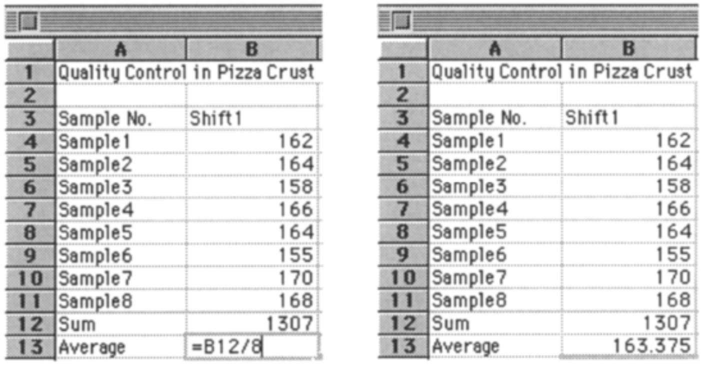
	A	B	C	D	E
1	Quality Control in Pizza Crust Manufacturing - Weight of pizza crust (gra				
2					
3	Sample No.	Shift1	Shift2	Shift3	
4	Sample1	162	166	160	
5	Sample2	164	165	159	
6	Sample3	158	163	160	
7	Sample4	166	172	160	
8	Sample5	164	158	161	
9	Sample6	155	154	159	
10	Sample7	170	166	163	
11	Sample8	168	162	161	
12	Sum	=B4+B5+B6+B7+B8+B9+B10+B11			

Figure 1.17 To add the contents of cells B4:B11 in cell B12.

	A	B
1	Quality Control in Pizza Crust	
2		
3	Sample No.	Shift1
4	Sample1	162
5	Sample2	164
6	Sample3	158
7	Sample4	166
8	Sample5	164
9	Sample6	155
10	Sample7	170
11	Sample8	168
12	Sum	1307

Figure 1.18 The sum of cells B4:B11 displayed in cell B12.

To manually calculate the average of weight measurements taken during Shift 1, type **=B12/8** in cell B13 (Fig. 1.19). Press the **Enter** key.



	A	B
1	Quality Control in Pizza Crust	
2		
3	Sample No.	Shift1
4	Sample1	162
5	Sample2	164
6	Sample3	158
7	Sample4	166
8	Sample5	164
9	Sample6	155
10	Sample7	170
11	Sample8	168
12	Sum	1307
13	Average	=B12/8

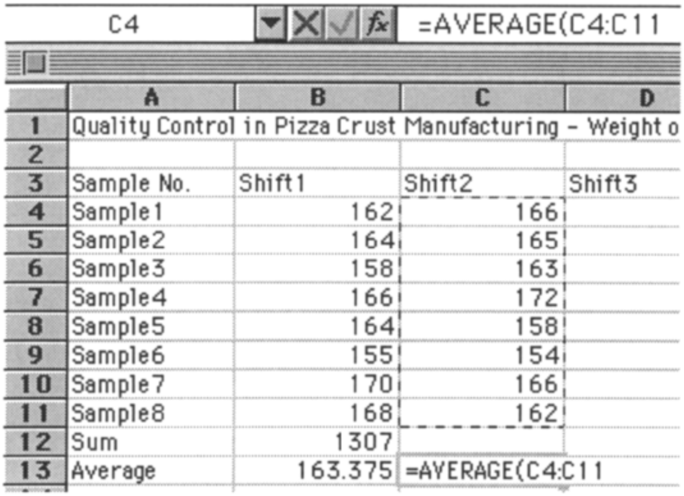
	A	B
1	Quality Control in Pizza Crust	
2		
3	Sample No.	Shift1
4	Sample1	162
5	Sample2	164
6	Sample3	158
7	Sample4	166
8	Sample5	164
9	Sample6	155
10	Sample7	170
11	Sample8	168
12	Sum	1307
13	Average	163.375

Figure 1.19 Average of cells B4:B11; result shown in cell B13.

1.8b Use of Formulas in Calculations

We can use an Excel formula AVERAGE() to calculate the average value for different cell entries. In cell C13, as shown in Fig. 1.20, type **=AVERAGE(C4:C11)**. The term C4:C11 instructs the computer that the data are in column C starting from cell C4 through C11.

An alternate procedure to enter the range C4:C11 as follows. After typing **=AVERAGE(** click on cell C4 and drag the mouse to cell C11. Note that cell C13 is still highlighted, and the range is automatically filled in it. You do not need to place a closing parenthesis. Just press the **Enter** key, and the average value is displayed in cell C13.



C4 =AVERAGE(C4:C11

	A	B	C	D
1	Quality Control in Pizza Crust Manufacturing - Weight o			
2				
3	Sample No.	Shift1	Shift2	Shift3
4	Sample1	162	166	
5	Sample2	164	165	
6	Sample3	158	163	
7	Sample4	166	172	
8	Sample5	164	158	
9	Sample6	155	154	
10	Sample7	170	166	
11	Sample8	168	162	
12	Sum	1307		
13	Average	163.375	=AVERAGE(C4:C11	

Figure 1.20 Typing a formula directly in cell C13.

If you are wondering how you were able to keep cell C13 highlighted while clicking on cell C4 and dragging to cell C11, the answer is simple: if you begin a cell entry with an = sign, that cell remains active until you press the **Enter** key. That is why you can select any other cell or range of cells and add them to your formula as long as the **Enter** key is not pressed. This also means that after you enter a formula your last key stroke must be the **Enter** key. Note that you can also click on the **Enter** icon, , in the formula bar, if you do not want to use the keyboard. To cancel a cell entry before pressing the **Enter** key, either press the **Esc** key (in Excel for Windows), or **Command+.** keys.

1.8c Use of Copy and Paste Functions in Calculations

To copy contents of one cell into another:

- First select a cell containing the contents to be copied.

- Either choose the menu commands **Edit, Copy**, or use the keys **Command+C** (**Ctrl+C** in Windows).
- Select the cell where the contents are to be pasted.
- Either choose the menu commands **Edit, Paste** command, or use the keys **Command+V** (**Ctrl+V** in Windows).

After using the **Paste** command or **Command+V** (**Ctrl+V** in Windows), the marquee remains active around the cells that were copied. You can remove the marquee by pressing the **Esc** key.

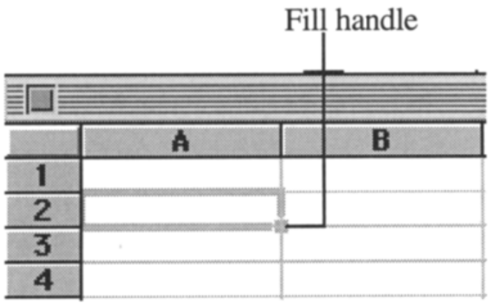


Figure 1.21 A fill handle.

Copying may also be done using the fill handle. As seen in Fig. 1.21, the fill handle is small square box on the bottom right-hand corner of an active cell. To copy and paste using the fill handle:

- Select the cells to be copied.
- Point at the fill handle, the mouse pointer will change from a hollow cross, , to a solid cross,  .
- Drag over the adjacent cells where copied cells are to be pasted.
- Release the mouse button to complete the pasting step.

If the fill handle is not displayed, choose the menu items **Tools, Options**, select the **Edit** tab, and click the **Drag and Drop** check box.

When using the fill handle, the copied cells can be pasted only into adjacent cells. Any previously typed information in the adjacent cells will be overwritten.

If the cell contains a value, it is copied and pasted as is into another cell.

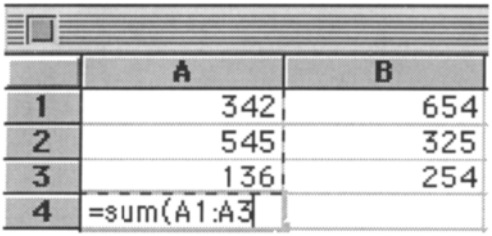


Figure 1.22 Calculating the sum of numbers.

If the cell contains a formula, the formula is copied and pasted with updated relative references to cells whose values are used in the formula.

For example, in Fig. 1.22, some numbers are entered in cells A1:A3 and B1:B3. Cell A4 contains a formula to calculate the sum of the numbers listed in cells A1:A3. In Fig. 1.22, a formula in cell A4 is used to display the sum of the values in cells A1:A3. If the formula from cells A4 is copied and pasted into B4, then Excel automatically changes the cell references to calculate and display the sum of the values in cells B1:B3, as shown in Fig. 1.23.

> When you copy and paste a cell with a relative reference, the references change, but if you use cut and paste, the relative references do not change.

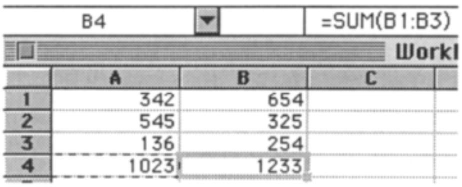


Figure 1.23 Copying cell A4 to B4.

In certain calculations, you may want to copy a formula from one cell to another with an absolute reference to some other cells that contain values or results of formulas. For an absolute reference to a cell

- type $ before the row and column heading.

For example, an absolute reference to the contents of cells A1:A3 in the formula in cell B4 is accomplished by using a $ sign for each cell address in the formula as shown in Figures 1.24 and 1.25.

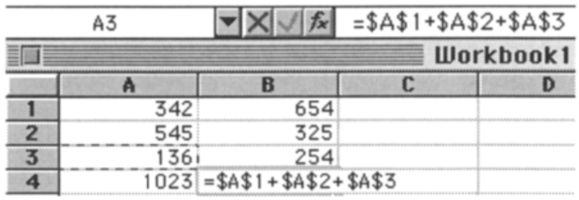


Figure 1.24 Using absolute references to cells.

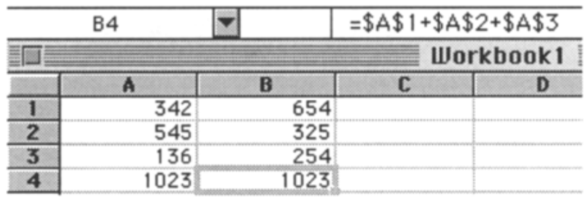


Figure 1.25 Sum of cells A1:A3 shown in cell B4.

When editing cells, you can convert an ordinary reference to a cell into an absolute reference by first clicking the insertion point to the cell address in the formula bar then pressing **Command+T (F4** in Windows).

For mixed reference to cells in a column

- type $ before the column name only.

For example, an absolute reference to the contents of column B is accomplished by typing $B3; the column reference will remain absolute but the reference row 3 will be relative.

For mixed reference to cells in a row

- type $ before the row name only.

For example, an absolute reference to the contents of row 3 is accomplished by typing A$3; the row reference will remain absolute but the reference to column A will be relative.

For our problem on pizza crust (Fig. 1.20), after calculating the average values for the eight samples for shift 1 and 2, we still need to calculate the average values for Shift 3. Although we can repeat the steps that we used for the data of Shifts 1 and 2, there is an easier way as follows:

- Since the formula for our calculations remains the same, select cell C13.

	A	B	C	D
1	Quality Control in Pizza Crust Manufacturing - Weight of pizz			
2				
3	Sample No.	Shift1	Shift2	Shift3
4	Sample1	162	166	160
5	Sample2	164	165	159
6	Sample3	158	163	160
7	Sample4	166	172	160
8	Sample5	164	158	161
9	Sample6	155	154	159
10	Sample7	170	166	163
11	Sample8	168	162	161
12	Sum	1307		
13	Average	163.375	163.25	160.375

Figure 1.26 Copy contents of cell C13 into D13.

- Copy its contents, by selecting **Edit**, **Copy** or simply highlighting cell C13 and pressing the **Command+C** (**Ctrl+C** in Windows) keys, and,
- Paste the contents in cell D13 by selecting **Edit**, **Paste** or simply the **Command+V** (**Ctrl+V** in Windows) keys as shown in Fig. 1.26.

While copy and paste for two or three columns is fine, it becomes tedious if you have to do this for tens of columns. There is an even simpler way that we will consider in the following section.

1.8d Use of the AutoFill Command in Calculations

Let us use Excel to determine the minimum weight for all samples from a single shift.

- In cell B14, type =MIN(B4:B11) and press the **Enter** key.
- The minimum value will be displayed in cell B14.
- Instead of copying cell B14 into B15 and B16 as done previously, highlight cell B14.

	A	B	C	D
1	Quality Control in Pizza Crust Manufacturing - Weight of p			
2				
3	Sample No.	Shift1	Shift2	Shift3
4	Sample1	162	166	160
5	Sample2	164	165	159
6	Sample3	158	163	160
7	Sample4	166	172	160
8	Sample5	164	158	161
9	Sample6	155	154	159
10	Sample7	170	166	163
11	Sample8	168	162	161
12	Sum	1307		
13	Average	163.375	163.25	160.375
14	Minimum	155		

Figure 1.27 Use of the **AutoFill** command to copy and paste functions.

- Then use **AutoFill** to copy B14 into cells B15 and B16 using the procedure shown in Section 1.7. Remember that you can use the **AutoFill** command as long as your rows or columns are contiguous i.e., they are in contact with each other.

1.8e Use of the Function Wizard in Calculations

In order to determine the maximum weight recorded during Shift 1, we will use the **Function Wizard** available in Excel to help us select the appropriate function and ranges.

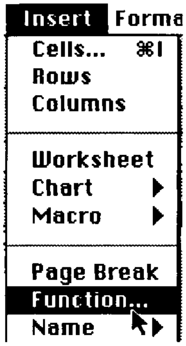


Figure 1.28 Selecting the **Function Wizard** in menu pad.

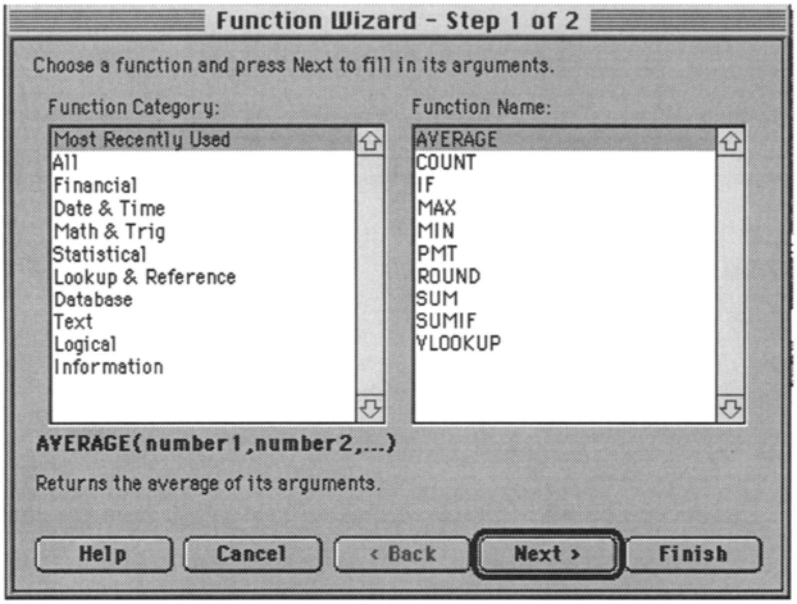


Figure 1.29 Step 1 of the **Function Wizard**.

To move a dialog box with a title bar, click in the title bar and, while keeping mouse button pressed, drag it to any desired location on the screen.

- Select cell B15.
- Either select the **Insert**, **Function**... menu items, or
- click on the **Function** icon  located in the formula bar. This will open a dialog box, as shown in Fig. 1.29.

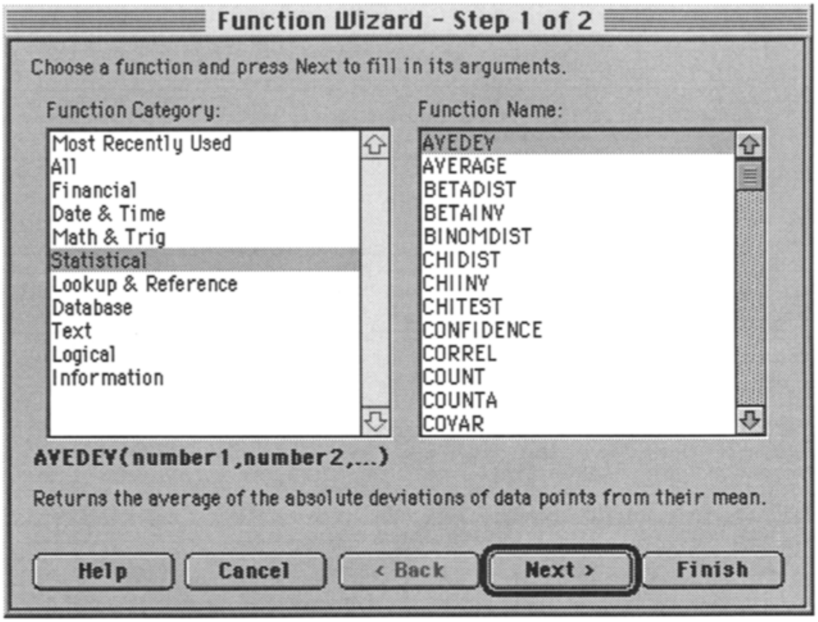


Figure 1.30 Select **Statistical** in the left-hand box named **Function Category**.

The dialog box in Fig. 1.29 contains 10 categories of functions shown in the left-hand box. The function names contained in each highlighted category are shown in the right-hand box.

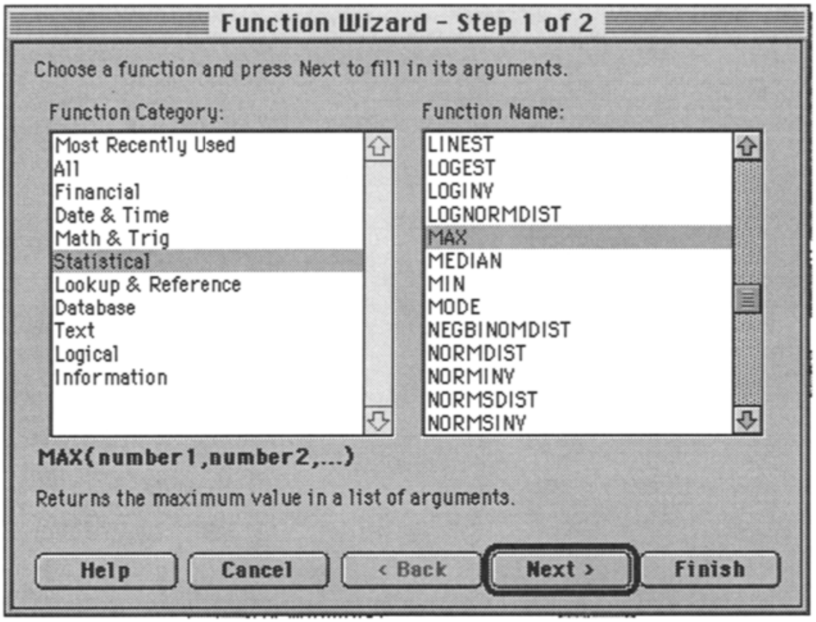


Figure 1.31 Locate **MAX** in the right hand side **Function Name** box.

Since we want to find the maximum value in cells B4:B11, use the statistical function called **MAX**:

- Click on **Statistical** in the left-hand box.
- In the right-hand box either scroll to find **MAX**, or simply press the **M** key to move quickly to the functions starting with the alphabet M (Fig. 1.31).
- Double-click on **MAX**. This will open the next dialog box, as shown in Fig. 1.32.

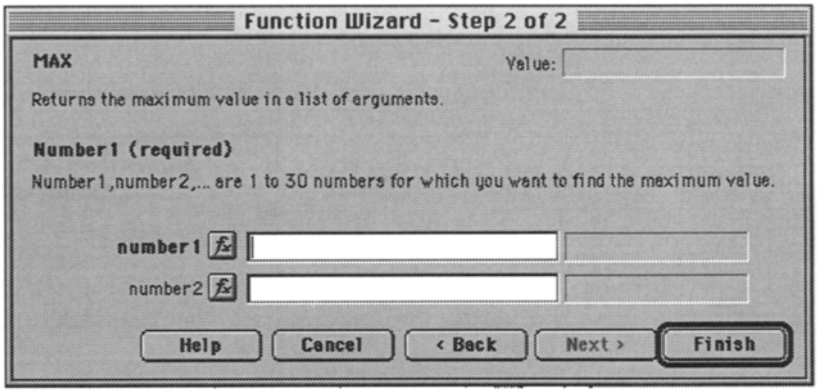


Figure 1.32 Enter the cell range in the **number 1** box.

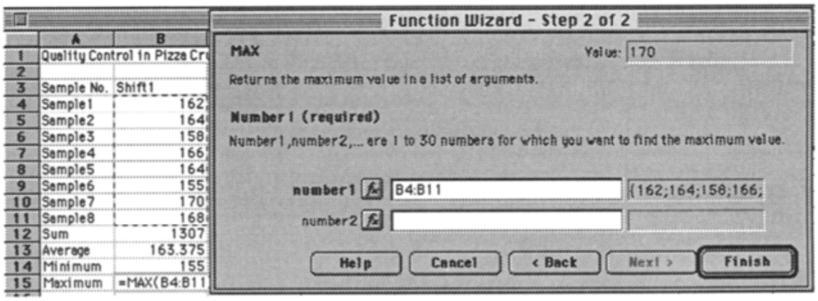


Figure 1.33 Cell range entered in the **number 1** box.

- Drag the dialog box on the side so that you can view your worksheet (Fig. 1.33); now drag over cells B4:B11. Note that **number 1** in the dialog box contains reference to B4:B11.
- Select **Finish**; after you are returned to the worksheet, press the **Enter** key. The results are displayed in cell B15.
- When using **Function Wizard**, if at any time you want to cancel or return to the previous steps, click on the **Cancel** or **<Back** buttons, respectively.

The final worksheet with calculations for minimum and maximum values for each shift is shown in Fig. 1.34.

	A	B	C	D	E
1	Quality Control in Pizza Crust Manufacturing - Weight of pizza crust (grams)				
2					
3	Sample No.	Shift1	Shift2	Shift3	
4	Sample1	162	166	160	
5	Sample2	164	165	159	
6	Sample3	158	163	160	
7	Sample4	166	172	160	
8	Sample5	164	158	161	
9	Sample6	155	154	159	
10	Sample7	170	166	163	
11	Sample8	168	162	161	
12	Sum	1307			
13	Average	163.375	163.25	160.375	
14	Minimum	155	154	159	
15	Maximum	170	172	163	

Figure 1.34 Worksheet with results of averages, and minimum and maximum values.

1.9 Naming the Worksheet

The worksheet is named at the time it is saved. For example:

- As shown in Fig. 1.35, choose the menu items **File**, **Save As...**. A dialog box will open (Fig. 1.36).
- Enter the name as desired (say *crustqc*) and click **OK**.
- Another dialog box will open for optional additional information such as keywords (keywords are useful in finding worksheet using **Find** command), and name of programmer. After entering the required information, click **OK**. The worksheet will be saved with the new name.

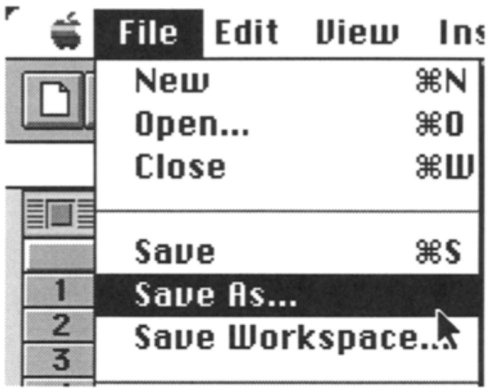


Figure 1.35 Menu commands to save a worksheet.

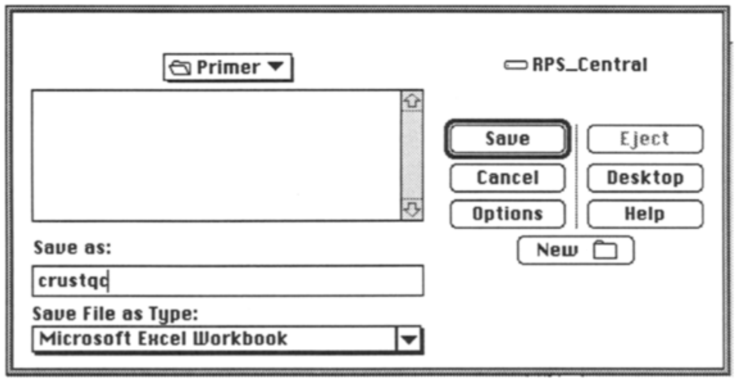


Figure 1.36 A dialog box to enter the name of a worksheet.

An alternate procedure to name a worksheet is as follows:

- In Excel for Macintosh, keeping the **Control** key pressed, point at the worksheet tab name **"Sheet1"** on the bottom row, as shown in Fig. 1.37. In Excel for Windows, simply point at the worksheet tab name "Sheet1" and click the right mouse button. A shortcut menu pad will be displayed.
- Drag to the **Rename...** key. A dialog box will open, as shown in Fig. 1.38.
- Enter the name for the worksheet. Press **Enter** or click **OK**. The new name will appear in the bottom ruler.

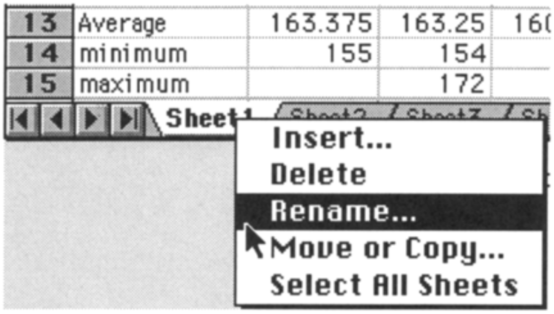


Figure 1.37 Shortcut to rename a worksheet.

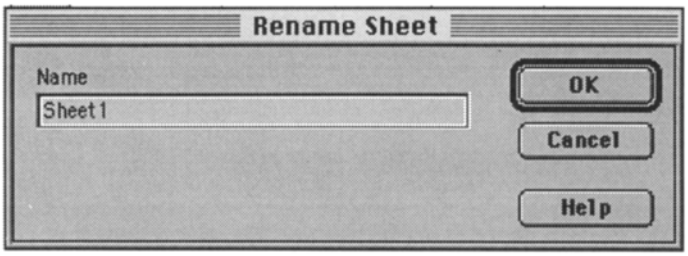


Figure 1.38 A dialog box to rename the worksheet.

1.9a Opening an Existing Worksheet

An existing worksheet may be opened as follows:

- Use the menu items **File, Open** command. A new dialog box will open, as shown in Fig. 1.40.
- Select the appropriate folder where your file is saved. If you have numerous worksheets in a folder, you may not see it in the file list in the dialog box, since the list is arranged alphabetically.

In the dialog box used for opening a file, if you check the read-only check box, you will be able to read the opened worksheet, but you will not be able to save any changes in it unless if you save it under another name. This is useful to avoid accidentally making any changes in a worksheet.

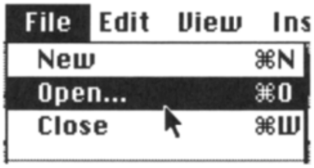


Figure 1.39 Menu selections to open a worksheet.

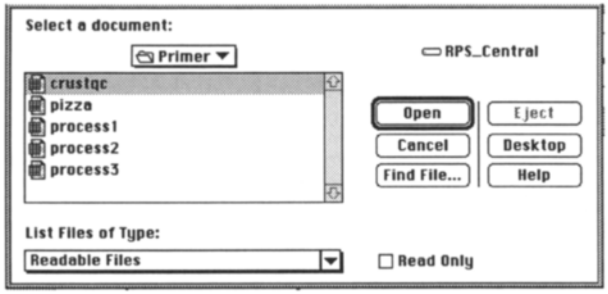


Figure 1.40 Dialog box to open a worksheet.

- Use the vertical scroll bar to locate the file name. For example, our file *crustqc* was saved in folder *Primer*. In Fig 1.40, the folder *Primer* is shown as the folder, and the file *crustqc* is in the file list.
- Highlight the file *crustqc* and either double-click or after highlighting it select **File, Open...**. This will open the previously saved worksheet.

1.10 Inserting and Deleting Rows and Columns

To illustrate additional calculation procedures, we will add another row to our worksheet to enter new data. Let us assume that additional data became available as Sample9 with values 171, 169, 166 for Shift 1, Shift 2 and Shift 3, respectively.

To insert a row:

- Point and click on the **row heading** that will be immediately below the new row to be inserted. For example, if we want to enter a row above row 12, then click **row heading** 12.
- From the menu, select the items **Insert**, **Rows**. This will add a new row. All rows will be automatically renamed.
- The procedure for entering columns is similar; click in any column heading that will be immediately to the left of the column being inserted. Select the menu items **Insert**, **Columns**.

To practice these new features, let us add the additional data for Sample9.

- Click in row heading 12.
- Use the menu items **Insert**, **Rows** (Fig. 1.41). A new blank row will be inserted.
- Type data in cells B12: B14, as shown in Fig. 1.42.

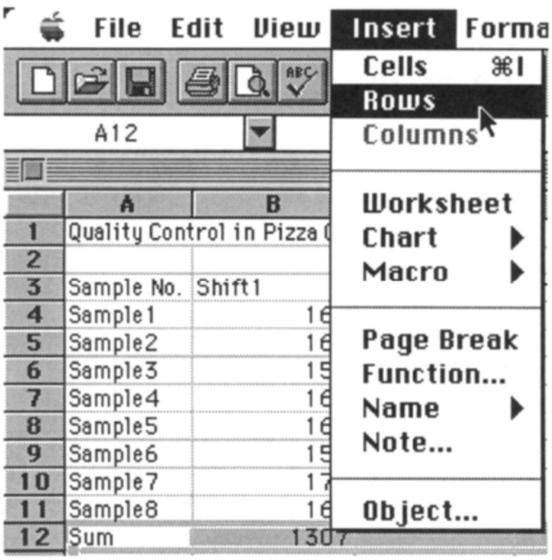
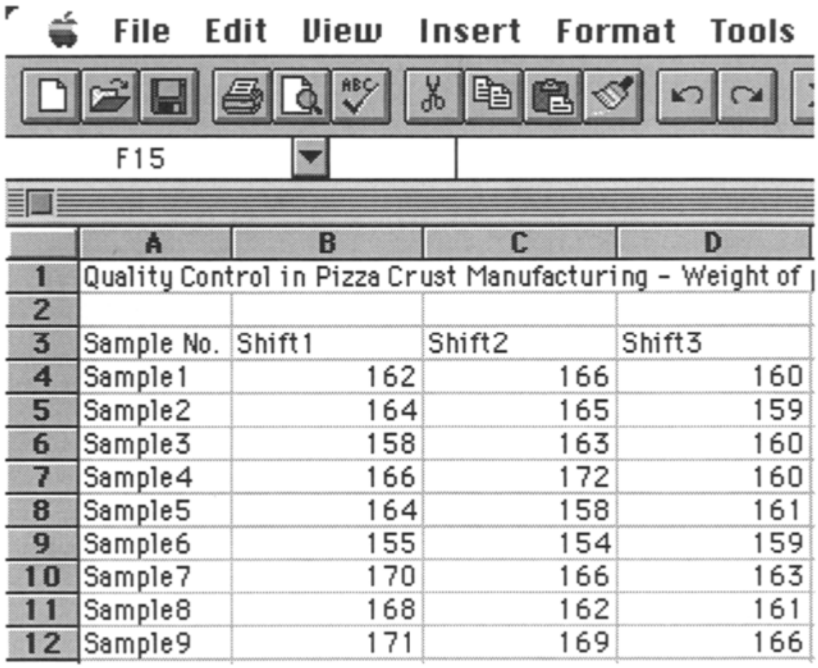


Figure 1.41 Inserting a row in a worksheet.



	A	B	C	D
1	Quality Control in Pizza Crust Manufacturing - Weight of			
2				
3	Sample No.	Shift1	Shift2	Shift3
4	Sample1	162	166	160
5	Sample2	164	165	159
6	Sample3	158	163	160
7	Sample4	166	172	160
8	Sample5	164	158	161
9	Sample6	155	154	159
10	Sample7	170	166	163
11	Sample8	168	162	161
12	Sample9	171	169	166

Figure 1.42 New data for Sample9 entered in row 12.

Note that the results for averages, minimum and maximum do not contain the newly added row. The formula entered for each of those functions must be updated to add the newly inserted row.

To delete a row or a column, first select the desired row or column by clicking in its heading and then select the menu items **Edit, Delete**. The highlighted row or column will be deleted. For example, to delete row number 2:

- Click in row heading 2.
- Select the menu items **Edit, Delete** as shown in Fig. 1.43. The row will be deleted.

Figure 1.43 Menu selection to delete a row.

1.11 Aligning Cell Contents

Alignment of contents of cells is done using the following commands:

- Highlight the appropriate cell(s) that need to be formatted.
- Select **Format**, **Cells...** (Fig. 1.44); a dialog box as shown in Fig. 1.45, will open.
- Select the **Alignment** tab from the dialog box.
- Select appropriate options, e.g., **Left** in **Horizontal** to move contents to align them to the left side.

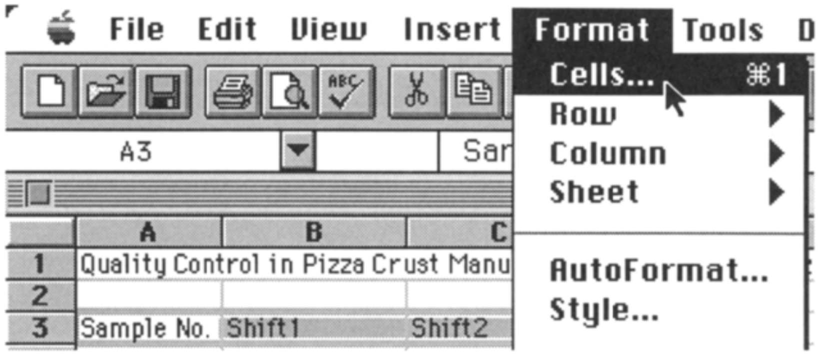


Figure 1.44 Formatting contents of cells.

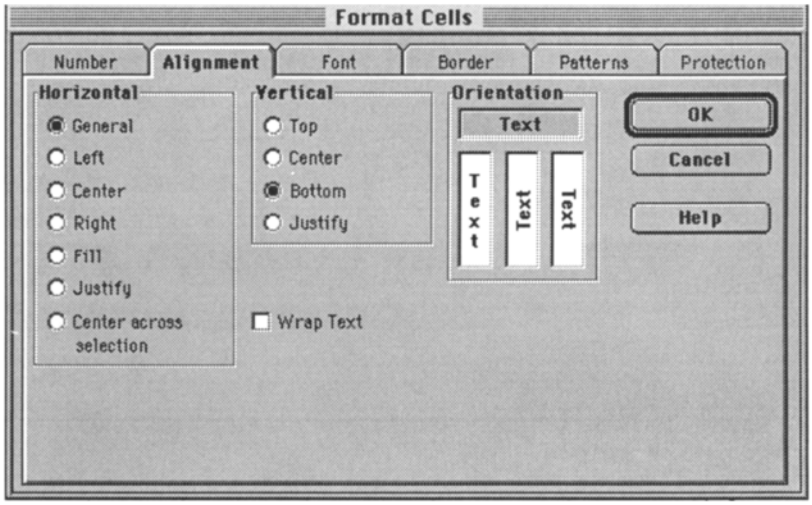
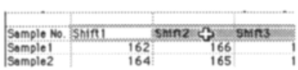


Figure 1.45 Dialog box for formatting cells.



An alternate procedure is to use the shortcut menus. To open a shortcut menu:

- Highlight the appropriate cell(s), e.g., cells A3:D3.
- Move the cursor inside the highlighted cells area, make sure that it is a hollow cross.
- While keeping the **Control** key pressed, press the mouse button; this will open the shortcut menu, as shown in Fig. 1.46. In Excel for Windows, after moving the cursor in the

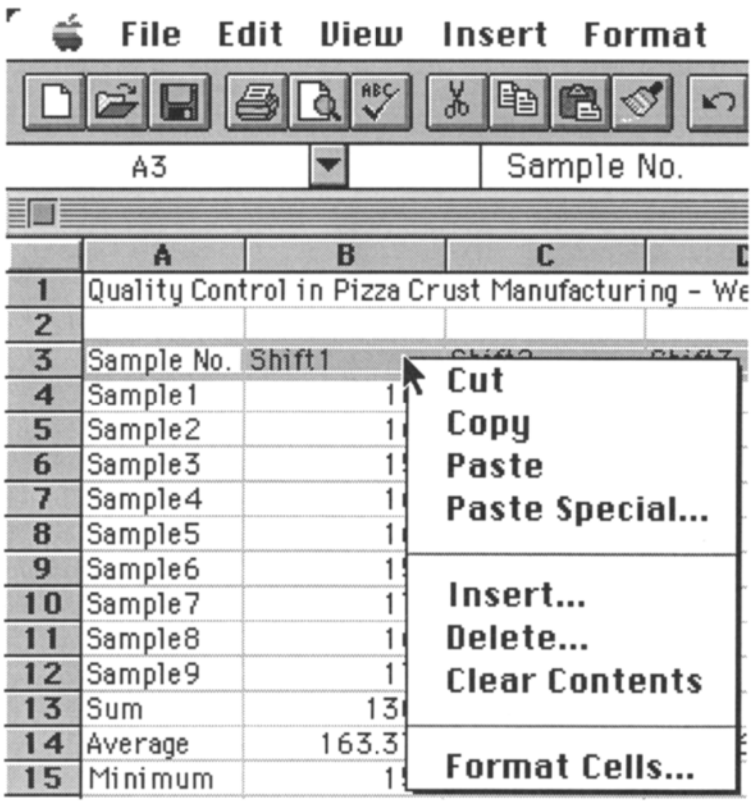


Figure 1.46 Using shortcut procedure to format cells.

highlighted cells area, simply click on the right mouse button.

- Select **Format Cells...**; a new dialog box will open, as shown in Fig. 1.47.
- A dialog box to format cells has several tabs; select the **Alignment** tab, as seen in Fig. 1.47.
- Several choices are available in the dialog box. Click in the appropriate check box for desired selection, for example, **Center** under **Horizontal**. Then select **OK**. The contents of cells A3:D3 will be center aligned.

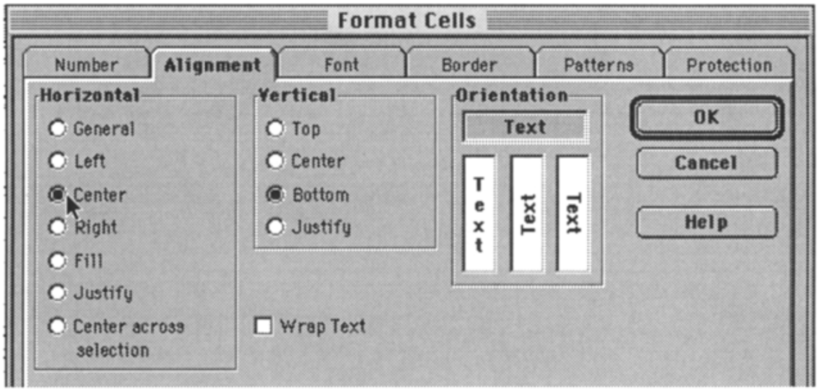


Figure 1.47 A dialog box to format cells.

1.12 Formatting Numbers

There are several formats available in Excel to display numbers. To format numbers:

- Select the appropriate cells that contain the numbers that you would like to format.
- Either choose the menu commands **Format**, **Cell**... to open a dialog box.
- Or simply, use the shortcut menu.

As an example, let us change the format of results displayed for average values of three shifts in Fig. 1.34 to two significant digits. The steps are as follows:

- Highlight cells B13:D13.
- Move the pointer into the highlighted area and open the shortcut menu as seen in Fig. 1.48. Select **Format Cells...**; this will open a dialog box as shown in Fig. 1.49, select the tab **Number** to bring the folder containing options for formatting numbers to the front, if it is not already.
- To display results to two significant digits, select the category **Number** and click on 0.00 in the **Format Codes**; the **Code** box contains 0.00. Click **OK**, and the

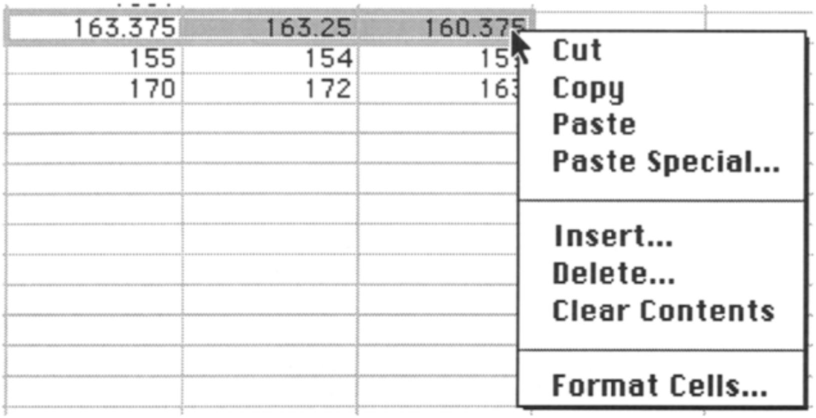


Figure 1.48 Shortcut menu to change the cell format.

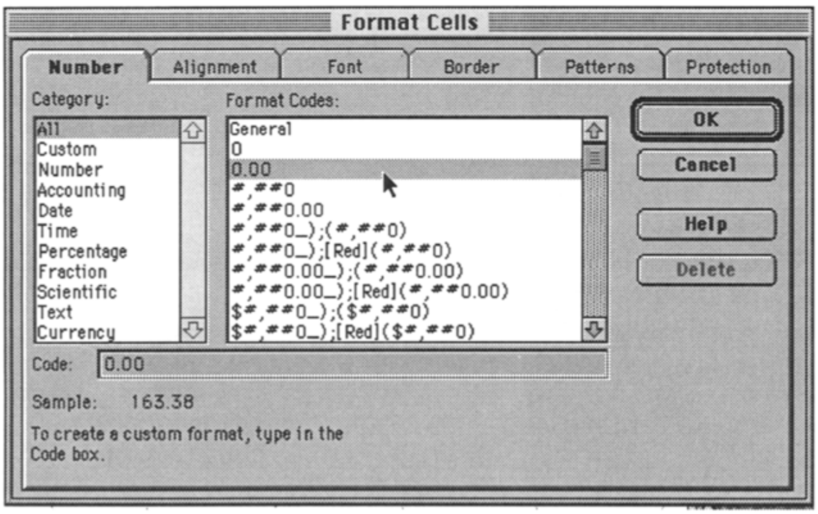


Figure 1.49 A dialog box to change the format of numbers.

numbers in the displayed cells are formatted to two significant digits.

If you want to display three significant digits, use the same procedure as above except, after the dialog box opens as shown in Fig. 1.49:

- Select 0.00 in the **Format Codes**, click in the **Code** box, change 0.00 to 0.000 by typing the extra zero, and click on **OK**, this will change the format in the cells to three significant digits.

Note the other options available in the category list, e.g., options for such formats as dates, time, currency, scientific, and percentage. These options make the formatting tasks very easy.

1.13 Changing Fonts

Changing the font of cell entries is similar to the steps used in the preceding section. It is generally advisable to avoid using more than two different types of fonts in the same worksheet. Let us change the font of the cell contents in cells A4:A12 to Courier, size 10.

- Highlight cells A4:A12.
- Choose the menu commands **Format**, **Cells....**
- Or, open the shortcut menu, and choose **Format Cells**... (Fig. 1.50); a dialog box will open.
- Click on the tab **Font** to bring the format folder to the front, as shown in Fig. 1.51.
- From the **Font** list box, scroll to select **Courier**, select **Regular** from the **Font Style** list, and **10** from the **Size** list, then click **OK**. This will change the font to Courier 10 for the selected cells.

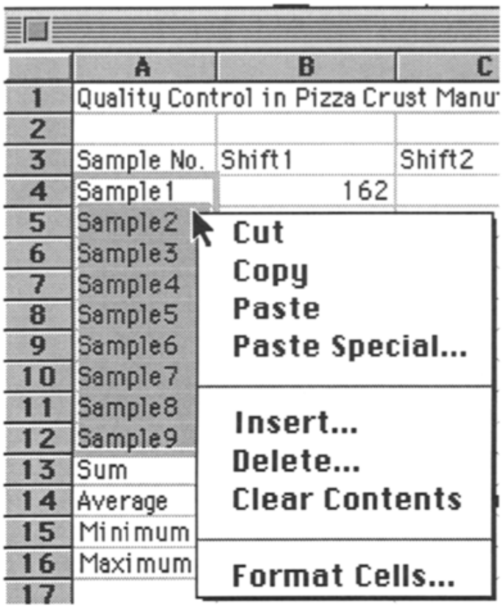


Figure 1.50 Shortcut to change the font of cells A4:A12.

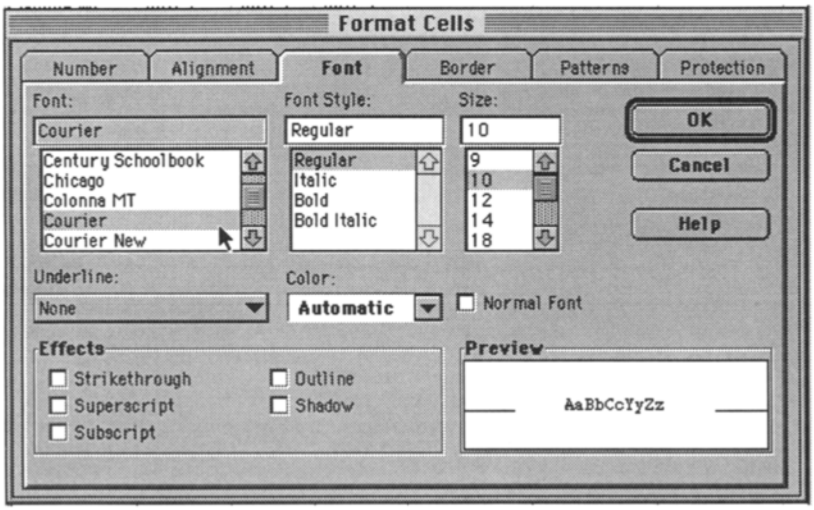


Figure 1.51 A dialog box to change the font of cell contents.

1.14 Adding Borders

Borders may be added by using the formatting dialog box. We will create a box outline around the cells A3:D16.

- Highlight cells A3:D16.
- Choose the menu commands, **Format**, **Cells....**
- Or use the short cut menu and select **Format Cells....** This will open the dialog box.
- Select the tab **Borders**, as shown in Fig. 1.52.
- Click in the **Outline** box, choose the size of the line from the **Style** category, and click **OK**. This will draw a box around the selected cells.

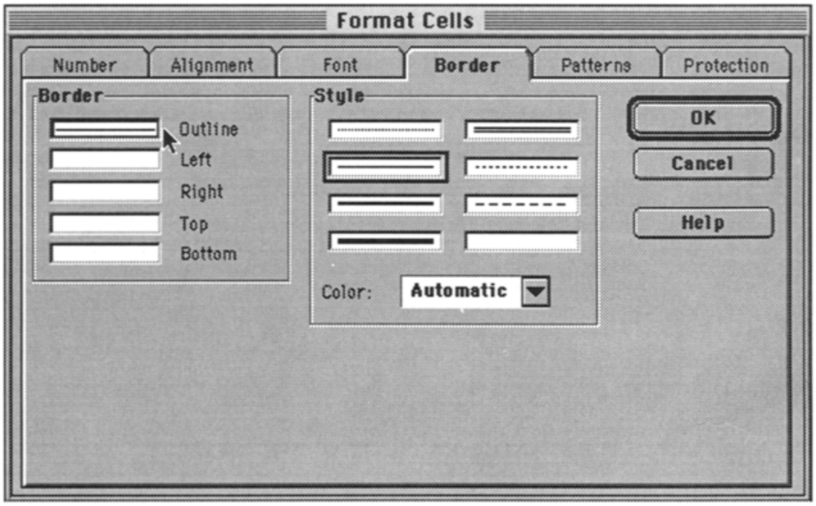


Figure 1.52 A dialog box to draw a border around selected cells.

crustqc

	A	B	C	D	E	F
1	Quality Control in Pizza Crust Manufacturing- Weight of pizza crust (grams)					
2						
3	Sample No.	Shift 1	Shift 2	Shift 3		
4	Sample1	162	166	160		
5	Sample2	164	165	159		
6	Sample3	158	163	160		
7	Sample4	166	172	160		
8	Sample5	164	158	161		
9	Sample6	155	154	159		
10	Sample7	170	166	163		
11	Sample8	168	162	161		
12	Sample9	171	169	166		
13	Sum	1478				
14	Average	164.222	163.89	161		
15	minimum	155	154	159		
16	maximum	171	172	166		

Figure 1.53 Worksheet with border drawn around the selected cells.

If you wanted to draw lines in between the outline box so that each cell is surrounded by boxes, select **Left**, **Right**, **Top,** and **Bottom** in the **Border** choice in the dialog box shown in Fig. 1.52.

1.15 Protecting Cells

To protect a worksheet so that a password will be required to make any changes, we will illustrate using our example on *crustqc*. The steps are as follows:

- Choose the menu items **Tools**, **Protection**, **Protect Sheet...**(Fig. 1.54) and a dialog box opens, as shown in Fig. 1.55.
- Enter a password and select **OK**; remember that passwords are case-sensitive.

You will be asked to re-enter the password.

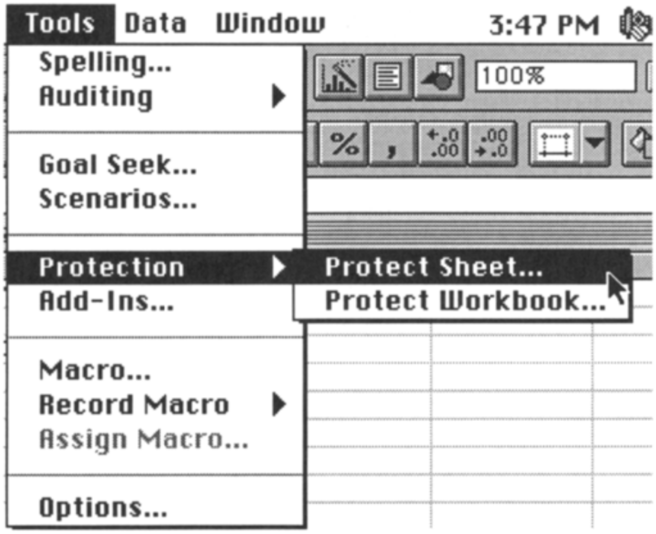


Figure 1.54 Menu commands to protect the worksheet.

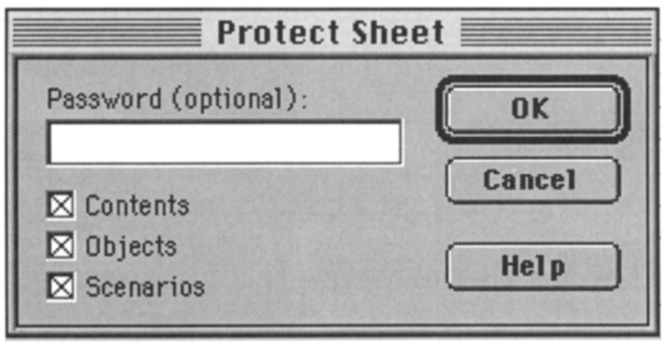


Figure 1.55 A dialog box to enter a password.

After the worksheet is protected, the cell contents cannot be changed. If you want to un-protect the worksheet:

- Select the menu items **Tools**, **Protection**, **Unprotect Sheet...** (Fig. 1.56). A dialog box will open as shown in Fig. 1.57.

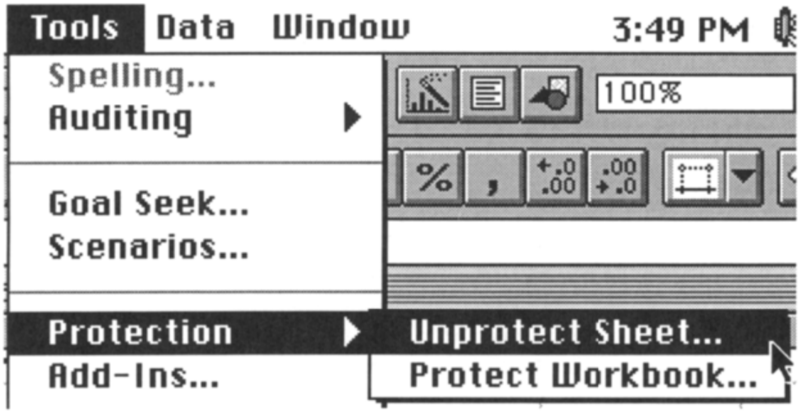


Figure 1.56 Menu commands to unprotect a worksheet.

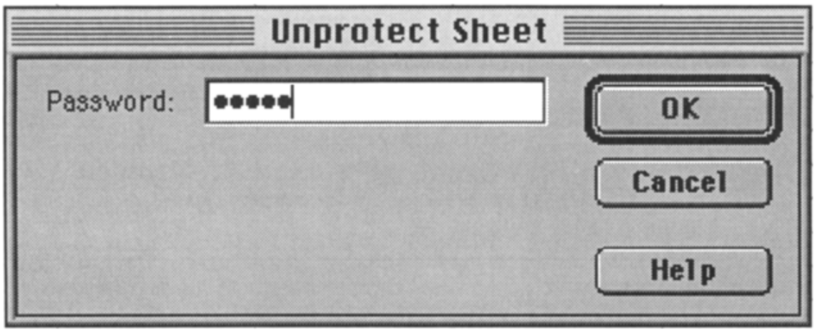


Figure 1.57 A dialog box to enter a password to unprotect a worksheet.

- Enter the password used earlier to protect the worksheet. This will remove the protection. Remember that if you forget the password there is no way to unprotect the worksheet. Therefore, it is important to keep the names of worksheets and passwords in a safe location.

1.16 Printing Worksheets (Previewing Pages, Headers and Footers)

Before printing the worksheet, we will examine some of the choices in the **Page setup** command.

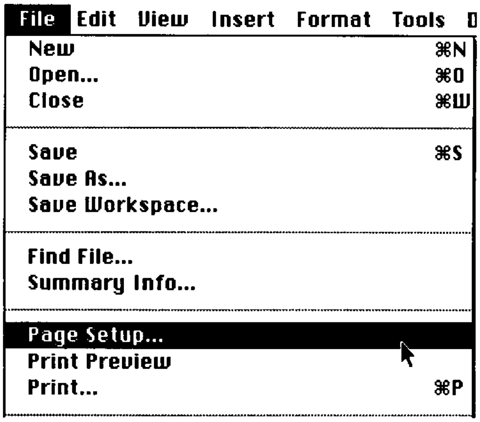


Figure 1.58 Menu commands to open **Page Setup**.

- Choose the menu items **File**, **Page Setup...** (Fig. 1.58). A dialog box will open, as shown in Fig. 1.59.
- If you want to print the row and column headers, then select the tab **Sheet**, as shown in Fig. 1.59.
- Click in the check box for **Row and Column Headings**.
- If you want gridlines to be printed, then click in the **Gridlines** check box. Select **OK**. There are other choices for setting up pages, but this should suffice for the time being.

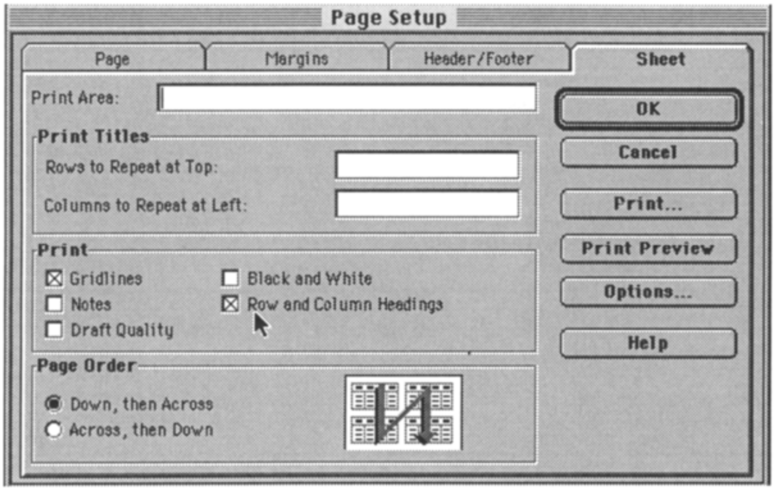


Figure 1.59 A dialog box to select printing attributes.

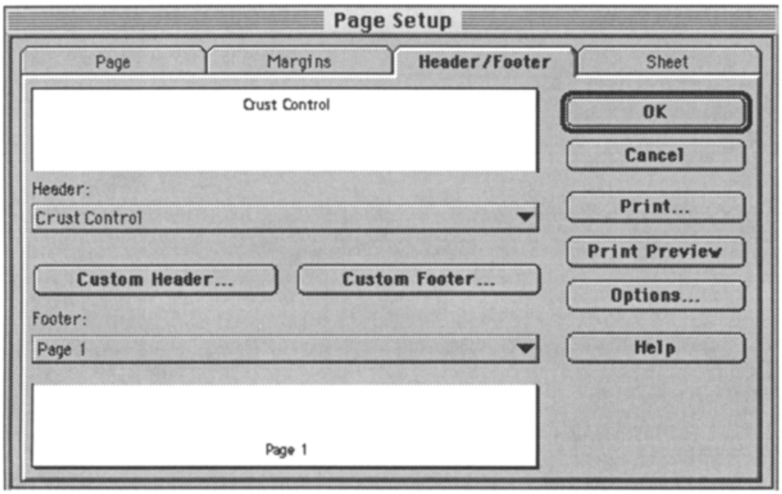


Figure 1.60 A dialog box to write **Header/Footer** statements.

- Click on the tab **Header/Footer** (Fig. 1.60).
- The header and footer statements may be changed by typing in the respective boxes. Click on **OK** when done.

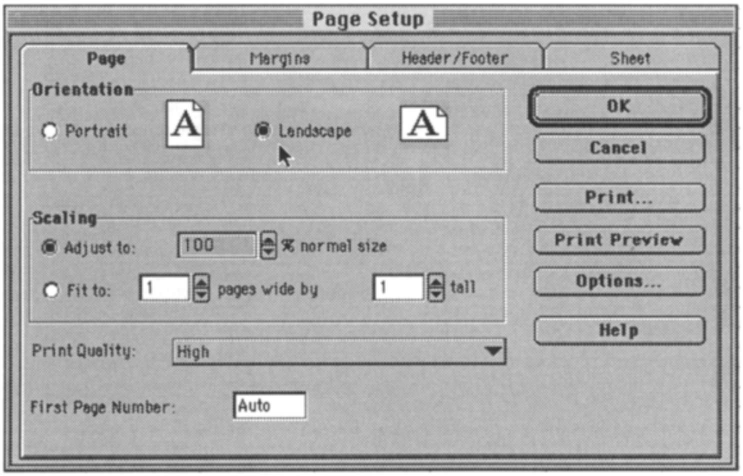


Figure 1.61 A dialog box to change page attributes.

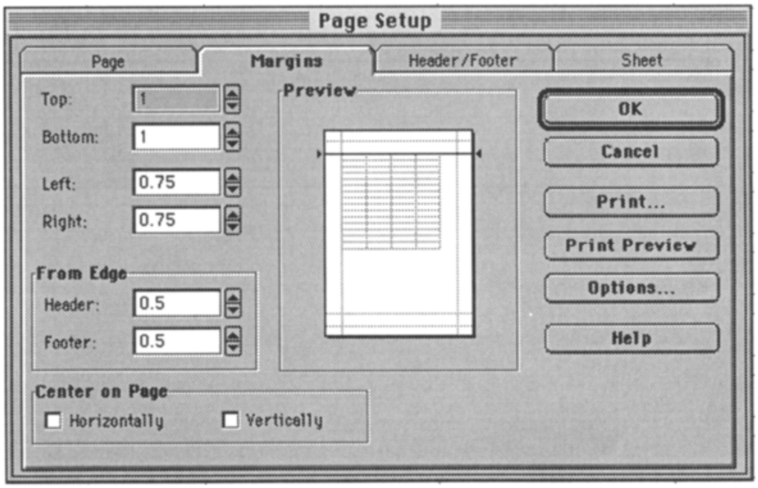


Figure 1.62 A dialog box to change margins.

To change from **Portrait** to **Landscape** design:

- Select the folder tab **Page**, as shown in Fig. 1.61.
- Select the **Landscape** check box.

To center the worksheet on the page:

- Select the tab **Margins**, as shown in Fig. 1.62.
- After making required changes, click **OK**.

1.17 Charts

There are several types of charts available in Excel. In this section we will consider some of the common types of charts used in illustrating numerical data in food science and engineering applications.

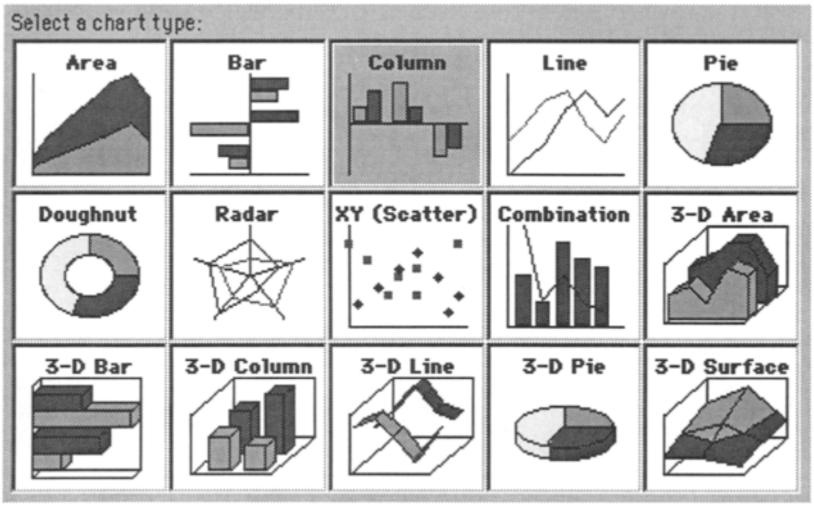


Figure 1.63 Chart types available in Excel.

1.17a Line Charts

Line charts are helpful in seeing trends in data. For example, one can quickly determine the high or low points in the line chart. These charts are also useful when the data set is very large. It is important to note that in a line chart only one data series is plotted on the y-axis. These charts are not appropriate to show relationship between two data series, for those cases x–y charts should be used. A variety of different formats of line charts are available, as shown in Fig. 1.64. Within line charts, one can also select a 3-D representation.

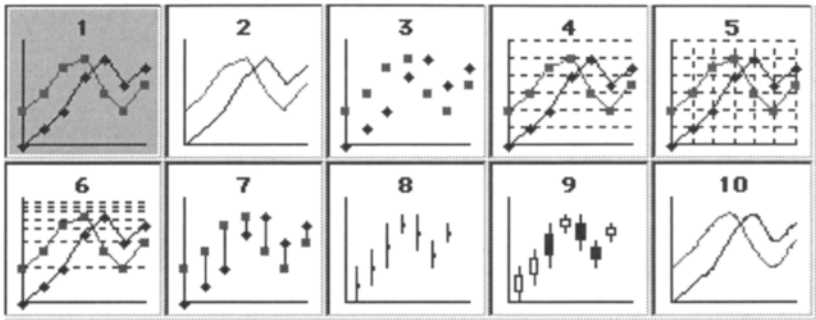


Figure 1.64 Different formats for line charts.

1.17b Area Charts

Area charts are same as line charts, except the space between the lines is filled in (Fig. 1.65). Similarly, in a 3-D format, the area is filled in with a different color or shading.

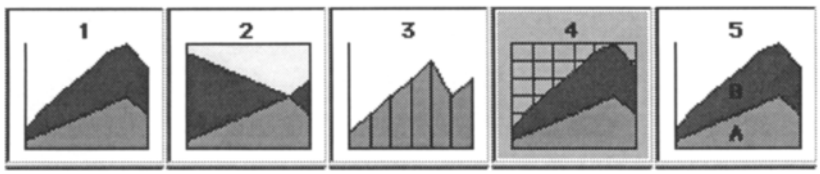


Figure 1.65 Different formats for area charts.

1.17c XY (Scatter) Charts

XY charts are most commonly used in engineering applications when relationships between two different data series are to be shown. In XY charts, both the x– and y–axes are used to enter the values from data series. The different formats available for XY charts are shown in Fig. 1.66.

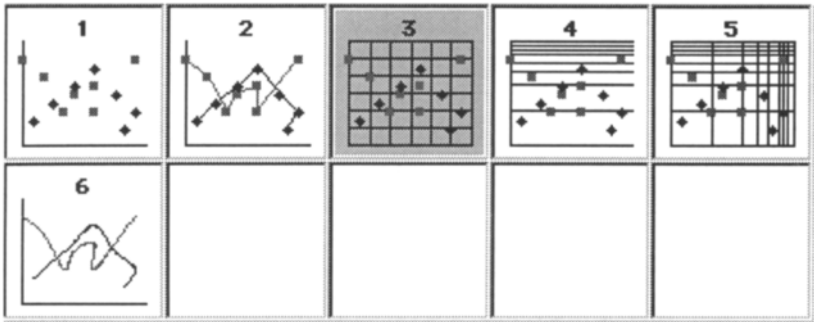


Figure 1.66 Different formats of XY scatter plots.

1.17d Combination Charts

With combination charts, one can combine two different chart types. This is useful in providing a contrast between different data series. The available formats for combination charts are shown in Fig. 1.67.

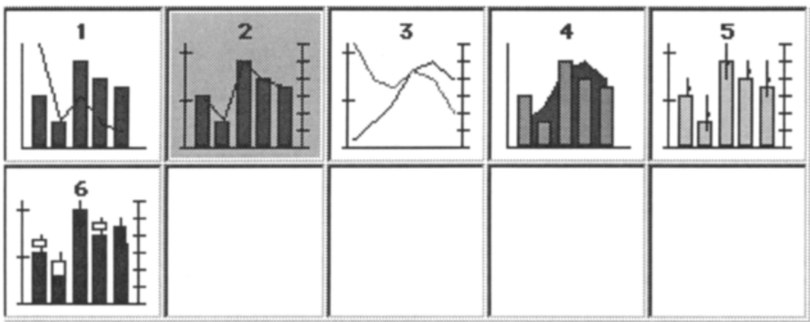


Figure 1.67 Different formats for combination charts.

1.18 Creating a Chart

Let us create a chart that shows the data on weights of pizza crust measured during three shifts. We will first plot the average values for three shifts and then add the entire data on the plot.

- Open the worksheet called **crustqc** (Fig. 1.68). We need to first identify the data on the worksheet that will be used in the plot.
- Select ranges B3 through D3 and B13 through D13. To select only these cells, first drag over cells B3 through D3, keep the **Command** (**Ctrl** in Windows) key pressed, then drag over cells through B13 and D13. This allows selection of non-contiguous ranges.

	A	B	C	D
1	Quality Control in Pizza Crust Manufacturing - Weight of			
2				
3	Sample No.	Shift1	Shift2	Shift3
4	Sample1	162	166	160
5	Sample2	164	165	159
6	Sample3	158	163	160
7	Sample4	166	172	160
8	Sample5	164	158	161
9	Sample6	155	154	159
10	Sample7	170	166	163
11	Sample8	168	162	161
12	Sum	1307		
13	Average	163.375	163.25	160.375

Figure 1.68 A worksheet with data for the pizza crust manufacturing.

- We will use the **ChartWizard** to create a chart. With cell ranges selected as in the preceding step, click on the **ChartWizard** icon, , in the tool bar, then click in cell F3 to identify the top left hand corner of the chart. The first **ChartWizard** dialog box will appear as shown in Fig. 1.69. The **Range** text box will display the selected cells; you can check these by looking at the highlighted cells in the worksheet. The dollar sign in front of the cell name indicates an absolute reference. If necessary, one can make any changes in the edit box. Since for this example the **Range** is correct, press the **Next** button.

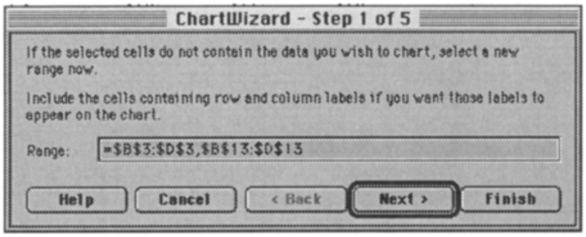


Figure 1.69 Dialog box for step 1 of the **ChartWizard**.

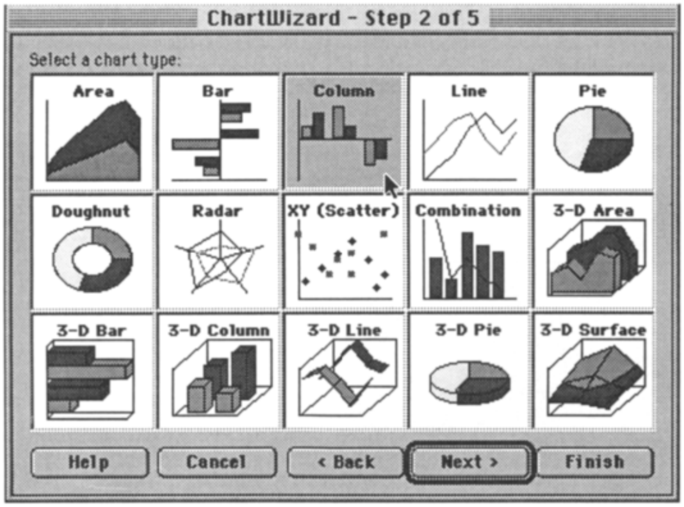


Figure 1.70 Dialog box for step 2 of the **ChartWizard**.

- The second step in the **ChartWizard** shows the different chart types available (Fig. 1.70). We will select the **Column** chart type by clicking in its box. Click **Next**.

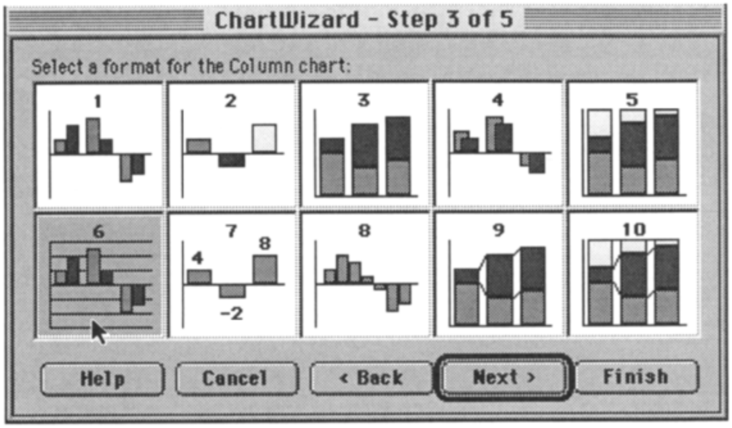


Figure 1.71 Dialog box for step 3 of the **ChartWizard**.

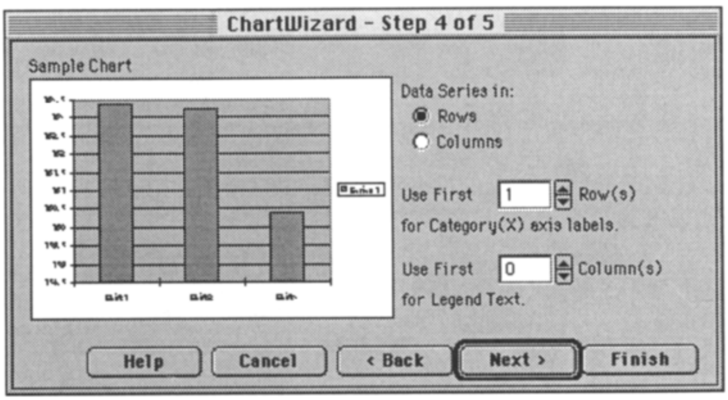


Figure 1.72 Dialog box for step 4 of the **ChartWizard**.

- The third step of the **ChartWizard** contains the different formats of the **Column** Chart (Fig. 1.71). We will select the format shown in box number 6. This format will draw the horizontal grid. Click **Next**.
- The fourth step of the **ChartWizard** shows a preview of the chart. If at this time you are not satisfied with the chart type, it is easy to retrace your steps by clicking on the **Back**

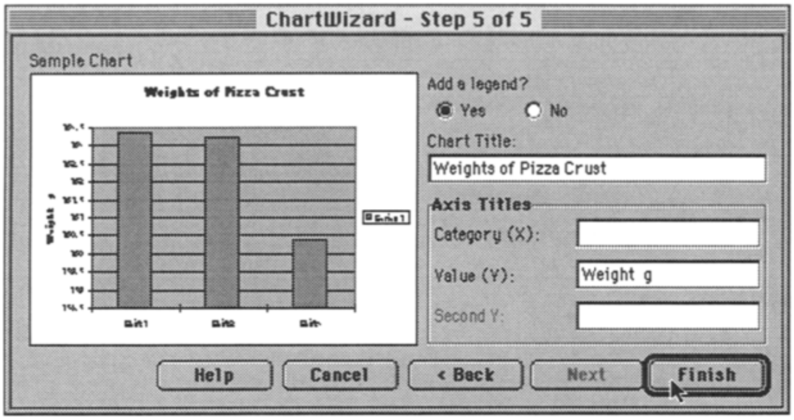
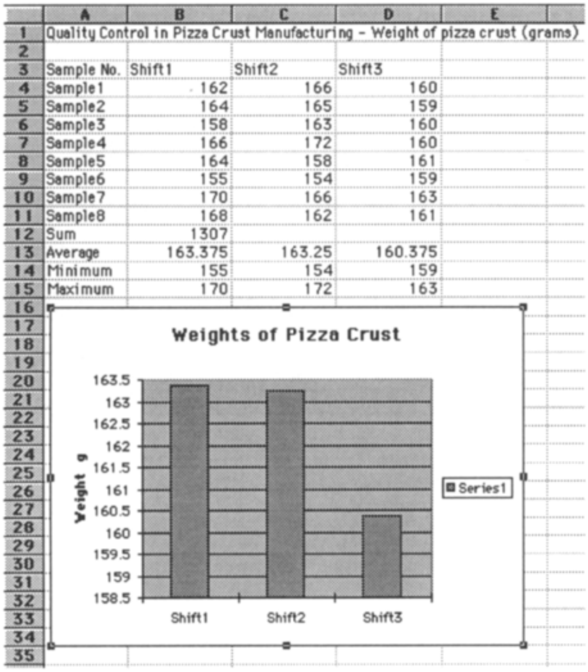


Figure 1.73 Dialog box for step 5 of the **ChartWizard**.

button to step 1 of **ChartWizard**. As seen in Fig. 1.72, the Data series is in **Rows**. If, on the other hand, your data series is in **Columns**, you can select the option box for **Columns**. In our case, the data are in **Rows** so we will not make any change. The dialog box also allows you to correctly identify the row that contains the **Category(X) axis labels**. You may make changes if necessary. Again in our case the x-axis labels are in the first row, therefore no change is required. Similarly select the appropriate column for the legend text. Again no change is necessary. Click **Next**.

- In the next dialog box (Fig. 1.73) we will select the **Yes** option box for **Add a legend**. This will assure that the data series will be appropriately identified with a legend. Click inside the **Chart Title** and type **Weights of Pizza Crust**. The **Axis** Titles may also be included. We will leave the **Category(X)** blank since the shift numbers are already listed, but we need to include the **Value (Y)**; type **Weight g**. Click **Finish**. The chart will be displayed as in Fig. 1.74. You may need to resize the Chart by dragging the bottom right corner. Make the chart as big or small as you see appropriate.



	A	B	C	D	E
1	Quality Control in Pizza Crust Manufacturing - Weight of pizza crust (grams)				
2					
3	Sample No.	Shift1	Shift2	Shift3	
4	Sample1	162	166	160	
5	Sample2	164	165	159	
6	Sample3	158	163	160	
7	Sample4	166	172	160	
8	Sample5	164	158	161	
9	Sample6	155	154	159	
10	Sample7	170	166	163	
11	Sample8	168	162	161	
12	Sum	1307			
13	Average	163.375	163.25	160.375	
14	Minimum	155	154	159	
15	Maximum	170	172	163	

Figure 1.74 Chart embedded in a worksheet.

- The screen now includes both the worksheet and the chart. We call this an embedded chart since any changes made on the worksheet are immediately viewed on the chart.

If you click anywhere inside the chart box, you will be able to move the whole chart or resize it, but you will be unable to change any individual elements of the chart. In order to make the chart active, double-click inside the chart area. The boundary of the activated chart box will change, as shown in Fig. 1.75. Then you can manipulate any individual elements of the chart.

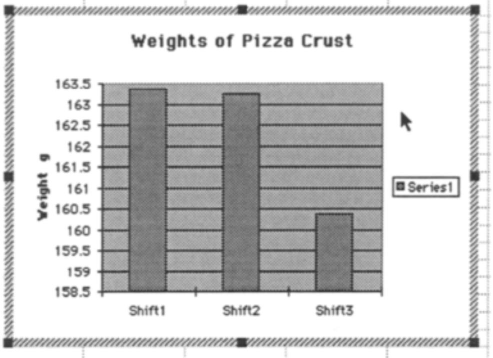


Figure 1.75 Chart made active by double-clicking in chart area.

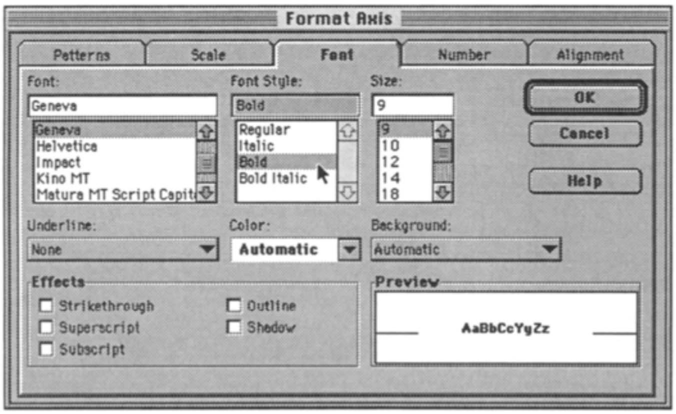


Figure 1.76 A dialog box to change the format font used in axis labels.

- To change the font style of the x-axis labels to bold. Point to **Shift 1** and double-click. This will open a dialog box (Fig. 1.76). Select folder named **Font**, select **Bold** in the Font **Style**, and click **OK**.

Similarly, you can make any other desired changes. For example to add shading to columns, double click anywhere inside the chart, a dialog box called **Format Data Series**

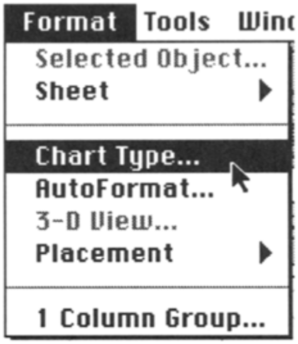


Figure 1.77 Menu commands **Format** and **Chart Type...**.

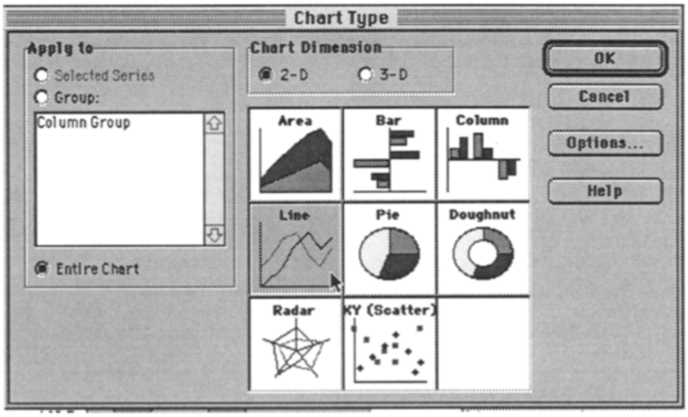


Figure 1.78 A dialog box to change the chart type.

will open. Under **Area**, select folder named **Patterns**; select the desired pattern. Click **OK**.
Let us assume that you wanted to changed the chart type from **Column** to **Line**. It is quite easy. First double click on the chart to activate it, then choose the menu commands **Format** and **Chart Type...** (Fig. 1.77). Click inside the **Line chart** icon and click **OK**. This will change the chart type to line type. Let us undo the last command to revert to **Column chart** type. Click on the undo icon, or choose **Edit** and **Undo Chart**.

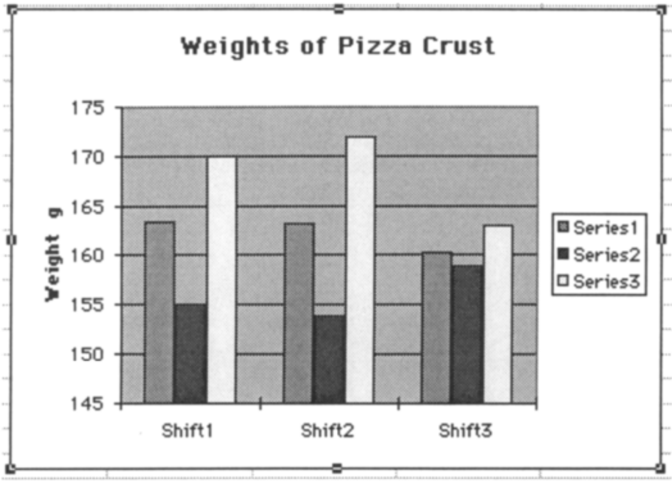


Figure 1.79 Adding maximum and minimum values as additional data series.

Let us consider adding two additional columns showing the minimum and maximum values for each shift. The procedure is as follows.

- In the worksheet (see Fig. 1.74), highlight the cells containing the minimum values for each shift, i.e. drag on cells B14:D14 and while keeping the mouse pressed, drag all the way onto the chart area and release.

The series is automatically added to the chart. Similarly, to add the data series containing maximum values, highlight the series B15:D15 in the worksheet and drag it over to the chart area and release. The new chart will be as shown in Fig. 1.79.

1.19 Drawing on the Worksheet

You can draw lines arrows and other drawing shapes on the worksheet as desired. To activate the drawing toolbar, choose the menu commands **View** and **Toolbars...** (Fig. 1.80). From the dialog box double-click in the check box (Fig. 1.81). A drawing toolbar as shown in Fig. 1.82 will be displayed. In this section, we will use this toolbar to draw on the worksheet.

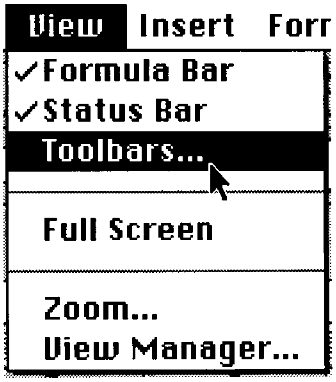


Figure 1.80 Choosing toolbars from the **View** menu.

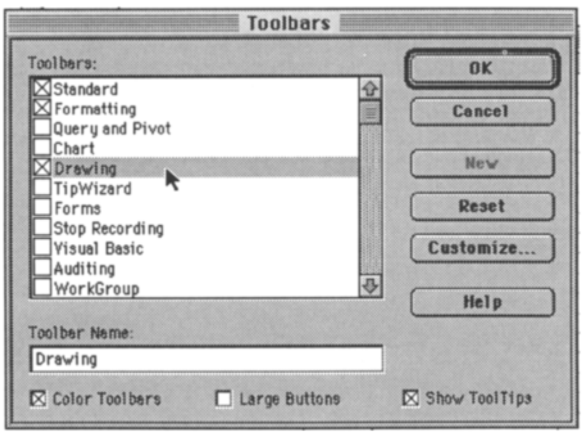
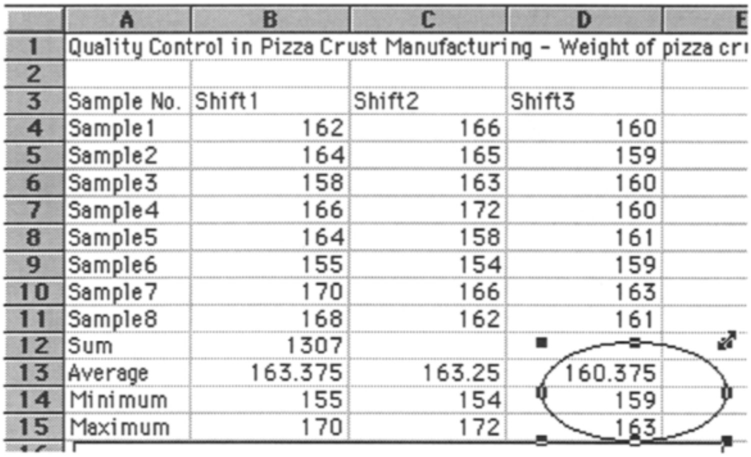


Figure 1.81 Selecting drawing toolbar from dialog box.

Figure 1.82 Drawing toolbar.



	A	B	C	D	E
1	Quality Control in Pizza Crust Manufacturing - Weight of pizza cr				
2					
3	Sample No.	Shift1	Shift2	Shift3	
4	Sample1	162	166	160	
5	Sample2	164	165	159	
6	Sample3	158	163	160	
7	Sample4	166	172	160	
8	Sample5	164	158	161	
9	Sample6	155	154	159	
10	Sample7	170	166	163	
11	Sample8	168	162	161	
12	Sum	1307			
13	Average	163.375	163.25	160.375	
14	Minimum	155	154	159	
15	Maximum	170	172	163	

Figure 1.83 An oval border drawn around the calculated results of cells D13:D15.

Let us say that you want to enclose the result data for Shift 3 (Fig. 1.74) in an oval shape and draw an arrow from it to the column plot for Shift 3. We will use the following steps:

- Click on the drawing symbol for circle and drag around the cells D13:D15. An oval border will be drawn that can be resized by pointing on the black squares and the cursor will change shape (Fig. 1.83); drag as necessary to position the circle around the cells.
- Click on the line icon on the **Drawing** tool bar. Drag from the edge of the circle to the bars shown for *Shift 3*. A line will be drawn as shown in Fig. 1.84.

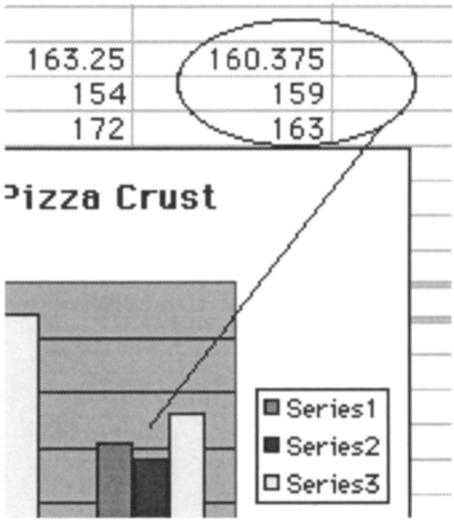


Figure 1.84 A line drawn from the oval shape to the plot.

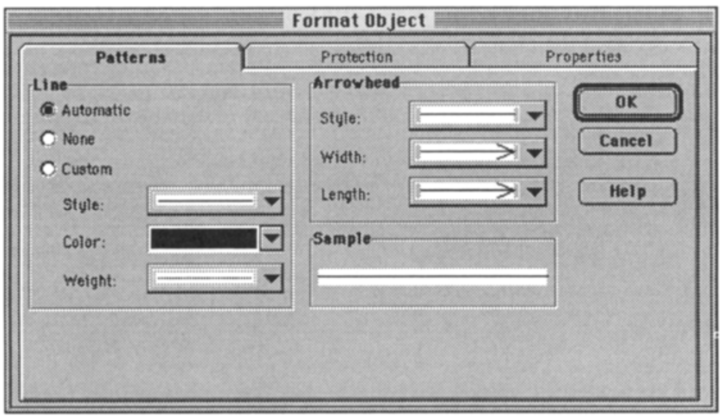


Figure 1.85 A dialog box obtained upon clicking on the line drawing in the worksheet.

- To convert the line into an arrow, double-click on the line. A dialog box (Fig. 1.85) will open. Select the arrowhead (Fig. 1.86). Click **OK**. The line will convert to an arrow as shown in Fig. 1.87.

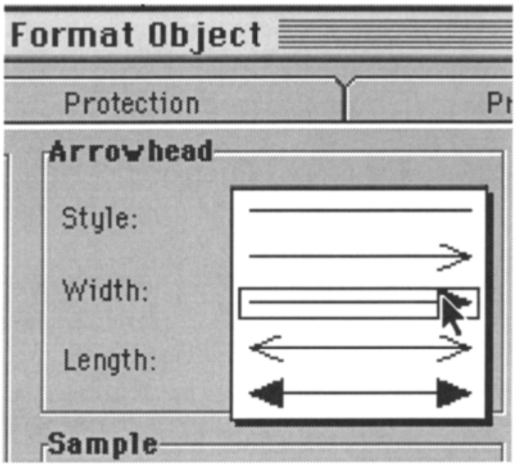


Figure 1.86 Selection of an arrowhead for the line.

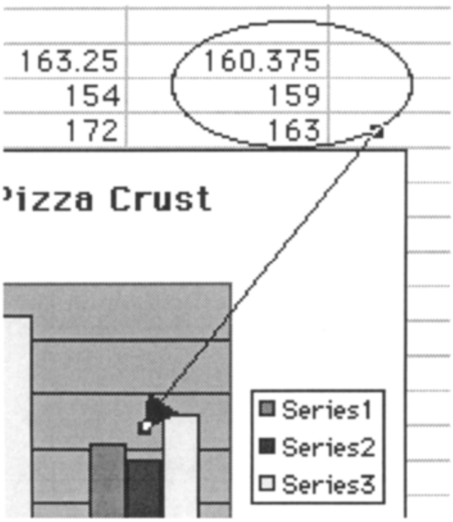


Figure 1.87 The line drawing changed to an arrow on the worksheet.

- You may want to display a note somewhere on the chart or the worksheet. For this purpose, we will use the list box.

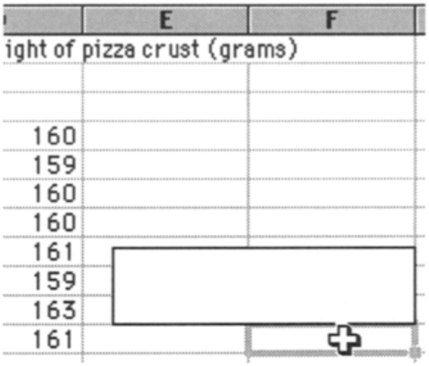


Figure 1.88 A list box drawn in the worksheet.

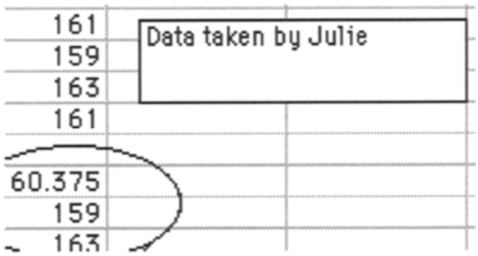


Figure 1.89 Typing text in the list box.

- First click on list box icon,  The cursor will change into cross-hair. Then drag in any space on the worksheet where you intend to display the note (Fig. 1.88).
- You can type your note inside the list box by first selecting it and then directly typing in the box (Fig. 1.89). The words will automatically wrap within the box.
- The list box may be resized as necessary by moving its corner handles.

The list box feature is very useful in displaying formulas used in a cell for calculations. Let us print the equation for cell D13 in a list box.

Figure 1.90 Copying the formula from the **Formula** bar for cell D13.

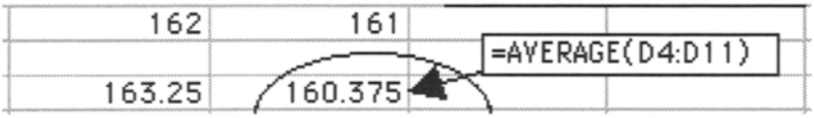


Figure 1.91 Pasting the formula into the list box, and connecting list box with an arrow to the calculated result of cell D13.

- First, select the list box from the **Drawing** tool bar, then drag it in to any open space on the worksheet. The list box will open with a blinking cursor inside it.
- Click in cell **D13**. The formula will be shown in the **Formula** bar (Fig. 1.90). Click in the **Formula** bar and drag to select the contents that you want to copy.
- Copy the formula using the menu commands **Edit** and **Copy**.
- Click inside the list box and use the menu commands **Edit** and **Paste**. You may need to resize the list box to fit the formula, as shown in Fig. 1.91.
- Next draw an arrow from the list box to cell **D13** to identify the cell.

1.20 Creating Pivot Tables

Pivot tables are a powerful option available in Excel to easily manipulate large amounts of tabulated data into organized forms for quick analysis. In this section, we will create a pivot table using a database of sales information for a cannery. The sales data are shown in Fig. 1.92. The cannery processes two products, namely, crushed tomatoes and peeled tomatoes. The sales data are for two years 1994 and 1995. Two persons managing the sales are Ms. Chen and Mr. Rodriguez. The regions of sales are Pacific Rim and South America. As seen in Fig. 1.92, the data are entered in no particular order. Using the **PivotTable** option we can organize this information in a variety of convenient ways.

	A	B	C	D	E	F
1	Product	Year	Quarter	Salesperson	Region	Units Sold
2	Peeled Tomato	1994	1	Rodriguez	South America	3467
3	Peeled Tomato	1994	1	Chen	South America	1223
4	Peeled Tomato	1994	1	Rodriguez	South America	864
5	Crushed Tomato	1995	1	Chen	Pacific Rim	990
6	Peeled Tomato	1995	1	Rodriguez	Pacific Rim	8634
7	Crushed Tomato	1994	2	Chen	South America	4526
8	Crushed Tomato	1994	2	Chen	Pacific Rim	6564
9	Crushed Tomato	1995	2	Chen	South America	4585
10	Crushed Tomato	1995	2	Chen	Pacific Rim	677
11	Peeled Tomato	1995	2	Rodriguez	South America	543
12	Peeled Tomato	1995	2	Rodriguez	South America	5433
13	Crushed Tomato	1995	2	Rodriguez	South America	8632
14	Peeled Tomato	1995	3	Rodriguez	Pacific Rim	4535
15	Peeled Tomato	1995	3	Chen	Pacific Rim	543
16	Crushed Tomato	1994	3	Rodriguez	Pacific Rim	8673
17	Crushed Tomato	1995	3	Rodriguez	Pacific Rim	7565
18	Peeled Tomato	1995	3	Chen	South America	886
19	Crushed Tomato	1995	3	Chen	South America	1233
20	Crushed Tomato	1995	4	Chen	Pacific Rim	6755
21	Crushed Tomato	1995	4	Chen	Pacific Rim	8564
22	Peeled Tomato	1995	4	Rodriguez	South America	8786
23	Peeled Tomato	1995	4	Chen	South America	8599
24	Peeled Tomato	1995	4	Chen	Pacific Rim	4678
25	Crushed Tomato	1995	4	Rodriguez	Pacific Rim	643
26	Peeled Tomato	1994	4	Rodriguez	South America	8569
27	Crushed Tomato	1995	4	Chen	Pacific Rim	6543
28	Crushed Tomato	1995	4	Rodriguez	South America	4322
29	Crushed Tomato	1995	4	Chen	South America	7345

Figure 1.92 Sales data for a food cannery manufacturing crushed and peeled tomatoes.

We will use the **PivotTable Wizard** to create a pivot table. The steps are as follows:

- Open a new worksheet expanded to full size.
- In cells A1:F29, type the text labels and data values as shown in Fig. 1.92.
- Click on any cell in the range A1:F29, e.g., cell B10.

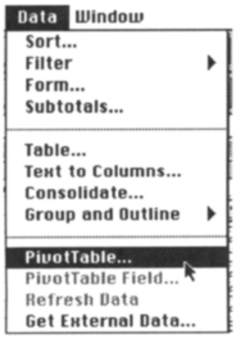


Figure 1.93 Selection of menu items **Data** and **PivotTable ...** to launch the **PivotTable Wizard**.

- Choose the menu items **Data**, **PivotTable...** (Fig. 1.93), a dialog box, with step 1 of the **PivotTable Wizard** will open as shown in Fig. 1.94.
- Select the **Microsoft Excel List or Database**. Click **Next**.
- The database range will be displayed in the **Range** edit box (Fig. 1.95). Because in step 1 you had clicked inside the cells A1:F29, Excel automatically detects the boundaries of the database table. If necessary, a different range may be entered by typing a new address in the edit box. Click **Next**.

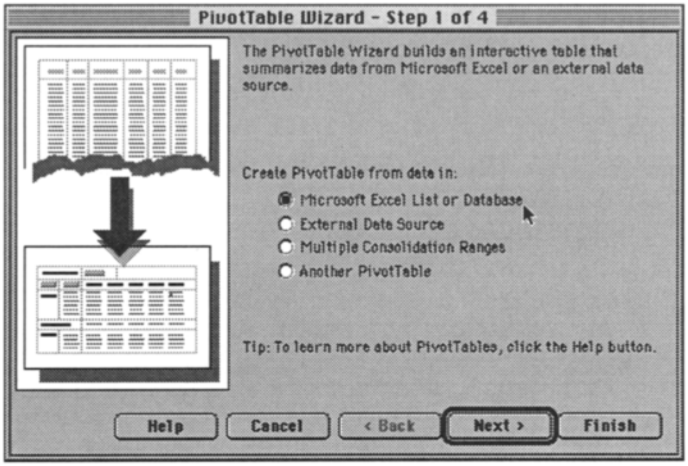


Figure 1.94 Step 1 of the **PivotTable Wizard**.

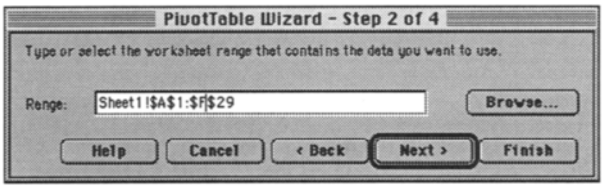


Figure 1.95 Step 2 of the **PivotTable Wizard**.

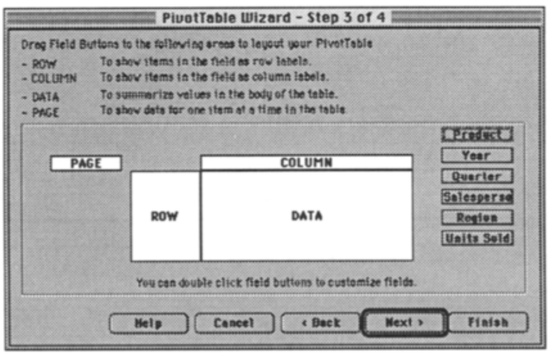


Figure 1.96 Step 3 of the **PivotTable Wizard**.

- The next dialog box, step 3 of 4, shows all the fields on the right-hand side (Fig. 1.96). You can select any of these fields to become row or column heads. Just drag and drop the fields in the desired **ROW** or **COLUMN** boxes. The field with numeric data is usually dropped in the **DATA** box. You can also move a field into the **PAGE** box to limit results of that field on a single page. For example, if you want to see the results for different years, then drag and drop **Year** field in the **PAGE** box. Let us drag fields as shown in Fig. 1.97, **Year** in **PAGE** box, **Salesperson** in **ROW**, **Product** in **COLUMN** box and **Units sold** in the **DATA** box. Click **Next**.

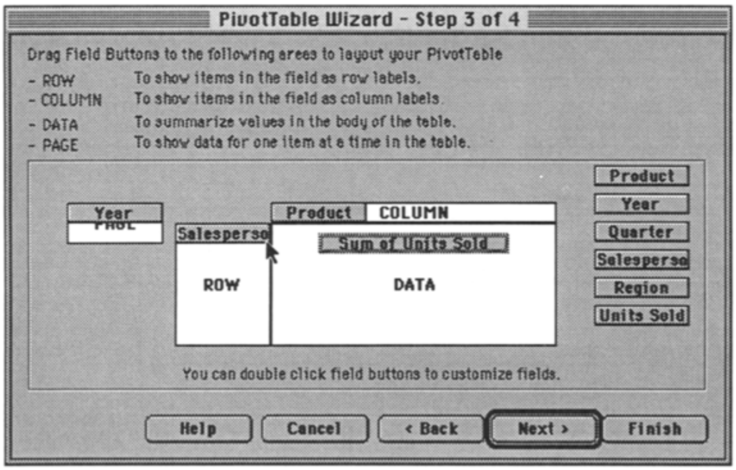


Figure 1.97 Entering fields by dragging into respective areas in the dialog box, Step 3 of the **PivotTable Wizard**.

- The last step is to identify a cell which will become the top left corner of the results table (Fig. 1.98). If you do not identify the starting cell, Excel will create a new worksheet within your workbook. You may also select check boxes if you wish Excel to calculate the grand totals for columns and rows, save data with table layout and autoformat the resulting table. Click **Finish**. The pivot table will be shown as in Fig. 1.99.

Figure 1.98 Step 4 of the **PivotTable Wizard.**

	A	B	C	D
1	Year	(All)		
2				
3	Sum of Units Sold	Product		
4	Salesperson	Crushed Tomato	Peeled Tomato	Grand Total
5	Chen	47782	15929	63711
6	Rodriguez	29835	40831	70666
7	Grand Total	77617	56760	134377

Figure 1.99 The results table organized according to the selected fields shown in Fig. 1.97.

- The table layout can be easily changed by dragging the field buttons on the worksheet. For example, we can move the **Product** into **ROW** and **Salesperson** into **COLUMN** in Fig. 1.99 by dragging a field item into desired location.

	A	B	C	D
1	Year	(All)		
2				
3	Sum of Units Sold	Salesperson		
4	Product	Chen	Rodriguez	Grand Total
5	Crushed Tomato	47782	29835	77617
6	Peeled Tomato	15929	40831	56760
7	Grand Total	63711	70666	134377

Figure 1.100 The results table when the field **Product** is moved into **ROW** and **Salesperson** into **COLUMN** in Fig. 1.97.

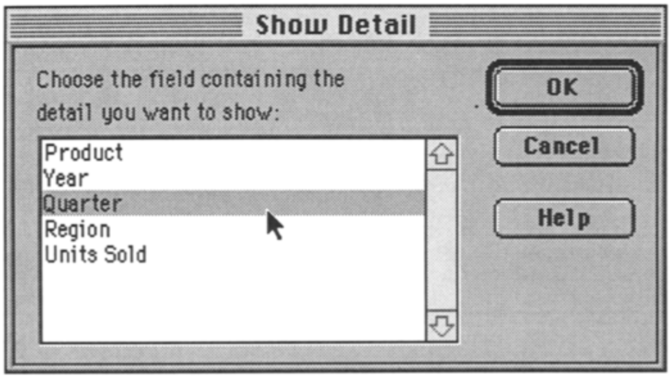


Figure 1.101 Dialog box to choose additional fields for more details.

- The pivot table shown in Fig. 1.100 is a condensed version, you can obtain more background information as desired. For example, let us assume that you wanted to see the units sold by Chen in each quarter in 1995. Double-click in cell B4 (Fig. 1.100) containing the name Chen, a dialog box will open (Fig. 1.101), double-click on **Quarter**. The result will be shown as in Fig. 1.102. Similarly, if you wanted to see the sales by Rodriguez by region, double-click on the cell containing the name Rodriguez. A dialog box will open. Double-click on **Region**, and the result will be as shown in Fig. 1.103.

	A	B	C	D	E	F	G	H
1	Year	(All)						
2								
3	Sum of Units Sold	Salesperson	Quarter					
4		Chen				Chen Total	Rodriguez	Grand Total
5	Product	1	2	3	4			
6	Crushed Tomato	990	16352	1233	29207	47782	29835	77617
7	Peeled Tomato	1223	0	1429	13277	15929	40831	56760
8	Grand Total	2213	16352	2662	42484	63711	70666	134377

Figure 1.102 Expanded information to display sales by quarters for salesperson Ms. Chen.

	A	B	C	D	E	F
1	Year	(All)				
2						
3	Sum of Units Sold	Salesperson	Region			
4		Chen	Rodriguez		Rodriguez Total	Grand Total
5	Product		Pacific Rim	South America		
6	Crushed Tomato	47782	16881	12954	29835	77617
7	Peeled Tomato	15929	13169	27662	40831	56760
8	Grand Total	63711	30050	40616	70666	134377

Figure 1.103 Expanded view of display sales data for salesman Mr. Rodriguez by region.

The example shown in this section illustrates the enormous capabilities of the pivot tables in organizing information.

1.21 Macros

Macros are programs that automate a number of steps involved in calculations into a single or few steps. When worksheets involve a number of repetitive steps, macros are extremely useful in saving time. In this section, we will build a simple macro to illustrate how macros are created and run. For more information on macro building as well as editing already created macros, refer to the owner's manual of Excel.

- Let us create a macro that allows us to draw a border around selected cells and centrally aligns the contents of the cells while changing the text font to Times, size 12, and bold style. The steps are as follows.

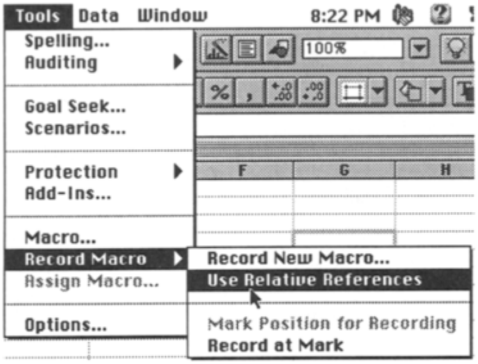


Figure 1.104 Selecting the **Use Relative References** command.

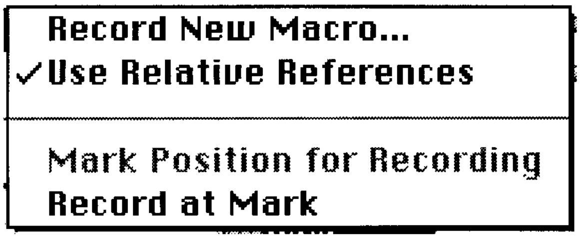


Figure 1.105 Checking to see that the **Use Relative References** command is selected.

- Open a new worksheet expanded to full size.
- Select cell B2.
- Choose the menu items **Tools**, **Record Macro**, **Use Relative References** and release mouse key (Fig. 1.104). We choose **Use Relative References** command so that we can use this macro for any cell or group of cells that we wish in a worksheet. A toggle mark will be displayed next to the **Use Relative References** command (Fig. 1.105).
- Choose the menu items **Tools**, **Record Macro**, **Record New Macro...**. A dialog box will open (Fig. 1.106).
- In **Macro Name,** type the following:
  Highlighter

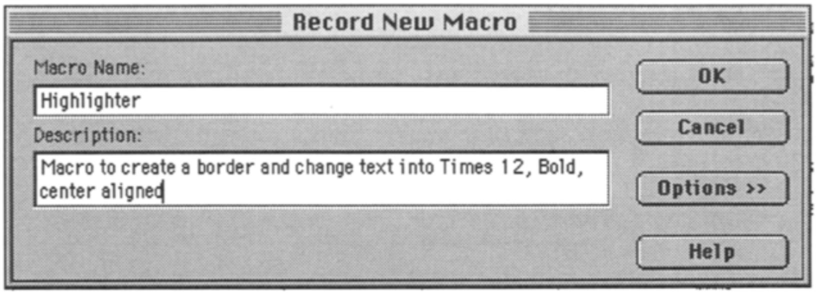


Figure 1.106 A dialog box to enter macro name and description.

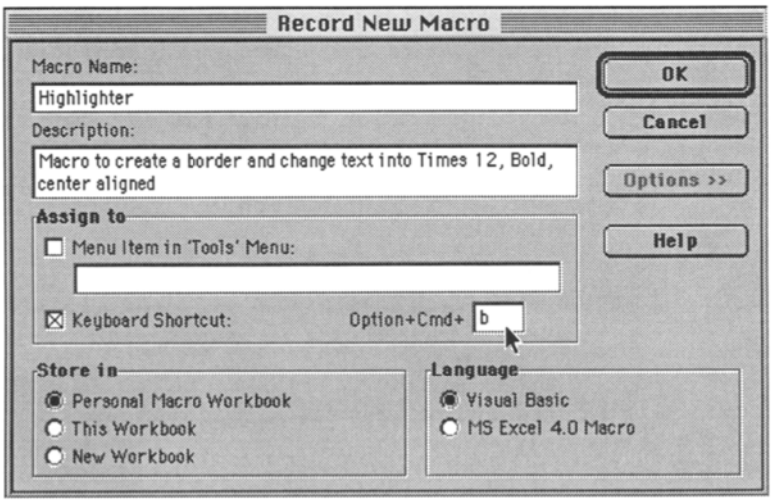
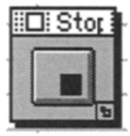


Figure 1.107 Entering shortcut key and selecting **Personal Macro Workbook** in the dialog box.

- The macro name cannot have more than one word. You may combine two or more words using the uppercase letter from each word, for example, **ThreeWordName**
- In **Description**, type the following:

  Macro to create a border and change text into Times 12, Bold, center aligned

- Click on the **Options>>** button. The dialog box will expand as seen in Fig. 1.107.
- Under **Store in**, choose **Personal Macro Workbook**. This step will make the macro available for any workbook where you want to use it.
- In **Assign to**, type **b** in **Option+Command+** edit box. This will give you a keyboard shortcut anytime you want to run the macro.
- Click **OK**.
- A **Float** window with a **Stop** button will appear on the screen. This indicates that the macro recorder is on. Any steps executed will be recorded in the macro.
- Select the tab **Font** (Fig. 1.108). Select font **Times**, font style **Bold,** and size **12**.
- Select the tab **Alignment** (Fig. 1.109). Select **Horizontal, Center**.



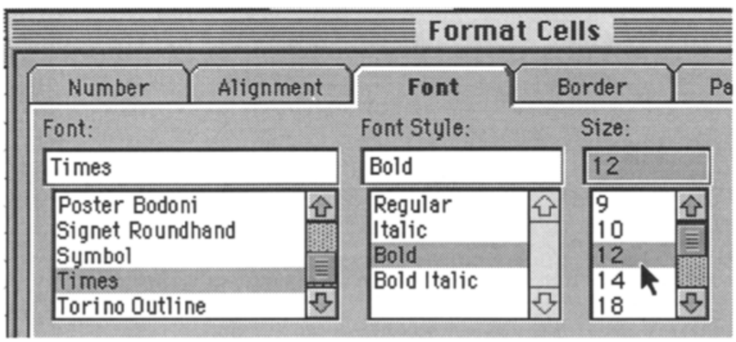


Figure 1.108 Formatting cells with font name, style, and size.

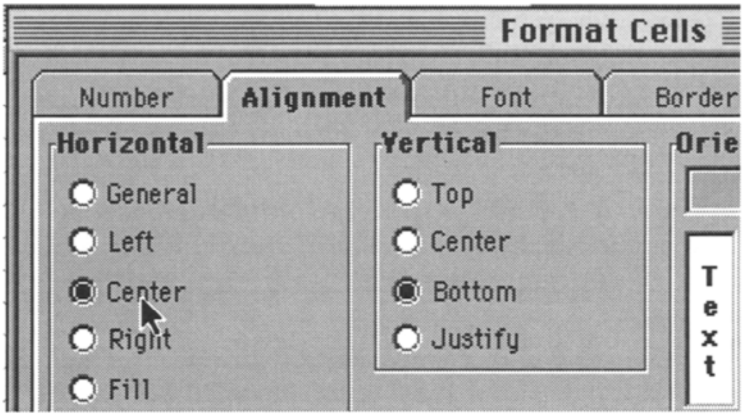


Figure 1.109 Selecting center alignment in dialog box.

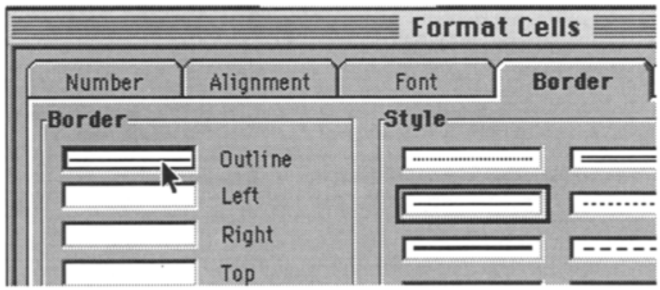


Figure 1.110 Selecting outline border in dialog box.

- Choose the menu commands **Format**, **Cells....** A dialog box will open (Fig. 1.110). Select the tab **Borders**. Select **Outline**.
- Click on the **Stop** button to stop the recorder.
- The macro is now recorded. To run the macro we will first type some text in cells B2:D2 as shown in Fig. 1.111.
- Select cells B2:D2 by dragging on the cells.

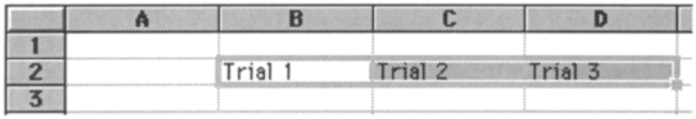


Figure 1.111 Some text labels in cells B2:D2 that need to be highlighted with the macro **Highlighter**.

Figure 1.112 Choosing the **Macro...** command to run a macro.

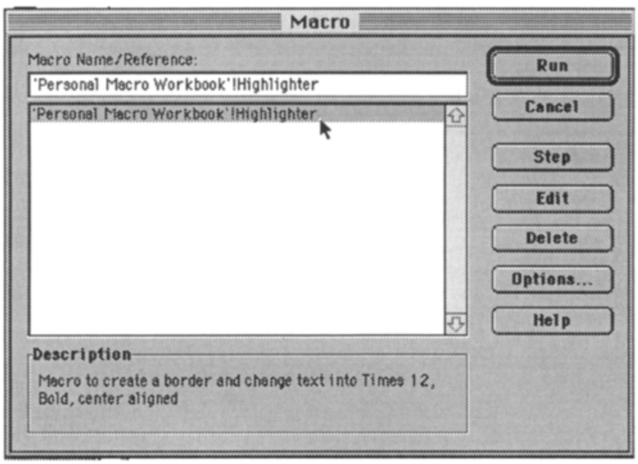


Figure 1.113 A dialog box to select the name of the macro to run

- Choose the menu items **Tools**, **Macro**... (Fig. 1.112). A dialog box will open (Fig. 1.113).

- Double click on **Highlighter.**
- The cell entries will be converted to Times 12, bold, center aligned, and surrounded with a border (Fig. 1.114).

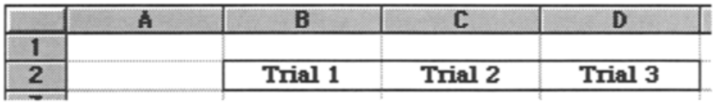


Figure 1.114 The result of running the macro **Highlighter**.

1.22 Database

The database handling capabilities of Excel allow us to convert large worksheets into manageable forms. This feature is especially useful when one is seeking some desired information from worksheets that may have several thousand entries. In this section, we will work with a simple example of conducting search with the database features of Excel. For more complex searches, use the **Help** command or refer to the manual.

In the disk supplied with this text, there is a large worksheet, Foods.xls, containing composition values of 2483 foods. These data were obtained from Watt and Merrill (1975). Some of the data are shown in Fig. 1.115. The composition values are presented per 100 grams of edible portion. We will use the database features of Excel to search for desired information in this worksheet using the following steps:

- Open the worksheet Foods.xls available on the disk.

Foods.xls

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Product (100g)	Water (%)	Food Energy (Calories)	Protein (g)	Fat (g)	Carbohydrate _Total (g)	Carbohydrate _Fiber (g)	Ash (g)	Calcium (mg)	Phosphorus (mg)	Iron (mg)	Sodium (mg)	Potassium (mg)
2	Abalone, raw	75.8	98	18.7	0.5	3.4	0	1.6	37	191	2.4	0	
3	Abalone, canned	80.2	80	16	0.3	2.3	0	1.2	14	128	0	0	
4	Acerola, raw, pulp and skin Barbados-cherry or West Indian cherry	92.3	28	0.4	0.3	6.8	0.4	0.2	12	11	0.2	8	8
5	Acerola juice, raw	94.3	23	0.4	0.3	4.8	0.3	0.2	10	9	0.5	3	
6	Albacore, raw	66.2	177	25.3	7.6	0	0	1.3	26	0	0	40	29
7	Alewife, raw	74.4	127	19.4	4.9	0	0	1.5	0	218	0	0	
8	Alewife, canned solids and liquids	73	141	16.2	8	0	0	3.4	0	0	0	0	
9	Almonds, dried	4.7	598	18.6	54	19.5	2.6	3	234	504	4.7	4	77
10	Almonds, roasted and salted	0.7	627	18.6	58	19.5	2.6	3.5	235	504	4.7	198	77
11	Almond meal partially defatted	7.2	408	39.5	18	28.9	2.3	6.1	424	914	8.5	7	140
12	Amaranth, raw	86.9	36	3.5	0.5	6.5	1.3	2.6	267	67	3.9	0	41

Figure 1.115 A sample of worksheet containing the food composition data.

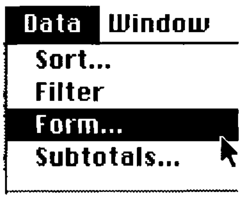


Figure 1.116 Menu items **Data** and **Form...** to convert a worksheet into a database form.

- Choose the menu commands **Data** and **Form...** (Fig. 1.116).
- A database form will be displayed as shown in Fig. 1.117. This form shows the names of fields and corresponding data values. Note that the names of fields are the same as first row entries in the worksheet. In the top right-hand corner there is a counter that tells us that this is the first record among 2478 items. All the composition values from the worksheet for Abalone are displayed in the form.

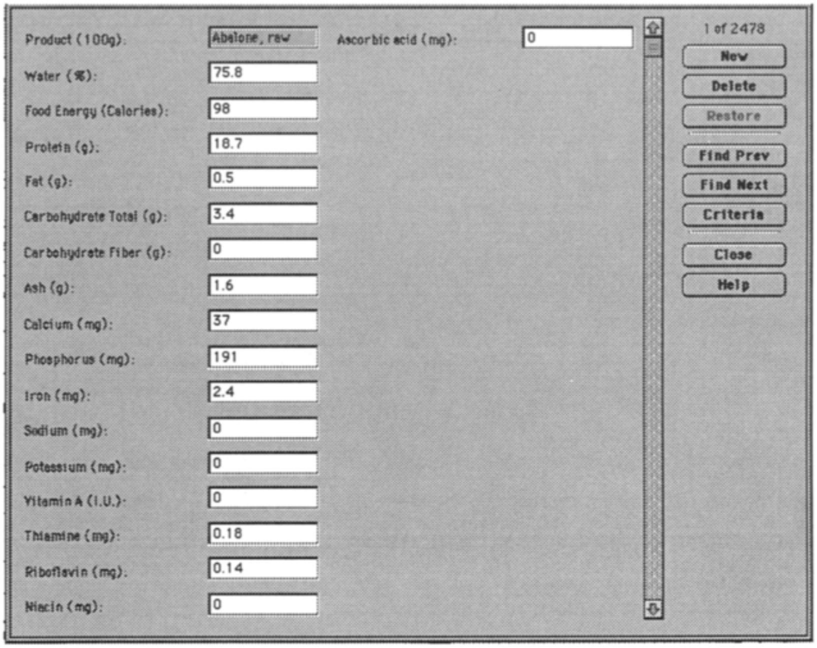


Figure 1.117 A database form obtained for the worksheet containing the food composition data.

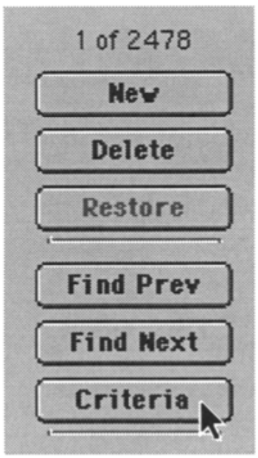


Figure 1.118 Using the **Criteria** command to search for desired information in the database.

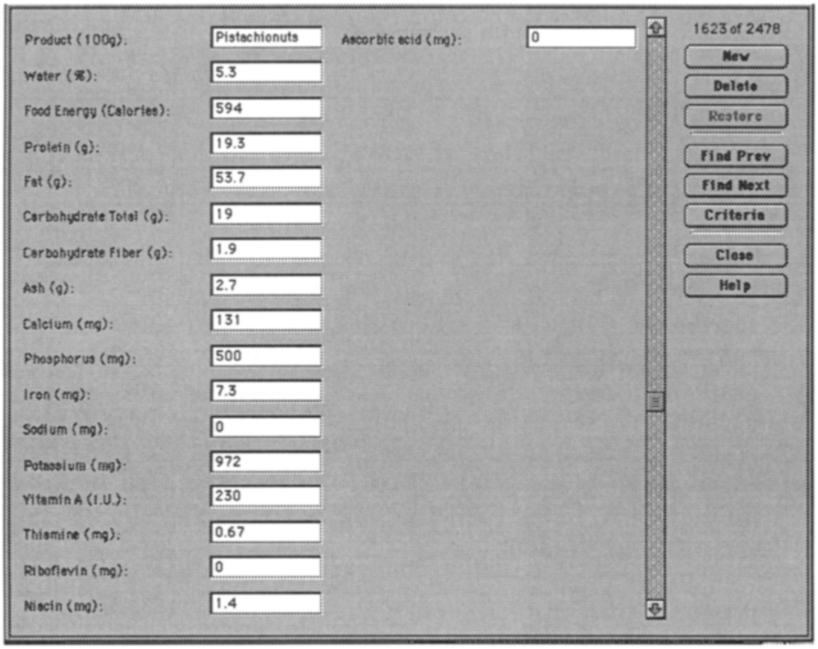


Figure 1.119 Results of searching for **Pistachionuts** in the database.

- In order to conduct a search such as composition for another product, first click on the **Criteria** button as shown in Fig. 1.118.
- An empty form will appear. Type the name **Pistachionuts** in the **Product** field and click **OK.**
- The resulting form containing the property data for **Pistachionuts** will be displayed as shown in Fig. 1.119. This record is number 1623 in 2478 records. If more than one record is found during the search, you may use the **Find Next** and **Find Prev** buttons to scroll to the desired record.

In summary, the conversion of a worksheet into a database form is quite simple. It is important to properly list the field names in the first row of the worksheet. Excel then automatically converts the worksheet into a database form. For more advanced searches see the manual or use the **Help** feature of Excel.

1.23 Goal Seek

Goal Seek is an extremely useful command available in Excel. It allows you to seek a desired answer by automatically changing the input values. Thus you can quickly determine what input value will give you the required answer.

Let us examine this command using an example. A food sample has an initial weight of 35.65 g. It is dried in an oven to a final weight of 15.86 g. We want to first determine the moisture content and then find out what should be the final weight if the desired moisture content is 80%.

We use the given information in a worksheet and calculate the moisture content. As seen in Fig. 1.120, the given data are entered in cells B1 and B2. A formula for moisture content is entered in cell B3 as follows:

- In cell B3, type the following formula:

  =(B1-B2)*100/B1

  This formula calculates percent moisture content on a wet basis.
- The result of this calculation is seen in cell B3 as 55.51%

Next, we will use the **Goal Seek** command to determine what should be the final weight of a sample if the desired moisture content is 80%.

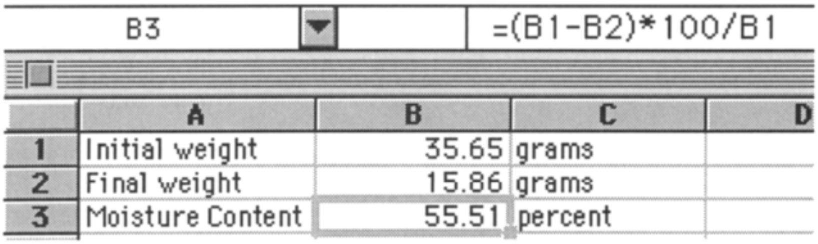


Figure 1.120 Enter data and formula to calculate moisture content

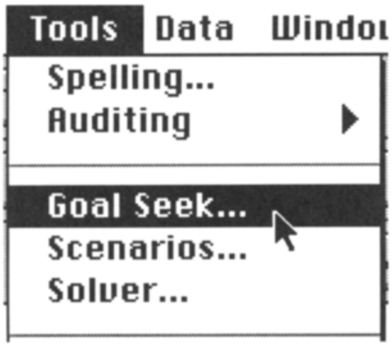


Figure 1.121 Select **Goal Seek...** from the **Tools** menu

From the menu item **Tools**, select **Goal Seek...** (Fig. 1.121). A dialog box will open as shown in Fig. 1.122.

Since the cursor was previously in cell B3, the **Set cell:** already contains the address $B$3. This address may be changed if required by either typing directly in the edit box or clicking on the appropriate cell in the worksheet. This address should be of the cell that contains a formula, the result of which you want to change to some other value.

Type the desired result, in our case 80, in the edit box with a title **To value:**. The cell address containing the quantity that

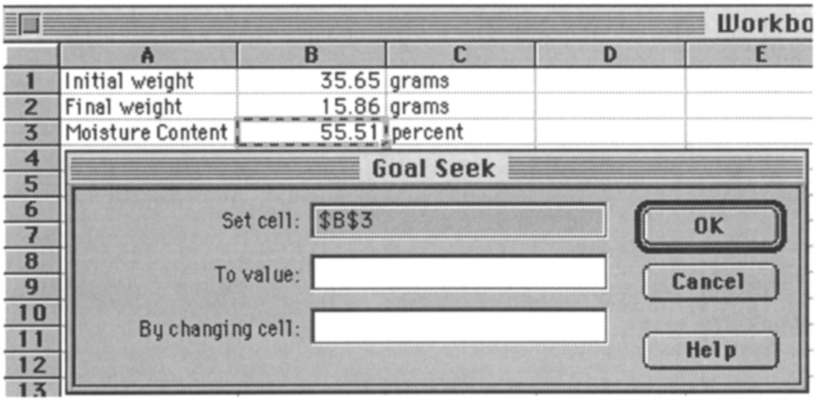


Figure 1.122 A dialog box to enter values and cell addresses for **Goal Seek** calculations.

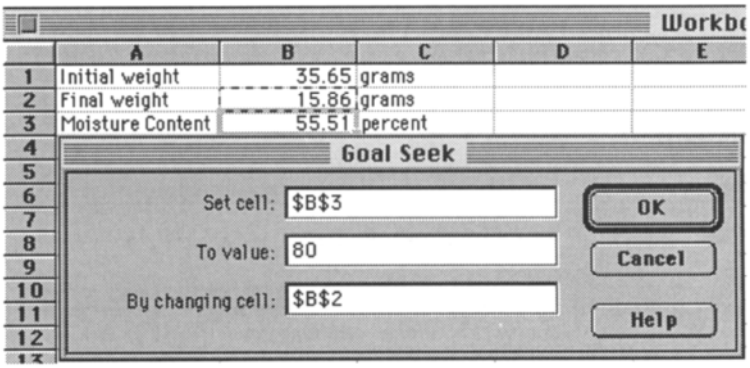


Figure 1.123 The **Goal Seek** dialog box with required information typed in edit boxes

must be changed to yield the desired result is typed in the edit box titled **By changing cell:**. For our example, type $B$2 as shown in Fig. 1.123 (or first select the edit box and then click on cell B2 in the worksheet). Click **OK**.

A dialog box **Goal Seek Status** (Fig. 1.124) will show the iterations to arrive at the final result. Once Excel finds a solution it will indicate both the target value and the current value obtained from iterations.

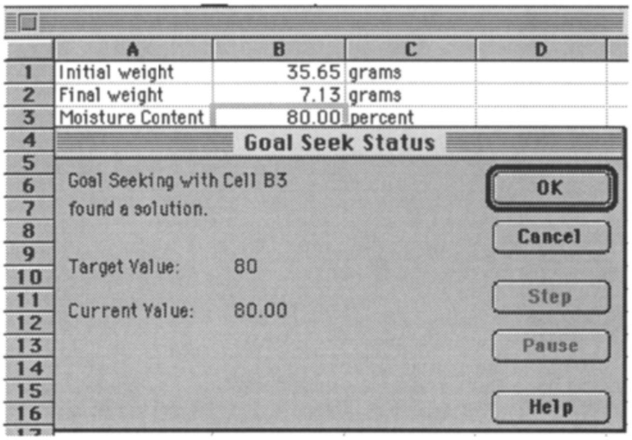


Figure 1.124 A dialog box showing the status of **Goal Seek** calculations and the final results in the worksheet.

As seen in Fig. 1.124, the final results are displayed in the worksheet. For our example, a moisture content of 80% will be obtained when the final weight of the sample is reduced to 7.13 g.

We will see additional applications of the **Goal Seek** command in later chapters in this book.

1.24 Use of the Data Analysis Command in Calculations

The **Data Analysis...** command offers several advanced features for calculations. First you have to make sure that this command is available to you. If the **Data Analysis...** command does not appear in the **Tools** menu, then choose menu commands **Tools**, **Add-Ins...** (Fig. 1.125). A dialog box will open as shown in Fig. 1.126. Select the check box for **Analysis ToolPak**. Click **OK**.

Figure 1.125 Menu commands **Tools** and **Add-Ins...**.

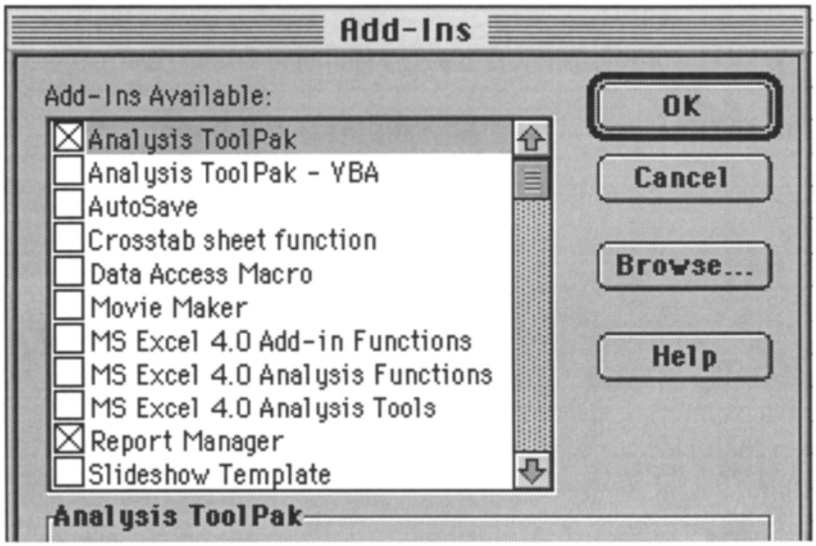


Figure 1.126 Dialog box to select **Analysis ToolPak**.

After the **Analysis ToolPak** is added into your application, you should see the **Data Analysis...** command under the **Tools** menu as shown in Fig. 1.127.

Figure 1.127 Using the **Data Analysis...** command.

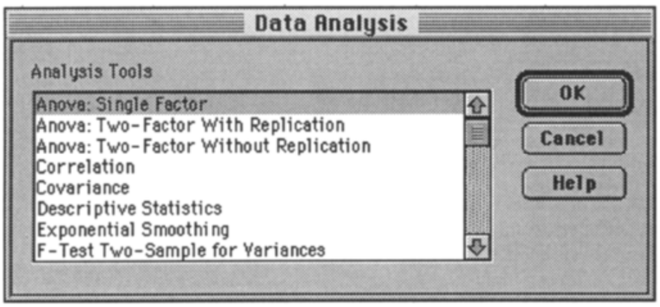


Figure 1.128 A dialog box for the **Data Analysis...** command.

Following steps should be used for any tools needed from the **Data Analysis...** command.

- From the **Tools** menu, select **Data Analysis....** A dialog box will open as shown in Fig. 1.128.
- Select any appropriate analysis tool from the list box. Click **OK**.

- Another dialog box will open for you to type the input range, the output range, and any other desired options. Examples of using the **Data Analysis** command are presented later in this book.

Chapter TWO

Chemical Kinetics in Food Processing

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2.1 Determining Rate Constants of Zero-Order Reactions

Chemical reactions in foods that follow zero-order kinetics exhibit a constant rate of change in the concentration of a reactant or a product. When the concentration is plotted against time on an ordinary graph paper, one obtains a straight line. The slope of the straight line gives the zero-order rate constant. In this example, we will determine the rate constant for a zero-order reaction.

Problem Statement:

In a chemical reaction, following concentration values of the reactant were observed as a function of time.

Time (s)	Concentration (mg/L)
0	131
60	110
120	92
180	71
240	49
300	29

Determine the rate constant for this reaction.

Approach:

First, we will assume that the kinetics of this reaction is zero order. Therefore, a plot of concentration against time should yield a straight line. We can check the linearity of the plot by determining the r^2 value from linear regression. If the linearity check is validated, then we can determine the slope of the concentration vs time data. The slope gives the zero-order rate constant.

> After entering the number or text label, you click the **Return** key, the information is entered and the pointer moves one cell down.

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cells A1:B10, type the text labels and data values as shown in Fig. 2.1.
3. In cells A11:A14, type the text labels as shown in Fig. 2.1.
4. In cell B11, type the following formula:
   =RSQ(B3:B8,A3:A8)
5. In cell B12, type the following formula:
   =SLOPE(B3:B8,A3:A8)
6. In cell B14, type the following formula:
   =ABS(B12)
7. Select cells A2:B8. Click on the **ChartWizard** button, , and create an **XY (Scatter)** chart, as shown in Fig. 2.2.

Discussion:

The high r^2 value (0.9994) indicates that the kinetics of the reaction follows zero order. The slope gives us the zero-order rate constant. Since the concentration of the reactant is decreasing, the slope is negative; therefore, we use the absolute value to get the result for the rate constant.

Worksheet Comments:

In this worksheet we used functions *RSQ(), SLOPE()*, and *ABS()*. We created an **XY (Scatter)** chart to plot concentration against time.

	A	B
1	Given:	
2	Time (s)	Concentration (mg/L)
3	0	131
4	60	110
5	120	92
6	180	71
7	240	49
8	300	29
9		
10	Solution:	
11	rsquare =	0.9994
12	Slope =	-0.34
13		
14	Zero Order Constant (mg/L.s)	0.34

Figure 2.1 A worksheet for data given in Example 2.1.

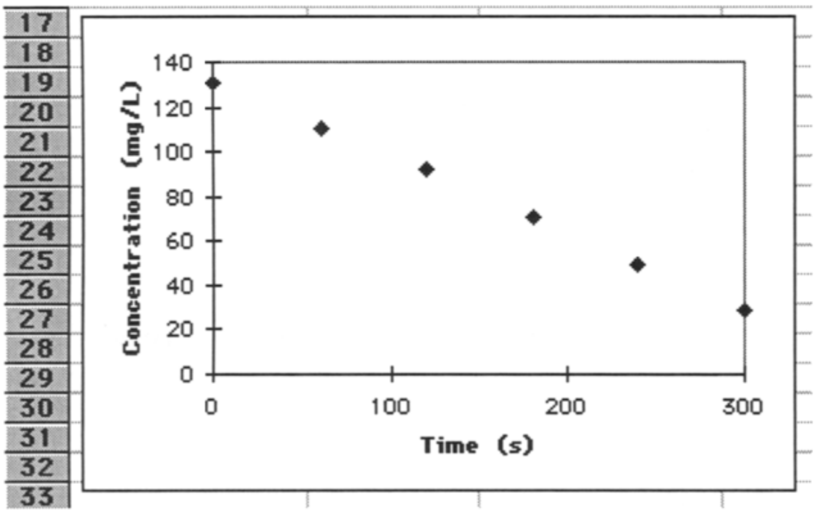

Figure 2.2 A plot of concentration vs time data for a zero-order reaction.

2.2 First-Order Rate Constants and Half-Life of Reactions

Many chemical reactions occurring during food processing and storage follow first-order kinetics. If we plot the concentration of a reactant against time we get an exponential type plot. The rate constant for a first-order reaction may be obtained by first taking the natural logarithm of concentrations and then plotting against time on an ordinary scale. If the reaction follows first-order kinetics, then the plot of natural logarithm of concentration against time should yield a straight line. The slope of this straight line gives the first-order rate constant.

Problem Statement:

Following data were obtained for the concentration of a reactant as a function of time.

Time (s)	Concentration (mg/L)
0	330.0
100	148.3
200	66.6
300	29.9
400	13.5
500	6.0

Determine the kinetic order, the rate constant, and the half-life of the reaction.

Approach:

We will first determine the r^2 value for linear regression between concentration vs time data. If the r^2 value is less than 1, it would indicate that the reaction is not a zero-order reaction. The next step will involve taking natural logarithm of the concentrations, and determining r^2 of the natural logarithm(concentration) vs time data. If a high r^2 is obtained, that will signify a linear relationship. The slope of the straight line will be determined as the first-order rate constant. The relevant expressions for a first order reaction where a reactant A undergoes change from initial concentration of A_0 is

$$A = A_0 e^{-kt} ,$$

where A is the concentration of a reactant or a product, A_0 is the initial concentration of a reactant or a product, k is the first-order rate constant, and t is the time.

The half life of the reaction will be obtained from the following expression:

$$t_{halflife} = \frac{0.693}{k} .$$

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cells A1:B10, type the text labels and data values as shown in Fig. 2.3.
3. In cell C2, type **ln(Concentration)**.
4. In cell C3, type the following formula: **=LN(B3)**
5. Copy the contents of cell C3 into cells C4:C8.
6. In cells B11:B15, type the text labels as shown in Fig. 2.3.
7. In cell C11, type the following formula: **=RSQ(B3:B8,A3:A8)**
8. In cell C12, type the following formula: **=RSQ(C3:C8,A3:A8)**
9. In cell C13, type the following formula: **=SLOPE(C3:C8, A3:A8)**
10. In cell C14, type the following formula: **=ABS(C13)**
11. In cell C15, type the following formula: **=0.693/C14**

> Any number you type into a cell is aligned to the right, while any text entered in a cell is aligned to the left. You can later change the alignment using the menu commands **Format, Alignment**.

12. Reduce the significant number of digits in cell C15 to one, using the button **Decrease Decimal** 

available in the **Format** tool bar.
13. Select cells A3:B8. Click on the **ChartWizard** button,  and create an **XY (Scatter)** chart, as shown in Fig. 2.4.
14. Select cells A3:A8, then keeping **Command** (**Ctrl** in Windows) key pressed, select cells C3:C8. This procedure allows selection of non-contiguous columns. Use **ChartWizard** to create an **XY (Scatter)** chart as shown in Fig. 2.5.

Discussion:

The r^2 value for a linear regression between concentration and time data showed a poor correlation, indicating that the kinetics of this reaction was not zero order. Therefore, the natural logarithms of the concentration values were calculated and the slope was determined. The half-life was calculated from the value obtained for the first-order rate constant.

Worksheet Comments:

In this worksheet we used the functions *RSQ(), SLOPE(),* and *LN().* We created **XY (Scatter)** type charts.

	A	B	C
1	Given:		
2	Time (s)	Concentration (mg/L)	ln(Concentration)
3	0	330.0	5.7991
4	100	148.3	4.9992
5	200	66.6	4.1987
6	300	29.9	3.3979
7	400	13.5	2.6027
8	500	6.0	1.7918
9			
10	Solution:		
11		rsquare	0.782
12		rsquare (first order)	1.000
13		Slope =	-0.008
14		First Order Constant	0.008
15		Half Life (s)	86.5

Figure 2.3 A worksheet for data given in Example 2.2.

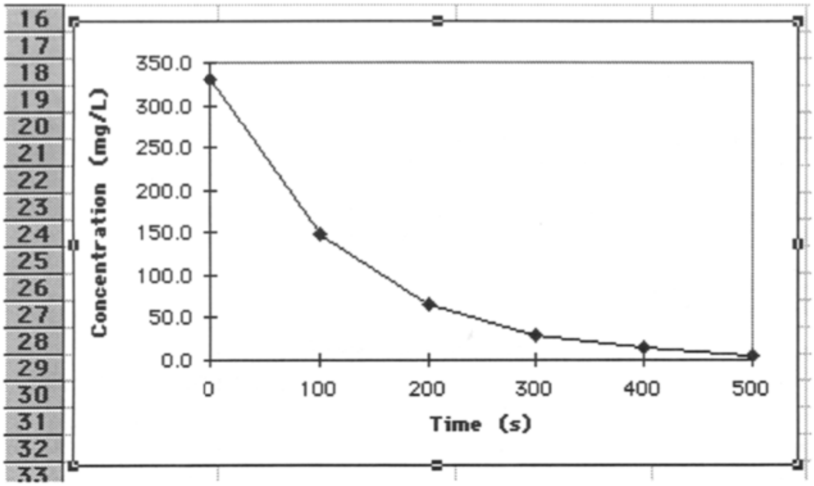

Figure 2.4 A plot of concentration vs time data for a first-order reaction.

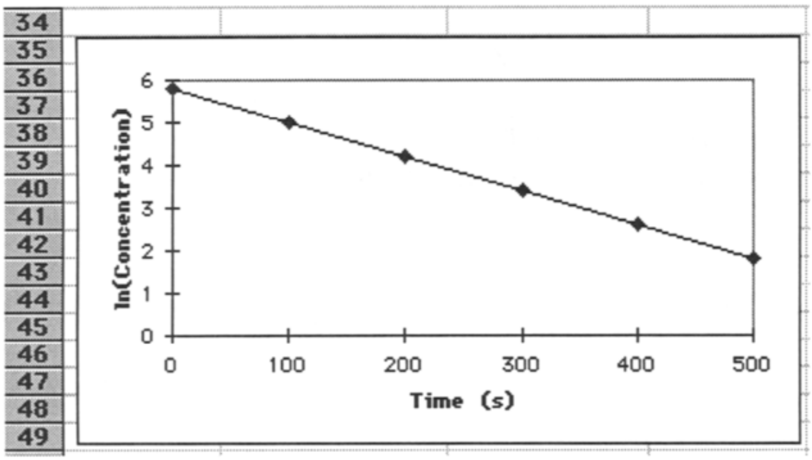

Figure 2.5 A plot of ln(concentration) vs time data for a first-order reaction.

2.3 Determining Energy of Activation of Vitamin Degradation during Food Storage

Kinetic analysis of vitamin degradation involves determining concentrations of the vitamin at selected storage times. The rate constants are determined from the concentration of vitamin vs time data. Storage studies conducted at different temperatures yield rate constants for each temperature. The rate constants vs temperature data are often analyzed using the Arrhenius equation. In this example, we will develop a worksheet to determine the activation energy. The activation energy will be used to determine the percent loss of vitamin at desired storage times.

Problem Statement:

In a study conducted to determine the loss of riboflavin during storage of milk, the following data were obtained. The rate constants were obtained assuming first-order rate kinetics.

Temperature (°C)	Rate Constant (1/s)
1.7	0.001652
4.4	0.002272
10	0.003115

Determine the activation energy and percent loss of riboflavin at a storage temperature of 4.4°C and at 0, 24, 48, and 72 hr of storage period.

Approach:

The data in this example are obtained for riboflavin loss in milk stored in blow molded polyethylene bottles under 300 footcandles light intensity (Singh *et al.* 1975). The Arrhenius equation that relates rate constant as a function of temperature is as follows:

$$k = Ae^{-E_a / RT} \ .$$

Where k is the first order rate constant, E_a is the activation energy, R is the gas constant, and T is the absolute temperature (K).

The percent loss of vitamin as a function of time, t, is expressed as:

$$Percent\ Loss = (1 - e^{-kt}) \times 100 \ .$$

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cells A1:B8, enter text labels and data values as shown in Fig. 2.6.
3. In cell A9, type the following formula:
   =1/(273+A3)
4. In cell B9, type the following formula:
   =LN(B3)
5. Copy contents of cell A9 into cells A10:A11
6. Copy contents of cell B9 into cells B10:B11
7. In cell A12: A13, type text labels as shown in Fig. 2.6
8. In cell B12, type the following formula:
   =SLOPE(B9:B11,A9:A11)
9. In cell B13, type the following formula:
   =1.98717*B12
10. In cell A16:B16, type the text labels as shown in Fig. 2.6
11. In cells A17:A21, enter a series from 0 to 96 with an interval of 24 using the **AutoFill** command.
12. In cell B17, type the following formula:
    =(1-EXP(-$B$4*A17))*100
13. Copy the contents of cell B17 into cells B18:B21

When editing cells, you can convert an ordinary reference to a cell into an absolute reference by first clicking the insertion point to the cell address in the formula bar then pressing **Command+T** (**F4** in Windows).

14. Select cells A9:B11. Click on the **ChartWizard** button,  and create an **XY (Scatter)** chart, as shown in Fig. 2.7.

Discussion:

The activation energy is calculated as 11,369 kcal/mole. The percent loss of vitamin at different storage time is shown in the worksheet. This worksheet was developed for first-order kinetics. Similar type of formulas may be written for zero-order kinetics.

Worksheet Comments:

In this worksheet, we needed to determine the slope of a straight line on a semilog plot, instead we took natural logarithm of rate constants and determined the slope of straight line between the natural logarithm of rate constant vs 1/absolute temperature using the function *SLOPE()*.

	A	B
1	Given:	
2	Temperature (C)	Rate Constant (1/s)
3	1.7	0.001652
4	4.4	0.002272
5	10	0.003115
6		
7	Solution:	
8	1/Temperature (K^-1)	ln(k)
9	0.0036403	-6.4058
10	0.0036049	-6.0871
11	0.0035336	-5.7715
12	slope=	-5721.6
13	slope*1.98717=	-11369.7
14		
15		
16	Time hours	Percent Loss
17	0	0.0
18	24	5.3
19	48	10.3
20	72	15.1
21	96	19.6

Figure 2.6 A worksheet for data given in Example 2.3.

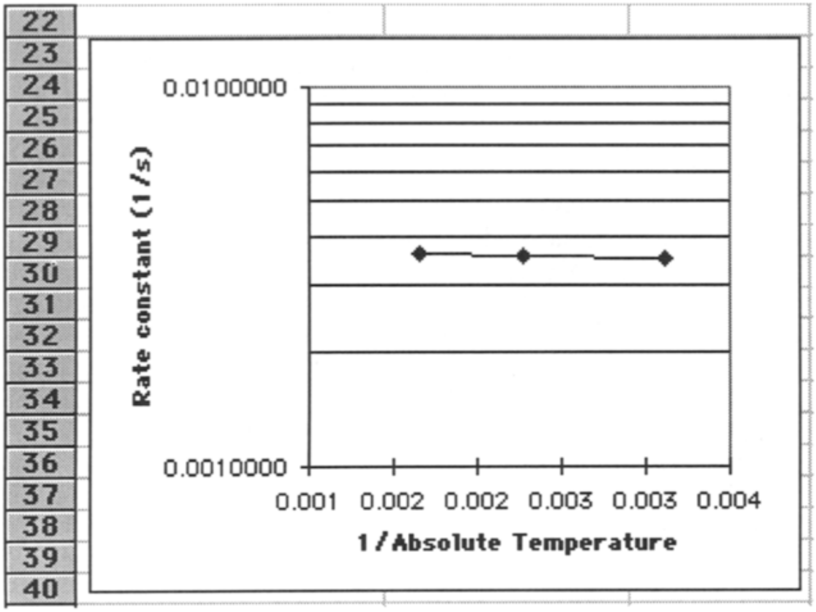

Figure 2.7 An Arrhenius plot of rate constant vs 1/absolute temperature.

2.4 Rates of Enzyme-Catalyzed Reactions

In enzyme-catalyzed reactions, two important kinetic parameters are determined, namely, the maximum velocity, V_{max}, and K_m,the Michaelis–Menten constant. Linear plots between velocity and concentration data are drawn to obtain V_{max} and K_m as discussed by Whitaker (1994). The most common method is the Lineweaver–Burk method, the other two are the Augustinsson method and the Eadie–Hofstee method. In this worksheet, we will analyze a set of data on concentrations and velocities to obtain V_{max} and K_m using all three methods.

Problem Statement:

Using the following data given by Whitaker (1994, Table 2, p. 175), determine K_m and V_{max} with Lineweaver-Burk method, Augustinsson method and Eadie–Hofstee method.

Initial Substrate Concentration A_o (M)	Initial Velocity v_o (M/s)
2.00E-05	1.67E-06
4.00E-05	2.86E-06
6.00E-05	3.70E-06
1.00E-04	4.95E-06
2.00E-04	6.50E-06
3.00E-04	7.40E-06
5.00E-04	8.14E-06

Approach:

The equation describing the Michaelis–Menten kinetics is as follows:

$$v_o = \frac{V_{max}(A_o)}{K_m + (A_o)} \ .$$

This equation is of a right hyperbola. For simplicity in calculations, this equation has been converted into linear forms as follows:

Lineweaver–Burk method,

$$\frac{1}{v_o} = \frac{K_m}{V_{max}(A_o)} + \frac{1}{V_{max}} \ .$$

Augustinsson Method,

$$\frac{(A_o)}{v_o} = \frac{K_m}{V_{max}} + \frac{(A_o)}{V_{max}} \ .$$

Eadie–Hofstee Method,

$$v_o = V_{max} - \frac{v_o}{(A_o)} K_m \ .$$

We will create columns of data for A_0, v_0, $1/A_0$, $1/v_0$, A_0/v_0 and v_0/A_0 that will be used to calculate the slopes and intercepts for each of the three preceding linear equations.

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cells A1:B9, type the text labels and data values as shown in Fig. 2.8.
3. In cell C3, type the following formula:
   =1/A3
4. In cell D3, type the following formula:
   =1/B3
5. In cell E3, type the following formula:
   =A3/B3
6. In cell F3, type the following formula:
   =1/E3

> When parentheses are typed, Excel helps in making the corresponding parentheses bold. If the number of parentheses in a formula do not match, Excel displays an error message.

7. Copy the contents of cells C3:F3, into cells C4:F9 using the **AutoFill** command.
8. In cells A11:F11, A12:A15, C12:C15, and E12:E15 type the text labels as shown in Fig. 2.8.
9. In cell B12, type the following formula: **=INTERCEPT(D3:D9,C3:C9)**
10. In cell B13, type the following formula: **=SLOPE(D3:D9,C3:C9)**
11. In cell B14, type the following formula: **=1/B12**
12. In cell B15, type the following formula: **=B14*B13**
13. In cell D12, type the following formula: **=INTERCEPT(E3:E9,A3:A9)**
14. In cell D13, type the following formula: **=SLOPE(E3:E9,A3:A9)**
15. In cell D14, type the following formula: **=1/D13**
16. In cell D15, type the following formula: **=D12*D14**
17. In cell F12, type the following formula: **=INTERCEPT(B3:B9,F3:F9)**
18. In cell F13, type the following formula: **=SLOPE(B3:B9,F3:F9)**
19. In cell F14, type the following formula: **=F12**
20. In cell F15, type the following formula: **=ABS(F13)**
21. Using cells C3:C9 and D3:D9, create an **XY (Scatter)** chart as shown in Fig. 2.9.
22. When the chart is active, double-click on the *x*-axis, a dialog box will open, select the tab **Scale**, in the edit box **Minimum**, type **-10000**. Click **OK**. Use the toolbar **Drawing**, and draw a straight line extending the linear portion of the line to intercept *x*-axis on the negative side of *x*-axis. This plot is called the Lineweaver-Burk Plot, as shown in Fig. 2.9.

Discussion:

As seen from the results, the K_m and V_{max} values obtained from the three methods are very close. This linearization process makes it convenient to obtain the two unknown quantities.

Worksheet Comments:

In this worksheet we used the functions *INTERCEPT()* and *SLOPE()*. We created an **XY (Scatter)** chart and used the drawing capability to extend a straight line.

	A	B	C	D	E	F
1	Given:					
2	Ao (M)	vo (M/s)	1/Ao (1/M)	1/vo (s/M)	Ao/vo (s)	vo/Ao (1/s)
3	2.00E-05	1.67E-06	50000.0	598802.4	11.9760	0.0835
4	4.00E-05	2.86E-06	25000.0	349650.3	13.9860	0.0715
5	6.00E-05	3.70E-06	16666.7	270270.3	16.2162	0.0617
6	1.00E-04	4.95E-06	10000.0	202020.2	20.2020	0.0495
7	2.00E-04	6.50E-06	5000.0	153846.2	30.7692	0.0325
8	3.00E-04	7.40E-06	3333.3	135135.1	40.5405	0.0247
9	5.00E-04	8.14E-06	2000.0	122850.1	61.4251	0.0163
10						
11	Lineweaver-Burk Method		Augustinsson Method		Eadie-Hofstee Method	
12	Intercept	1.03E+05	Intercept	9.95E+00	Intercept	9.71E-06
13	Slope	9.91E+00	Slope	1.03E+05	Slope	-9.64E-05
14	Vmax (M/s)	9.69E-06	Vmax (M/s)	9.72E-06	Vmax (M/s)	9.71E-06
15	Km (M)	9.60E-05	Km (M)	9.68E-05	Km (M)	9.64E-05

Figure 2.8 A worksheet for data given in Example 2.4.

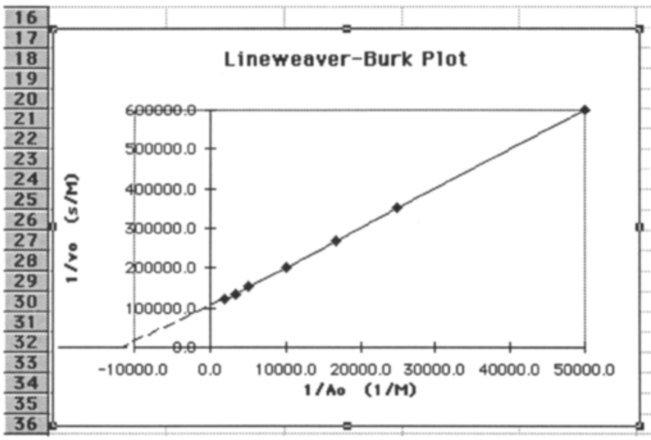

Figure 2.9 A Lineweaver–Burk plot for an enzyme-catalyzed reaction.

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Chapter THREE

Microbial Destruction in Thermal Processing of Foods

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3.1 Determining Decimal Reduction Time from Microbial Survival Data

In thermal processing, heat is applied to foods to kill microorganisms. The number of surviving microorganisms, after selected heating durations, are determined to obtain the decimal reduction time, commonly called the "*D*-value." The *D*-value is the time required to reduce the population of a microbe by 90%. Since the microbial destruction is considered to be exponential, the number of surviving microorganisms plotted against time on semilog coordinates yields a straight line. The time required to traverse a one-log cycle gives the *D*-value because one log cycle refers to a 90% change. In this example, we will use a worksheet to determine the *D*-value from experimental data collected on the number of surviving microorganisms after different periods of heating.

Problem Statement:

The following survivor data were obtained when heat was used to kill a microorganism. Determine the *D*-value.

Time (min)	Number of Survivors
0	2000
5	1100
10	750
20	275
30	90
40	32
50	11
60	4

Approach:

First, we will determine the log of surviving microorganisms at each time. Then, from a plot of the log of survivors vs time, we will determine the slope of the straight line. The inverse of the slope will give us the *D*-value.
The formula to calculate *D*-value is given as Equation 5.2, p. 226, in Singh and Heldman (1993),

$$D = \frac{t}{\log N_o - \log N},$$

where t is time for reducing the microbial population by 90%, s; N_o and N are microbial populations before and after one log cycle reduction. Thus, the denominator will be 1 and t will equal the *D*-value.

Programming the Worksheet:

> The contents of a cell may be cleared by first clicking on it to make it active, then pressing the **Delete** key and pressing the **Return** or **Enter** keys.

1. In cells A1:C2 and A3:B10, type the text labels and data values as shown in Fig. 3.1.
2. In cell C3, type the following formula:
   =LOG(B3)
3. Copy the contents of cell C3 into cells C4:C10 using the **AutoFill** command.
4. In cells A12:A14, type the text labels as shown in Fig. 3.1.
5. In cell B13, type the following formula:
   =SLOPE(C3:C10,A3:A10)
6. In cell B14, type the following formula:
   =ABS(1/B13)
7. The result will be displayed in cell B14.
8. Using **ChartWizard** and data from cells A3:A10 and C3:C10, create a plot of log(number of survivors) vs time as shown in Fig. 3.2.

Discussion:

In this worksheet, we obtained the *D*-value as an inverse of the slope of a straight line plot of survivor curve on a log scale. From the chart, Fig. 3.2, we can observe that one log cycle is traversed in 22 min.

Worksheet Comments:

In this worksheet we used the functions *LOG(), SLOPE(),* and *ABS().* We used the ABS() function because the slope for a microbial destruction line will be negative, but we require a positive value for *D* expressed in units of time.

	A	B	C
1	Given:		
2	Time (min)	Survivors	log(Survivors)
3	0	2000	3.30103
4	5	1100	3.041
5	10	750	2.875
6	20	275	2.439
7	30	90	1.954
8	40	32	1.505
9	50	11	1.041
10	60	4	0.602
11			
12	Solution:		
13	Slope	-0.045	
14	D value (min)	22.22	

Figure 3.1 A worksheet for data given in Example 3.1.

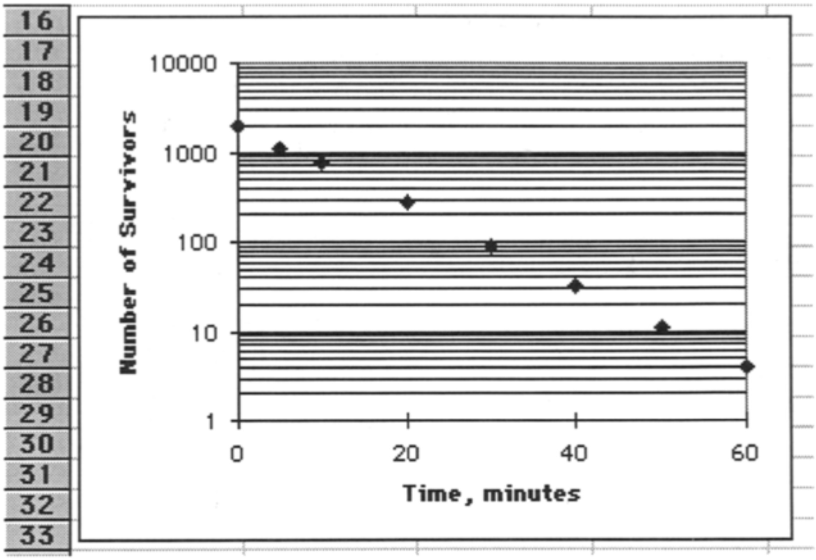


Figure 3.2 A plot of number of survivors vs heating time.

3.2 Thermal Resistance Factor, z-Value, in Thermal Processing of Foods

The effect of temperature on the rate of microbial destruction is expressed by the thermal resistance factor, commonly called the z-value. The z-value is a unique value for each microorganism. Experiments involving thermal resistance of a bacteria involve first determining the data on surviving microbes at different temperatures. These data at each temperature are analyzed to obtain the D-values. The D-values are then plotted against temperature on a semilog paper. This plot yields a straight line, and the z-value is obtained from its slope.

Problem Statement:

The following data on the number of surviving microorganisms at different times of heating were obtained from a series of experiments conducted at different temperatures. From these data, calculate the z-value.

Number of Survivors
Temperature (°C)

Time	120	122	124	126	128
0	1.00E+07	1.00E+07	1.00E+07	1.00E+07	1.00E+07
2	6800000	5440000	3800000	2165000	887000
4	4640000	2960000	1450000	470000	78800
6	3160000	1610000	550000	101500	7000
8	2150000	877000	210000	22000	620
10	1460000	477800	80000	4700	55

Approach:

We will first determine the D-value for each temperature. Then we will determine the z-value from D-values. An expression for calculating z-value is given by Singh and Heldman (1993) as Equation 5.4, p. 229, as follows:

$$z = \frac{T_2 - T_1}{\log D_{T_1} - \log D_{T_2}} \quad .$$

Where T_1 and T_2 correspond to temperatures before and after one log cycle reduction of D values from D_{T1} to D_{T2}

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cells A1:J2, type the text labels and data values as shown in Fig. 3.3.
3. In cells A3:A8, create a series from 0 to 10 with an increment of 2 using the **AutoFill** command.
4. In cells B3:B8, D3:D8, F3:F8, H3:H8 and J3:J8, type the data values as shown in Fig. 3.3.
5. In cell C3 type the following formula:
   =LOG(B3)
6. Copy the contents of cell C3 into cells C4:C8 using the **AutoFill** command.
7. In cell E3, type the following formula:
   =LOG(D3)
8. Copy the contents of cell E3 into cells E4:E8 using the **AutoFill** command.
9. In cell G3, type the following formula:
   =LOG(F3)
10. Copy the contents of cell G3 into cells G4:G8 using the **AutoFill** command.
11. In cell I3, type the following formula:
    =LOG(H3)
12. Copy the contents of cell I3 into cells I4:I8 using the **AutoFill** command.
13. In cell K3, type the following formula:
    =LOG(J3)
14. Copy the contents of cell K3 into cells K4:K8 using the **AutoFill** command.
15. In cells A9:B14. type the text labels as shown in Fig. 3.3.
16. In cell C9, type the following formula:
    =SLOPE(C3:C8,$A$3:$A$8)

> To delete a row or a column, first click in the row or column heading, then press **Command+K** (**Ctrl+-** in Windows).

17. Copy the contents of cell C9 into cells E9, G9, I9, and K9.
18. In cell C10, type the following formula:
    =ABS(1/C9)
19. Copy the contents of cell C10 into cells E10, G10, I10, and K10.
20. In cell C11, type the following formula:
    =LOG(C10)
21. Copy the contents of cell C11 into cells E11, G11, I11, and K11.
22. In cell C13, type the following formula:
    =SLOPE(C11:K11,B2:J2)
23. In cell C14, type the following formula:
    =ABS(1/C13)
24. The result will be shown in cell C14.
25. Using **ChartWizard** and data from cells B2: J2 and C11: K11, create an **XY (Scatter)** chart as shown in Fig. 3.4. Use the **Drawing** toolbar buttons  and  to draw the arrows to identify the locations where the plot intersects the log cycles.

When using the fill handle to copy cells into another area, any information in the destination area where cells are pasted will be overwritten.

Discussion:

In this worksheet, we used the microbe survival data to obtain the *D*-values at each of the five temperatures, then we used the log(*D*-values) vs temperature data to obtain the slope of a straight line. The inverse of the slope gave us the *z*-value.

Worksheet Comments:

In this worksheet we used functions *LOG(), SLOPE(),* and *ABS()*. We created a semilog plot and used chart drawing tools.

You can change the width or height of more than one column or row by selecting the desired rows or columns and dragging the border of any one of the selected rows or columns.

	A	B	C	D	E	F	G	H	I	J	K
1	Given:										
2	time	120		122		124		126		128	
3	0	1.00E+07	7.00	1.00E+07	7	1.00E+07	7	1.00E+07	7	1.00E+07	7
4	2	6800000	6.83	5440000	6.736	3800000	6.580	2165000	6.335	887000	5.948
5	4	4640000	6.67	2960000	6.471	1450000	6.161	470000	5.672	78800	4.897
6	6	3160000	6.50	1610000	6.207	550000	5.740	101500	5.006	7000	3.845
7	8	2150000	6.33	877000	5.943	210000	5.322	22000	4.342	620	2.792
8	10	1460000	6.16	477800	5.679	80000	4.903	4700	3.672	55	1.740
9	slope		-0.084		-0.132		-0.210		-0.333		-0.526
10	D	D	11.975		7.571		4.769		3.006		1.901
11	log(D)	log(D)	1.078		0.879		0.678		0.478		0.279
12											
13	slope of log(D) vs T		-0.10								
14		z=	10.00								

Figure 3.3 A worksheet with data given in Example 3.2

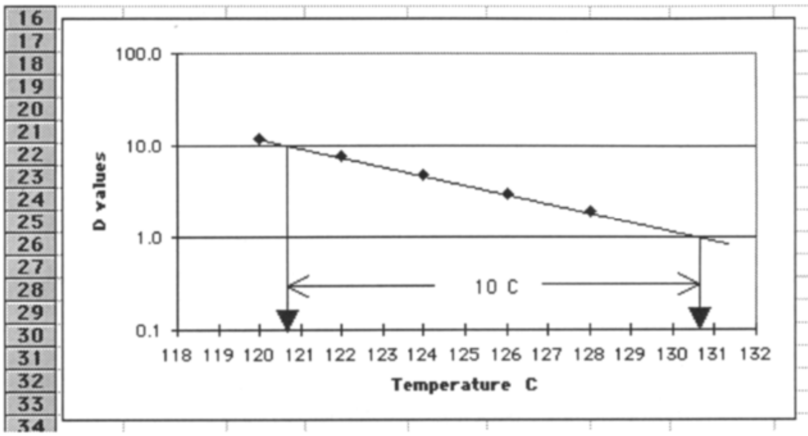


Figure 3.4 A plot of D vs temperature to determine the z-value.

3.3 Sampling to Ensure That a Lot Is Not Contaminated with More Than a Given Percentage

When conducting sampling of lots for the presence or absence of microbial contamination, it is often desirable to know how many samples should be tested. Statistical analysis using binomial distribution allows us to determine the number of samples needed for such purpose. In this example, we will develop a general worksheet that is useful to determine sample testing from a large lot.

Problem Statement:

Determine the number of samples that must test negative for a microbial contamination, if one wants to state with 90, 95, or 99% probability that not more than 0.1, 1, 2, or 5% of lot is contaminated.

Approach:

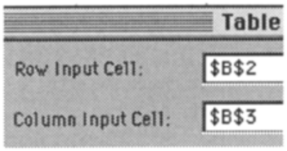
To create this worksheet we will use an expression given by Jarvis (1989). The equation is as follows:

$$n = \frac{\log_{10}(1-P)}{\log_{10}(1-d)} .$$

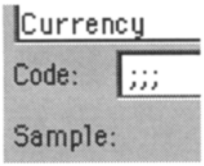
Where n is the number of samples that are shown to be satisfactory; P is the probability, in decimal; d is the percent incidence of contaminated items per 100 samples.
In our example, d is calculated as 0.001, 0.01, 0.02, and 0.05.

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cells A1:C6, type the text labels and data values as shown in Fig. 3.5.
3. In cells A8:A12 and B7:D7, enter data values as shown in Fig. 3.5.
4. In cell A7, type the following formula:
   =LOG(1-B2)/LOG(1-B3/100)
5. Highlight cells A7:D12.



6. Select the menu commands **Data**, **Table...**. A dialog box will open.
7. Enter $B$2 for row reference and $B$3 for column reference. Click **OK**.
8. A table will be generated as shown in Fig. 3.5.



9. In order to hide the contents of cell A7, first select cell A7, then choose the menu commands **Format**, **Cells**, and index tab **Number**. In the edit box for **Code**, type **;;;** and the contents of the cell will be hidden during display. The cell content is, however, retained in the memory and may be viewed by making the cell active (by clicking on it) and viewing in the formula bar.

Discussion:

The results show the number of samples that must test negative for a microbial contaminant before we can state with a certain probability that some percentage of a lot is contaminated. For example, to state with a 90% probability that a lot has less than 0.5% contamination, 459 samples must test negative. As seen from results in Fig. 3.5, decreasing our criterion of contamination in a lot, a large number of samples must test negative.

Worksheet Comments:

In this example, we used the **Table...** command, and a method to hide the contents of a cell.

	A	B	C	D
1	Given:			
2	Probability of occurrence	0.95		
3	Percent of lot not contaminated	0.1		
4				
5	Solution:	Number of Samples that must test negative		
6	Percent of lot contaminated		Probability Levels	
7		**0.9**	**0.95**	**0.99**
8	**0.1**	2301	2994	4603
9	**0.5**	459	598	919
10	**1**	229	298	458
11	**2**	114	148	228
12	**5**	45	58	90

Figure 3.5 A worksheet for the data given in Example 3.3.

3.4 Determining Process Lethality for Conduction Heating Food with a Microorganism with a *z*-Value of 18°F

Vintner *et al.* (1975) presented a method to determine the lethality (F_0) value for a process when the microbe has a z-value of 10°C or 18°F. The method allows computation of f_h/U using empirical expressions instead of using tabulated values as done traditionally. In this example, we will use this method to determine the lethality of a process and examine the adequacy of other processes where the required process conditions may not have been maintained.

Problem Statement:

Determine the F_o value if the retort temperature is 255°F and initial temperature is 130°F, the j-value is 0.98 and f_h value is 11 min, the process time is 18 min. It has been previously determined that the process must meet a lethality requirement of 4 for a minimum *Botulinum* cook and an F_o of 8 to achieve commercial lethality. If later it is discovered that the retort temperature was incorrectly set at 240°F, what should be done with the lot? Similarly, if the retort temperature is maintained at 255°F, but the initial temperature was 60°F, suggest a course of action.

Approach:

We will create a worksheet programmed with the empirical expressions given by Vinters *et al.* (1975). The expressions are as follows:

$F_1 = \log^{-1}\ [(250\text{-}RT)/z]$,

$\log jI = \log [(j(RT\text{-}IT)]$,

where $I = RT - IT$

$\log g = \log jI - (B_B/f_h)$.

If $\log g < -0.9542$,

$x = \log g$,

$\log f_h/U = 0.072465 \times x^5 + 0.06064 \times x^4 + 0.071368 \times x^3 + 0.23426 \times x^2 + 0.51548 \times x + 0.12384$.

Calculate f_h/U .

If $\log g > -0.9542$, then $\dfrac{f_h}{U} = \dfrac{1}{0.71 - \log g}$,

where F_1 is the equivalent time at retort temperature, minutes; F_0 is the sterilizing value or the equivalent time at the reference temperature of 250°F, minutes; *RT* is the retort temperature, °F; *IT* is the initial temperature, °F; *z* is the thermal resistance factor, °F; *j* is the lag factor before the heating curve assumes a straight line on a semilog paper; *g* is the difference between retort temperature and the maximum temperature reached at the end of heating period, °F; f_h is time in minutes required for the straight line of the heating curve to traverse one log cycle, minutes; B_B is the process time, minutes.

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cells A1:B6, type the text labels and data values as shown in Fig. 3.6.
3. In cells A8:A14, type the text labels as given in Fig. 3.6.
4. In cell B9, type the following formula:
   =10^((250-B2)/18)
5. In cell B10, type the following formula:

=LOG(B4*(B2-B3))

6. In cell B11, type the following formula:
   =B10-B6/B5
7. In cell B12, type the following formula:
   =IF(B11>-0.9542,(0.072465*B11^5)+(0.06064*B11^4)+0.071368*B11^3+0.23426*B11^2+0.51548*B11+0.12384,1/(0.71-B11))
8. In cell B13, type the following formula:
   =10^B12
9. In cell B14, type the following formula:
   =B5/(B13*B9)
10. In cells C2:D6, type the data values as shown in Fig. 3.6.
11. Copy the contents of cells from B9:B14, into cells C9:D14 using the **AutoFill** command.

Save your work often; use the shortcut **Command+S** (**Ctrl+S** in Windows).

Discussion:

The process lethality for the process is calculated as 8.02 min, which assures safety of the product. If the retort temperature of 240°F was used then the lethality is calculated as 2.46. This lethality value is less than that required for the minimum *Botulinum* cook, therefore the lot must be destroyed. If the initial temperature of the lot was 60°F, then although the minimum *Botulinum* cook was obtained, the commercial sterility was not achieved. In this case, no public health hazard is involved. The lot should be held for some period of time to sort for cans that may swell due to the inadequate commercial sterility.

Worksheet Comments:

In this worksheet, we programmed empirical expressions using *IF()* function. This allowed us to choose between two expressions based on a selected criteria. We also used the *LOG()* function in calculations.

	A	B	C	D
1	Given:			
2	Retort Temperature F	255	240	255
3	Initial Temperature F	130	130	60
4	j value	0.98	0.98	0.98
5	f_h value	11	11	11
6	Process Time (min)	18	23	18
7				
8	Solution:			
9	F_i	0.53	3.59	0.53
10	log (jI)	2.09	2.03	2.28
11	log g	0.45	-0.06	0.64
12	log fh/U	0.42	0.09	0.59
13	fh/U	2.60	1.24	3.90
14	Fo	8.02	2.46	5.34

Figure 3.6 A worksheet for the data given in Example 3.4.

3.5 Calculating Thermal Process Time for Food with a Microorganism with a z-Value of 18°F

Vinters *et al.* (1975) presented a procedure to calculate thermal process time using a computer. They provided empirical relationships useful in calculating the f_h/U values for a z=18°F (10°C). Normally, the f_h/U values are derived from tables (Stumbo, 1973). We will use this method to calculate the process time and examine how this method may be used to correct process deviations.

Problem Statement:

A thermal process for canned food involves a retort temperature of 255°F, and the initial temperature of the product in the can is 130°F. The heating rate parameters obtained from previously conducted experiments are j=0.98 and f_h =11 min. The minimum F_0 value for the process has been determined as 8.5 for a microorganism with a z=18°F. Calculate the process time. If in the middle of the process, it was determined that the retort temperature was incorrectly set at 245°F, how much additional process time is necessary to achieve the desired lethality?

Approach:

We will use the empirical expressions given by Vinters *et al.* (1975).

$F_I = \log^{-1}\ [(250\text{-}RT)/z]$

$\log jI = \log\ [(j(RT\text{-}IT)]$.

Calculate $\quad \log g = \log jI -\ (B_B/f_h)$.

Calculate $f_h / U = \frac{f_h}{F_o F_1}$.

If f_h/U >0.6

$R = \log f_h/U$

$\log g = 0.042808 \times R^5 - 0.35709 \times R^4 + 1.1929 \times R^3 - 2.1296 \times R^2 + 2.48447 \times R - 0.28274.$

If f_h/U <0.6

$$\log g = \frac{0.71 f_h / U - 1}{f_h / U}$$

$B_B = f_h(\log jI - \log g)$,

where F_1 is the equivalent time at retort temperature, minutes; F_0 is the sterilizing value or the equivalent time at the reference temperature of 250°F, minutes; *RT* is the retort temperature, °F; *IT* is the initial temperature, °F; *z* is the thermal resistance factor, °F; *j* is the lag factor before the heating curve assumes a straight line on a semilog paper; *g* is the difference between retort temperature and the maximum temperature reached at the end of heating period, °F; f_h is time in minutes required for the straight line of the heating curve to traverse one log cycle, minutes; B_B is the process time, minutes.

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cells A1:B6, type the text labels and data values as shown in Fig. 3.7.
3. In cells A8: A14, type the text labels as shown in Fig. 3.7.
4. In cell B9, type the following formula:
   =10^((250-B2)/18)
5. In cell B10, type the following formula:
   =LOG(B4*(B2-B3))
6. In cell B11, type the following formula:
   =B5/(B6*B9)
7. In cell B12, type the following formula:
   =LOG(B11)
8. In cell B13, type the following formula:
   IF(B11<0.6,(0.71*B11-1)/B11,0.042808*B12^5-

> Function names may be typed either upper or lower case, Excel converts them automatically to upper case.

0.35709*B12^4+1.1929*B12^3-2.1296*B12^2+2.4847*B12-0.28274)

9. In cell B14, type the following formula:
   =B5*(B10-B13)
10. In cell C2, type **245**.
11. Copy the contents of cell B3:B14 into C3:C14 using the **AutoFill** command.

Discussion:

The results show that when a retort temperature of 255°F is used, the calculated process time is 18.3 min. This time must be increased to 30.9 minutes, if the retort temperature is incorrectly set at 245°F. This method given by Vinters *et al.*(1975) is limited to z=18°F and it does not include any influence on the lethality of the cooling period. A more comprehensive method for process calculations is given by Pham (1987) as presented in Example 3.6

Worksheet Comments:

In this worksheet, we programmed an empirical expression and used *LOG()* function. In addition, we used the *IF()* function to select an appropriate expression based on the results of a previous computation.

	A	B	C
1	Given:		
2	Retort Temperature (C)	255	245
3	Initial Temperature (C)	130	130
4	j	0.98	0.98
5	f_h (minutes)	11	11
6	F_o	8.5	8.5
7			
8	Solution:		
9	F_i	0.5275	1.8957
10	log(jI)	2.0881	2.0519
11	f_h/U	2.4533	0.6826
12	log(f_h/U)	0.3898	-0.1658
13	log g	0.4249	-0.7590
14	Process Time (minutes)	18.3	30.9

Figure 3.7 A worksheet for data given in Example 3.5.

3.6 Determining Center and Mass-Averaging Sterilizing Value for a Thermal Process (I. High Sterilizing Value Case)

Pham (1987) presented a method to determine center and mass-averaging sterilizing values for a thermal process. His method is very versatile and covers a variety of processing conditions and z-values. In this example, we will create a worksheet that is useful in determining the sterilizing values when U/f_h is greater than 1 (or the high sterilizing values).

Problem Statement:

Calculate the center and mass-average sterilizing values for a process operating under the following conditions. Retort temperature = 110°C, initial temperature = 70°C, cooling medium temperature = 10°C, heating rate parameter f_h = 55 minutes, lag factor j = 2, process time = 169 minutes, z = 8°C, $D_{reference}$ = 3 minutes. In Pham's method either SI or English units may be used, because all calculations employ dimensionless quantities.

Approach:

We will use the equations given by Pham (1987) to calculate the center and mass-average sterilizing values. The equations are as follows:

$$D_h = D_r 10^{(T_r - T_h)/z}$$

$$N_1 = \frac{z}{T_h - T_i}$$

$$N_2 = \frac{z}{T_h - T_c}$$

$$A = 0.088 + 0.107\ N_2$$

$$B = 0.102\ N_1$$

$$C = 0.074\ N_1 + 0.177\ N_2 - 0.653$$

$$g_o = (T_h - T_c) \times 2 \times 10^{-t_h / f_h}$$

$$W_o = U_d/f = -\log_{10}(g_d/z) + A\,j - B/j + C$$

$$U_o = W_o \times f$$

$$U_s = U_o + D_h \log_{10}[1 + 10.9(0.301 - A\,j_d/2 - B/j_o)f/D_h],$$

where D_h is decimal reduction time at retort temperature, min; D_r is decimal reduction time at reference temperature (121.1°C), min; T_r is the reference temperature (121.1°C), °C; T_h is the retort temperature, °C; T_c is the cold stream temperature, °C; z is the thermal resistance factor, °C; A, B, C, N_1, and N_2 are constants as defined in preceding equations; t_h is the heating period, min; f_h is the time for residual temperature difference to change by a factor of 10 during the heating period, min; g is T_h-T_g, °C; T_g is product temperature at the end of heating period, °C; j is the lag factor; U_o is the sterilizing value at center, that is equivalent time at retort temperature, min; U_s is the mass-average sterilizing value, min.

> After entering a number or a text label in a cell, if you press the **Enter** key, the information is entered and the cell remains active.

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cells A1:B10, type the text labels and data values as shown in Fig. 3.8.
3. In cells A11:A21, type the text labels as shown in Fig. 3.8.
4. In cell B11, type the following formula:
   =B8*10^((121.11-B1)/B7)
5. In cell B12, type the following formula:
   =B7/(B1-B2)
6. In cell B13, type the following formula:
   =B7/(B1-B3)

7. In cell B14, type the following formula:
   =0.088+0.107*B13
8. In cell B15, type the following formula:
   =0.102*B12
9. In cell B16, type the following formula:
   =0.074*B12+0.177*B13-0.653
10. In cell B17, type the following formula:
    =(B1-B2)*B5*10^(-B6/B4)
11. In cell B18, type the following formula:
    =B17/B7
12. In cell B19, type the following formula:
    =-LOG(B18)+B14*B5-B15/B5+B16
13. In cell B20, type the following formula:
    =IF(B19>1,B19*B4,"Low Sterilizing Value! Use Pham's method Given in Example 3.7")
14. In cell B21, type the following formula:
    =B20+B11*LOG(1+10.9*(0.301-B14*B5/2-B15/B5)*B4/B11)

Discussion:

This worksheet is limited to situations when *W*>1. If the value of *W* is less than 1, then, during computations, a message will appear in cell B19 to indicate that an alternate procedure should be used as given in Example 3.7. This worksheet may be used to determine the influence of process deviations because of alternative process conditions.

Worksheet Comments:

In this worksheet we programmed the empirical expressions given by Pham(1987). We used *LOG()* and *IF()* functions.

	A	B
1	Retort Temperature (C)	110
2	Initial Temperature (C)	70
3	Cooling Medium Temperature (C)	10
4	f_h (min)	55
5	j	2
6	Heating period (min)	169
7	z (C)	8
8	D_ reference	3
9		
10	Solution:	
11	D at retort temperature	73.43
12	N1	0.20000
13	N2	0.08000
14	A	0.09656
15	B	0.02040
16	C	-0.62404
17	g_o	0.067665
18	g_o/z	0.008458
19	W	1.6316
20	Center Sterilizing Value	89.74
21	Mass average sterilizing Value	120.04

Figure 3.8 A worksheet for data given in Example 3.6.

3.7 Determining Center and Mass-Average Sterilizing Values For a Thermal Process (II. Low Sterilizing Values)

Pham(1987) presented a method for determining the center and mass-average sterilizing values. In this worksheet we will use the low-sterilizing case, $U/f_h < 1$.

Problem Statement:

Calculate the process time for the following data. Retort temperature = 121.11°C, initial temperature = 60°C, cooling medium temperature = 15.5°C, f_h = 10.9 minutes, z = 10°C, j_h = 1.23, j_c = 1.6, F_o = 5.

Approach:

We will use the empirical expressions given by Pham (1987) to create this worksheet. These expressions are as follows:

$$I = T_h - T_i$$

$$F_i = 10^{(T_r - T_h)/z}$$

$$U = F_o F_i$$

$$N_1 = \frac{z}{T_h - T_i}$$

$$N_2 = \frac{z}{T_h - T_c}$$

$$A_1 = -0.71 - 0.41\frac{N_1}{N_2}e^{-0.58/N_2}$$

$$A_2 = 2.14N_2^2 + 0.60N_2^2/N_1 - 0.26N_1^2 - 1.24N_1 + 1.02$$

$$B_1 = 0.31\sqrt{N_2/N_1} + 0.55\sqrt{N_2} + 0.61\sqrt{N_1} - 1.86$$

$$B_2 = (0.91N_1^2 - 3.18N_1 - 0.755)\sqrt{N_2/N_1} - 1.38N_1^2 + 2.55N_1 + 1.52$$

$$\log_{10} a = -W + A_1 + A_2 e^{-2.7\sqrt{W}}$$

$$\log_{10} b = -W + B_1 + B_2 e^{-2.7\sqrt{W}}$$

$$g/z = a + bj_c,$$

where T_r is the reference temperature (121.11°C), °C; T_h is the retort temperature, °C; T_c is the cold stream temperature, °C; T_i is the initial temperature of product, °C; z is the thermal resistance factor, °C; A_1, A_2, B_1, B_2, a, b, N_1, and N_2 are constants as defined in preceding equations; g is T_h-T_g, °C; T_g is product temperature at the end of heating period, °C; j_c is the lag factor for cooling period; F_o is the equivalent time at reference temperature (121.11°C or 250°F), min; F_i is the equivalent time at retort temperature, min.

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cells A1:B11, type the text labels and data values as shown in Fig. 3.9.
3. In cells A12:A25, type the text labels as shown in Fig. 3.9.
4. In cell B12, type the following formula:
   =LOG(B7*(B2-B3))
5. In cell B13, type the following formula:
   =10^((121.11-B2)/B6)
6. In cell B14, type the following formula:

=B5/(B9*B13)

7. In cell B15, type the following formula:
   =1/B14
8. In cell B16, type the following formula:
   =B6/(B2-B3)
9. In cell B17, type the following formula:
   =B6/(B2-B4)
10. In cell B18, type the following formula:
    =-0.71-0.41*(B16/B17)*EXP(-0.58/B17)
11. In cell B19, type the following formula:
    =2.14*B17^2+0.6*(B17^2)/B16-0.26*B16^2-1.24*B16+1.02
12. In cell B20, type the following formula:
    =0.31*((B17/B16)^0.5)+0.55*(B17^0.5)+0.61*(B16^0.5)-1.86
13. In cell B21, type the following formula:
    =(0.91*(B16^2)-3.18*B16-0.755)*((B17/B16)^0.5)-1.38*(B16^2)+2.55*B16+1.52
14. In cell B22, type the following formula:
    =IF(B15<1,-B15+B18+B19*EXP(-2.7*(B15^0.5)),"High Sterilizing value! Use Example 3.6")
15. In cell B23, type the following formula:
    =-B15+B20+B21*EXP(-2.7*B15^0.5)
16. In cell B24, type the following formula:
    =B6*(10^B22+(10^B23)*B8)
17. In cell B25, type the following formula:
    =B5*(LOG(B7*(B2-B3)/B24))

Discussion:

In this worksheet, we calculated the process time from the given data. Alternative process conditions, encountered in process deviations, may be substituted in the cells for given data to determine the new process times.

Worksheet Comments:

In this worksheet, we programmed the empirical expressions given by Pham(1987) to calculate process times for low sterilizing values. We used the *LOG()* and *IF()* functions.

	A	B
1	Given:	
2	Retort Temperature	121.11
3	Initial Temperature (C)	60
4	Cooling Medium Temperature (C)	15.55
5	f_h (min)	10.9
6	z (C)	10
7	j_h	1.23
8	j_c	1.6
9	Fo (min)	5
10		
11	Solution:	
12	log(jI)	1.8760
13	Fi	1.0000
14	f_h/U	2.1800
15	W	0.4587
16	N_1	0.1636
17	N_2	0.0947
18	A1	-0.7116
19	A2	0.8622
20	B1	-1.2081
21	B2	0.9485
22	log(a)	-1.0318
23	log (b)	-1.5145
24	g	1.4189
25	B (min)	18.79

Figure 3.9 A worksheet for data given in Example 3.7.

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Chapter FOUR

Statistical Quality Control in Food Processing

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4.1 Control Charts

Control charts are commonly used in food manufacturing processes to determine whether a process is operating under control. These charts are useful in finding ways to improve a process and assure production of satisfactory products. In this worksheet, we will use data obtained for some characteristics of a product obtained during a production run. We will create control charts from the given data. In addition, we will learn how to link to another worksheet and look up for some desired information.

Problem Statement:

A manufacturing line for production of pie crust is being monitored for variations in the thickness of the pie crust. In total, 50 data points are available. Use 10 subgroups of 5 samples each to develop average and range charts. The data on thickness (mm) of the pie crust are shown in the following table.

5.2548	5.2535	5.2539	5.2541	5.2536
5.2542	5.2537	5.2531	5.2521	5.2533
5.2546	5.2534	5.2536	5.2526	5.2531
5.2549	5.2538	5.2533	5.2522	5.2534
5.2548	5.2531	5.2537	5.2523	5.2533
5.2541	5.2539	5.2546	5.2534	5.2542
5.2549	5.2538	5.2549	5.2537	5.2546
5.2547	5.2539	5.2548	5.2539	5.2549
5.2543	5.2537	5.2546	5.2534	5.2546
5.2549	5.2539	5.2543	5.2533	5.2543

Approach:

First we will calculate average ($\overline{X}$) and range (R) of each subgroup. Then we will calculate an average of averages ($\overline{\overline{X}}$) and average of the range values ($\overline{R}$). The upper and lower limits for the averages and range are given by following expressions:

$$UCL_{\overline{X}} = \overline{\overline{X}} + A_2 \times \overline{R} \quad ,$$

$$LCL_{\overline{X}} = \overline{\overline{X}} - A_2 \times \overline{R} \quad ,$$

$$UCL_R = D_4 \times \overline{R} \quad ,$$

$$LCL_R = D_3 \times \overline{R} \text{ (if positive, otherwise zero)} \quad ,$$

where $\overline{\overline{X}}$ is the average of averages of subgroups, UCL is the upper control limit, LCL is the lower control limit, and A_2, D_3 and D_4 are constants.

To calculate the upper and lower control limits we will need to obtain constants A_2, D_3 and D_4 from Table A-8 (p. 269) given by Hubbard (1990). We will program this table in a separate linked worksheet and use a lookup function to read the required values from the table.

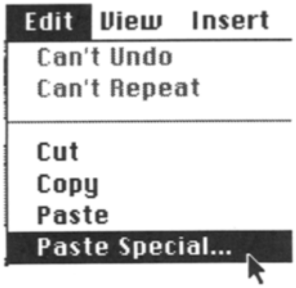
Programming the Worksheet:

1. Let us first create a worksheet that contains tabulated values for A_2, D_3 and D_4 for different subgroup sizes.
2. Open a new worksheet expanded to full size. Click on **Sheet 2** tab.
3. In cells A1:D21, type text labels and data values as shown in Fig. 4.1. Save this worksheet under a name **Factors for Control Limits** by renaming the **Sheet 2** tab.
4. Click on **Sheet 1** tab.
5. In cells A1: K7, type the text labels and data values as shown in Fig. 4.2.
6. In cell A8, type **X_bar**.
7. In cell A9, type **R**.
8. In cell B8, type the following formula:
   =AVERAGE(B2:B6)
9. In cell B9, type the following formula:
   =MAX(B2:B6)-MIN(B2:B6)

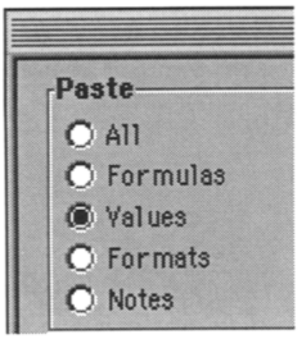
10. Using **AutoFill**, copy the contents of B8 into cells C8:K8.
11. Using **AutoFill**, copy the contents of B9 into cells C9:K9. And, rename the **Sheet 2** tab as **Control Chart**.
12. Type text labels in cells A11:A23, as shown in Fig. 4.2.
13. In cell B11, type **5**. This is the number of data points in each subgroup.
14. In cell B12 type the following formula:
    =AVERAGE(B8:K8)
15. In cell B13, type the following formula:
    =AVERAGE(B9:K9)
16. In cell B14, type the following formula:
    =B12+VLOOKUP(B11,
17. Open the worksheet named **Factors for Control Limits** by clicking on its sheet tab.
18. Highlight cells A3 to D21 (Fig. 4.1) by dragging with mouse.
19. Return to the original worksheet by clicking on the **Control Chart** sheet tab; the reference to the cells should appear in the cell address as follows:
    =B12+VLOOKUP(B11,'Factors for Control Limits'!$A$3:$D$21
20. Complete the formula as follows:
    =B12+VLOOKUP(B11,'Factors for Control Limits'!$A$3:$D$21,2,True) *B13
    The reason we entered 2 after the cell address was because the constant A2 is in column number 2, and **True** assures that when Excel looks for subgroup number it will match number 5 from cell B11 exactly with a value of 5 in column 1 of the lookup table.

21. In cell B15, using the same approach for using the lookup table as in steps 16 through 20, type the following formula:
    =B12-VLOOKUP(B11,'Factors for Control Limits'!$A$3:$D$21,2, True)*B13

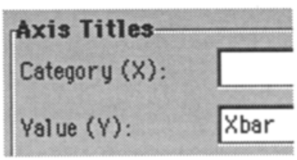
22. In cell B16, using the same approach for using the lookup table as in steps 16 through 20, type the following formula:
= VLOOKUP(B11,'Factors for Control Limits'!$A$3:$D$21,4, True)*B13
23. Since the value of constant D3 is 0 for a subgroup size of 5, the lower control limit for range is 0.
24. Next, we will make a plot of control chart. For this purpose we need to plot the X values and draw both upper and lower control limits; therefore, we will create rows of constant numbers for the upper and lower control limit values that can be plotted as straight lines.



25. To copy and paste a value rather than a formula from cell B12 into B19, first copy the content of cell B12, using **Edit**, **Copy**. Click on cell B19. Then use **Edit**, **Paste Special...**. A dialog box will open, click on the radio button **Values**. This will allow only the values to be pasted rather than formulas, since we need only numerical values for plotting. Click **OK**. The value from cell B12 will be pasted in cell B19.



26. Copy contents of cell B19 into cells C19:K19.
27. Using **Copy** and **Paste Special...**, copy only the values from cell B13, B14, B15 and B16 into cells B22:K22, B20:K20, B21:K21, B23:K23, respectively.
28. Highlight cells A8:K8. Keeping the **Command** (**Ctrl** in Windows) key pressed, highlight cells A19:K19, A20:K20 and A21:K21.
29. Drag on a desired area of the worksheet where you will like the chart to be inserted, e.g., cells A26:K36.
30. Click on the **ChartWizard** button. The dialog boxes will guide you through steps. In step 2 of **ChartWizard**, select **XY (Scatter)** chart.



31. In step 3 of **ChartWizard**, type the titles for Y axis **Xbar**.
32. After you click on the **Finish** button, the control chart will be drawn as shown in Fig. 4.3.
33. To plot a control chart for *R* values, highlight cells A9:K9. Keeping the **Command** (**Ctrl** in

Windows) key pressed highlight cells A22:K22 and A23:K23.

34. Using a similar procedure as in steps 29 through 32, create a chart for the *R* values (See Fig. 4.3).

Discussion:

The control chart (Figure 4.3) shows that the process is definitely out of control. Corrective action is needed to bring the process under control.

Worksheet Comments:

In this example, we used the *VLOOKUP()* function to obtain values from a table residing in another worksheet. This is another powerful feature of Excel that allows you to create and save a table of values, then later obtain a value and directly use it in calculations when and where desired in the main worksheet.

Excel performs calculations with 15-digit precision.

	A	B	C	D
1		Averages	R Chart	
2	Observations in Sample	A_2	D_3	D_4
3	2	1.88	0	3.267
4	3	1.023	0	2.575
5	4	0.729	0	2.282
6	5	0.577	0	2.115
7	6	0.483	0	2.004
8	7	0.419	0.076	1.924
9	8	0.373	0.136	1.864
10	9	0.337	0.184	1.816
11	10	0.308	0.223	1.777
12	11	0.285	0.256	1.744
13	12	0.266	0.284	1.716
14	13	0.249	0.308	1.692
15	14	0.235	0.329	1.671
16	15	0.223	0.348	1.652
17	16	0.212	0.364	1.636
18	17	0.203	0.379	1.621
19	18	0.194	0.392	1.608
20	19	0.187	0.404	1.596
21	20	0.18	0.414	1.586
22				
23				
24				

Sheet1 | Factors for Control Limits

Figure 4.1 A worksheet of factors for determining control limits.

	A	B	C	D	E	F	G	H	I	J	K
1	Given										
2		5.2548	5.2535	5.2539	5.2541	5.2536	5.2541	5.2539	5.2546	5.2534	5.2542
3		5.2542	5.2537	5.2531	5.2521	5.2533	5.2549	5.2538	5.2549	5.2537	5.2546
4		5.2546	5.2534	5.2536	5.2526	5.2531	5.2547	5.2539	5.2548	5.2539	5.2549
5		5.2549	5.2538	5.2533	5.2522	5.2534	5.2543	5.2537	5.2546	5.2534	5.2546
6		5.2548	5.2531	5.2537	5.2523	5.2533	5.2549	5.2539	5.2543	5.2533	5.2543
7	Solution										
8	X_bar	5.25466	5.2535	5.25352	5.25266	5.25334	5.25458	5.25384	5.25464	5.25354	5.25452
9	R	0.0007	0.0007	0.0008	0.002	0.0005	0.0008	0.0002	0.0006	0.0006	0.0007
10											
11	Subgroup	5									
12	X_bar_mean	5.25388									
13	R_mean	0.00076									
14	UCL_X_bar	5.254319									
15	LCL_X_bar	5.253441									
16	UCL_R	0.001607									
17											
18	To Plot:										
19	X_bar_mean	5.25388	5.25388	5.25388	5.25388	5.25388	5.25388	5.25388	5.25388	5.25388	5.25388
20	UCL_X_bar	5.25432	5.25432	5.25432	5.25432	5.25432	5.25432	5.25432	5.25432	5.25432	5.25432
21	LCL_X_bar	5.25344	5.25344	5.25344	5.25344	5.25344	5.25344	5.25344	5.25344	5.25344	5.25344
22	R_mean	0.00076	0.00076	0.00076	0.00076	0.00076	0.00076	0.00076	0.00076	0.00076	0.00076
23	UCL_R	0.001607	0.001607	0.001607	0.001607	0.001607	0.001607	0.001607	0.001607	0.001607	0.001607
24											

Control Chart / Factors for Control Limits

Figure 4.2 A worksheet for Example 4.1.

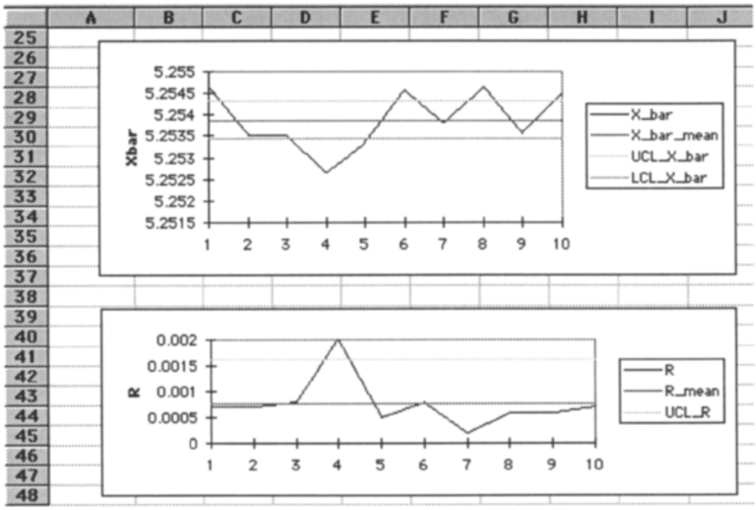


Figure 4.3 A control chart for data given in Example 4.1.

4.2 Probability of Occurrence in a Normal Distribution

In situations when data values do not follow normal distribution, the averages of groups of measurements taken from the parent data approach normal distribution. This fact is used in analyzing data of samples obtained from a large set of data. In this example, we will create a worksheet useful in analyzing a random sample obtained from data for a large shipment of goods.

Problem Statement:

The mean weight of a shipment of 10,000 packages of cheesecake pie-mix is 227 g with a standard deviation of 10 g. If a random sample of 100 packages is taken, what is the probability that the average weight will be less than 225 g?

Approach:

We will use the function *NORMDIST(Z)* available in Excel. This function requires a value of Z, expressed by Hubbard (1970) as

$$Z = \frac{\overline{X} - \mu}{\sigma_{\bar{x}}} ,$$

where $\overline{X}$ is the sample mean, μ is the population mean, and, $\sigma_{\bar{x}}$ is obtained as follows:

$$\sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n}} .$$

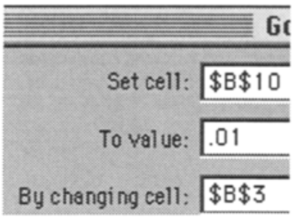
We will first calculate Z and then use it to obtain the probability.

Programming the Worksheet:

1. Open a new worksheet expanded to full size.

2. Type the data values and text labels in cells A1:B5 and A7:A10, as shown in Fig. 4.4.
3. In cell B8, type the following formula:
   =B4/(B5)^0.5
4. In cell B9, type the following formula:
   =(B3-B2)/B8
5. In cell B10, type the following formula:
   =NORMSDIST(B9)
6. Results will be displayed in cell B10.

Discussion:



The result indicates that the probability of getting a mean of 225 g for a sample of 100 packages is 0.0228.
Let us say that you want to know what will be the mean of this sample if you wanted to fix the probability at 0.01. You can solve this by using the **Goal Seek** command. Choose the menu items **Tools**, **Goal Seek....** A dialog box will open. Type values as shown. The result will be 224.67 g.

Worksheet Comments:

In this worksheet, we used the statistical function *NORMDIST()* to calculate the probability. Also, we used the **Goal Seek** command to determine the sample mean that yields a given probability.

	A	B
1	Given:	
2	mean weight	227
3	desired mean	225
4	standard deviation	10
5	sample size	100
6		
7	Solution:	
8	standard deviaiton of sample	1
9	Z value	-2
10	Probability	0.02275006

Figure 4.4 A worksheet for Example 4.2.

4.3 Using Binomial Distribution to Determine Probability of Occurrence

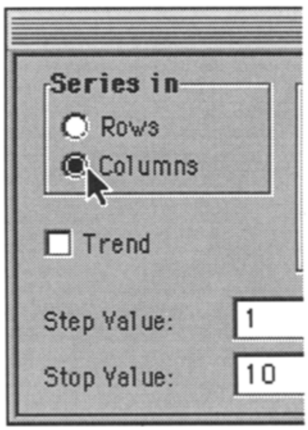
Examples of binomial distribution are common in processes where a product is characterized as one of two possibilities: it is either defective or acceptable, good or bad, etc. Thus a particular item can be classified only in one of the two categories. We will use the following example to show how Excel can be easily used in solving these types of problems.

Problem Statement:

An on-line cookie cutter is being used to cut dough into cookie shapes. It is known that the cutter produces 5% defective cookies. If a sample of 10 cookies is withdrawn, what is the probability that in that sample there are exactly 0 defective cookies. Also, calculate the probabilities for exactly 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10 defective cookies.

Approach:

We will use the statistical function *BINOMDIST()* to determine the probabilities. We will use the results for probabilites to draw a histogram. The function *BINOMDIST()* requires information on number of defectives, defect rate, and sample size.

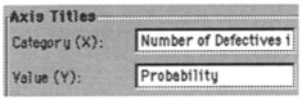


Programming the Worksheet:

1 Open a new worksheet expanded to full size.
2. In cells A1:B6, type the text labels and data values as shown in Fig. 4.5.
3. In cell A7, type **0**. Press **Enter.**
4. Choose the menu items **Edit**, **Fill**, **Series....** A dialog box will open. Enter the step value as **1** and the stop value as **10**. Select the check box

for series in **Columns**. Click **OK**. This will create a series from 1 to 10 in cells A8: A17. As an alternative, you can use the **AutoFill** command to create this series.

5. In cell B7, type the following formula:
   =BINOMDIST(A7,$B$3,$B$2/100, FALSE)
6. Copy cell B7 into cells B8:B17. The probabilities will be displayed for each number of defectives.
7. To plot a histogram of the probabilities, select cells A7:B17.
8. Click on the **ChartWizard** button and create a **Column** chart, as shown in Fig. 4.6. In step 4, select **1** column for category (X) axis labels. In step 5, for the title for Y axis, type **Probability**. For X axis, type **Number of Defectives in a sample of ten**. Click on **Finish**.



9. The histogram will be displayed as in Fig. 4.6.

Discussion:

The results show that about 3 out of 10 times we can expect to find one defective cookie in a sample of 10 cookies.

Worksheet Comments:

In this worksheet, we used the function *BINOMDIST()* to obtain the probability for a binomial distribution.

	A	B
1	Given:	
2	Defect Rate (Percent)	5
3	Sample size	10
4		
5	Solution	
6	Number of Defectives in sample	Probability
7	0	0.599
8	1	0.315
9	2	0.075
10	3	0.010
11	4	0.001
12	5	6.09E-05
13	6	2.67E-06
14	7	8.04E-08
15	8	1.59E-09
16	9	1.86E-11
17	10	9.77E-14

Figure 4.5 A worksheet for Example 4.3.

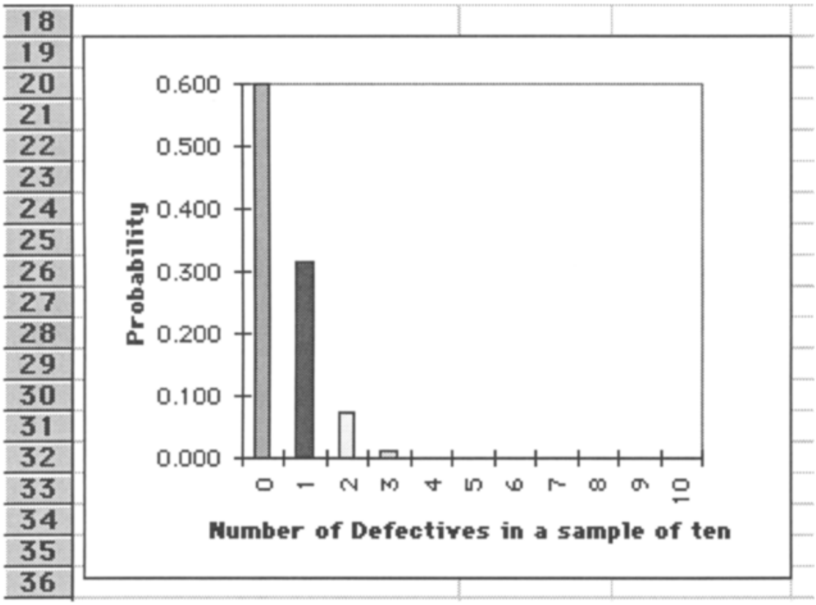


Fig. 4.6 A chart showing the probability of obtaining a certain number of defectives in a sample of 10.

4.4 Probability of Defective Items in a Sample Obtained from a Large Lot

In food quality control, samples are drawn from large lots to obtain an indication of the magnitude of defects. If the sample size is small compared to the lot size (say less than 10%), a Poisson distribution is used as an approximation of binomial distribution. In this example we will determine the probability of defective items in a sample assuming a certain defect rate in the lot.

Problem Statement:

A large shipment of granola bars has a known defect rate of 3%, the defect consists of broken bars. If a sample of 100 bars is drawn from the shipment, what is the percent probability that the sample will contain no broken bars, or at least 1, 3, 5, or 7 broken bars. Assuming that a purchaser will accept the shipment if there are no more than 5 broken bars in a sample of 100 bars, what is the probability that the shipment will be accepted?

Approach:

We will consider this to be an example of a Poisson distribution. We will first calculate the percent probability and then make a chart to plot percent probabilities vs number of defective units in the lot.

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cells A1:B6, and A7:A11 type the text labels and data values, as shown in Fig. 4.7.
3. In cell B7, type the following formula:

=100*POISSON(A7,$B$3*$B$2/100,TRUE)

4. Copy the contents of cell B7 into cells B8:B11
5. Select cells A7:B11. Click on the **ChartWizard** button and create a **Column** chart. In step 4, select **1** column for category (X) axis labels. In step 5 of **ChartWizard**, for X axis type **Number of Defectives** and for Y axis, type **Percent Probability**. The chart will be displayed as shown in Fig. 4.8.

Discussion:

The percent probability of the occurrence of 0, 1, 2, 3, 5, and 7 broken bars in 100 samples drawn from the shipment is shown in Fig. 4.8. If the purchaser will accept a shipment with no more than 5 broken bars in a sample of 100, then the probability of the shipment being accepted is 91.6%.

Worksheet Comments:

In this worksheet, we used the Poisson distribution function.

	A	B	C
1	Given		
2	Defect Rate (Percent)	3	
3	Sample size	100	
4			
5	Solution		
6	Number of defectives in sample	Percent Probability	
7	0	4.98	
8	1	19.91	
9	3	64.72	
10	5	91.61	
11	7	98.81	
12			

Figure 4.7 A worksheet for Example 4.4.

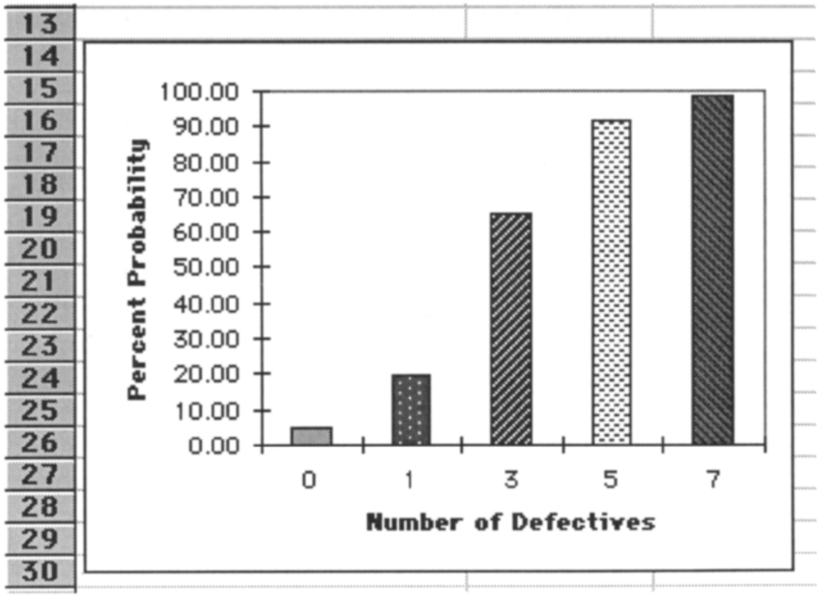


Figure 4.8 A chart showing the percent probability of obtaining a given number of defectives.

4.5 Determining Confidence Limits for a Population Mean Using t-Distribution

In quality control, there are situations when we need to know whether a sample mean lies within the confidence limits of the entire population. This can be accomplished by using t-distribution to determine confidence limits for a population mean using a selected probability. We will use Excel function *TINV()* to determine the t-distribution.

Problem Statement:

Ten cans of stewed tomatoes were removed at random from a population of 1000 cans. The drained weight of the contents were measured as 410.5, 411.4, 410.4, 412.6, 411.9, 411.5, 412.5, 411.4, 411.5, 410.1 g. Determine the 95% confidence limits for the entire population.

Approach:

We will first calculate the average of the ten data values using the *AVERAGE()* function. Next we will determine the standard deviation of the sample mean using *STDEV()* function. Then we will use the following expression given by Hubbard (1990, p. 76), to estimate the lower and upper limits of population mean μ:

$$\mu = \overline{X} \pm \frac{ts}{\sqrt{n}} .$$

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cells A1:B12 type the data values and text labels, as shown in Fig. 4.9.

> You can edit a formula either in the formula bar or directly in the cell by changing the display to formulas. Repeated use of the key strokes **Command+`** (**Ctrl+`** in Windows) allows switching back and forth between values and formulas

3. In cells A14:A21 type the text labels, as shown in Fig. 4.9.
4. In cell B15, type the following formula:
   =AVERAGE(B3:B12)
5. In cell B16, type the following formula:
   =STDEV(B4:B12)
6. In cell B17, type the following formula:
   =B16/(10)^0.5
7. In cell B18, type the following formula:
   =TINV(0.05,9)
8. In cell B19, type the following formula:
   =B18*B17
9. In cell B20, type the following formula:
   =B15+B19
10. In cell B21, type the following formula:
    =B15-B19
11. The upper and lower limits are displayed in cells B20 and B21. Use **Decrease Decimal**  button to decrease the number of significant digits.

Discussion:

The results show that the 95% confidence lower and upper limits for the population mean are 410.78 and 411.98, respectively.

Worksheet Comments:

In this worksheet, we used the function *TINV()*. This function returns the t-distribution.

	A	B
1	Given:	
2	Sample Number	Weight, g
3	1	410.5
4	2	411.4
5	3	410.4
6	4	412.6
7	5	411.9
8	6	411.5
9	7	412.5
10	8	411.4
11	9	411.5
12	10	410.1
13		
14	Solution:	
15	X_bar	411.38
16	standard deviation	0.833
17	s_X_bar	0.264
18	t_9,.05	2.262
19	s*t_9,.05	0.596
20	upper limit	411.98
21	lower limit	410.78

Figure 4.9 A worksheet for Example 4.5.

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Chapter FIVE

Sensory Evaluation of Foods

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5.1 Statistical Descriptors of a Population Estimated from Sensory Data Obtained for a Sample

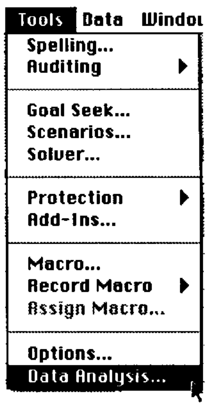
When a sample is taken from a large population and analyzed for selected sensory attributes, statistical analysis is helpful in obtaining estimates for the total population from which the sample was obtained. In this worksheet, we will use Excel's built-in data analysis techniques to determine various statistical descriptors for the sample and the population.

Problem Statement:

A sample of 10 cookies is obtained from a conveyor belt exiting a baking oven. The cookies are analyzed for color by comparing them with a standard color chart. The values recorded, in customized color units, are as follows: 34, 33, 36, 37, 31, 32, 38, 33, 34, and 35. Estimate the mean, variance, and standard deviation of the population.

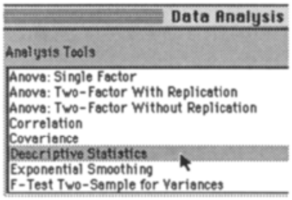
Approach:

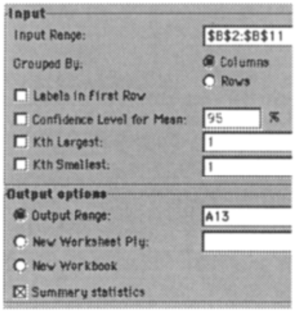
We will use the **Data Analysis** capability of Excel in determining the descriptive statistics for the given data. First, you should make sure that **Data Analysis...** is available under the menu command **Tools**. If it is not available, then see Section 1.24 for details on how to add this analysis package.



Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cells A1:B12, type the text labels and data values as shown in Fig. 5.1.





3. Choose the menu items **Tools, Data Analysis....** A dialog box will open as shown.
4. Double click on **Descriptive Statistics**.
5. In the edit box for **Input Range:**, type the range of cells as **$B$2:$B$11**.
6. Select the radio button **Columns**.
7. In output range type A13. Click **OK**.
8. Excel will calculate the descriptive statistics and display results in cells A13:B28 as shown in Fig. 5.1.

Discussion:

The results indicate that the sample mean is 34.3. The estimated mean for the population is also 34.3. The standard deviation for the population is 2.214, and the sample variance of the population is 4.9.

Worksheet Comments:

In this worksheet, we used the **Descriptive Statistics** available in the Excel's **Data Analysis...** command.

	A	B
1	Given:	
2		34
3		33
4		36
5		37
6		31
7		32
8		38
9		33
10		34
11		35
12	Solution:	
13	*Column1*	
14		
15	Mean	34.3
16	Standard Error	0.7
17	Median	34
18	Mode	34
19	Standard Deviation	2.21359436
20	Sample Variance	4.9
21	Kurtosis	-0.6899903
22	Skewness	0.29502299
23	Range	7
24	Minimum	31
25	Maximum	38
26	Sum	343
27	Count	10
28	Confidence Level(95.0%)	1.58351122
29		

Figure 5.1 A worksheet with the results of descriptive statistics for data given in Example 5.1.

5.2 Analysis of Variance: One-Factor, Completely Randomized Design

In consumer testing, it is sometimes not possible to use the same judges for testing different treatments. Although, it would be desirable to use the same judges to evaluate samples obtained from different treatments, it may not be economically feasible. In such cases, we have a completely randomized design. Using single-factor ANOVA, we can test to see whether the treatments had any influence on the judges scores; in other words, does the mean of each treatment differ?

Problem Statement:

Consider a sensory study where an engineered food with three different flavor compounds, A, B, and C was evaluated for the degree of liking of flavor on a 9-point hedonic scale. The following scores were obtained:

A	B	C
8	7	5
9	7	5
8	8	6
7	9	8
9	7	7

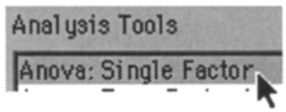
For each treatment, 5 samples were evaluated by 5 judges. The same judges were not available for the three treatments. Therefore, the design was completely randomized. Calculate the F value to determine whether the means of three treatments are significantly different.

Approach:

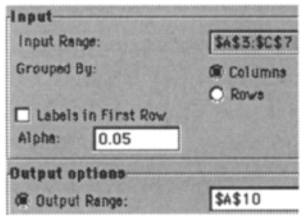
We will use a single factor analysis of variance available in Excel. We will determine the F value at probability of 0.95 and

0.99. These computations will allow us to determine if the means between the three different treatments are significantly different. First make sure that the **Data Analysis...** command is available under menu item **Tools....** If not, see section 1.24 on how to install it.

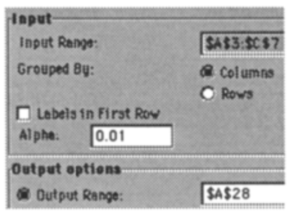
Programming the Worksheet:



1. Open a new worksheet expanded to full size.
2. In cells A1:C7, enter the text labels and data values, as shown in Fig. 5.2.
3. In cell A9, type **At 5% level**. Press **Enter**.
4. Choose the menu items **Tools**, **Data Analysis....** A dialog box will open.



5. Scroll to locate **Anova:Single Factor** and double click on it. A new dialog box will open.
6. In the dialog box, change the edit boxes as shown. Click **OK**.
7. The results are shown in cells A10:G24 in Fig. 5.2. You may want to reduce the number of significant digits in some of the cells such as D21, D22, F21, G21 by selecting them and clicking on the **Decrease Decimal** button in the **Format** toolbar.
8. In cell A26, type **At 1% level**. Press **Enter**.
9. Select the menu items **Tools**, **Data Analysis...** and **Anova single factor** from the dialog box. A new dialog box will open.



10. Make similar entries as in step 6, except that in the edit box for **Output Range**, change the **Output Range** to **$A$28**. This is important; otherwise, Excel will re-write over previous results. Also, change **Alpha** to **0.01**. Click **OK**.
11. The new table gives the Anova results at the 1% level.

Discussion:

The results show that the F value is 4.9375. The critical F values are
At the 5% level F = 3.885

At the 1% level F = 6.927.
This indicates that for the example problem the F value exceeds the value at the 5% level but not at the 1% level. Thus, we can say that the means differ significantly (P<0.05). In other words, the F value is significant at the 5% level.

Worksheet Comments:

In this worksheet, we used the built-in capabilities of Excel to conduct single-factor analysis of variance.

	A	B	C	D	E	F	G
1	Given:						
2	A	B	C				
3	8	7	5				
4	9	7	5				
5	8	8	6				
6	7	9	8				
7	9	7	7				
8	Solution:						
9	At 5%						
10	Anova: Single Factor						
11							
12	SUMMARY						
13	*Groups*	*Count*	*Sum*	*Average*	*Variance*		
14	Column 1	5	41	8.2	0.7		
15	Column 2	5	38	7.6	0.8		
16	Column 3	5	31	6.2	1.7		
17							
18							
19	ANOVA						
20	*Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
21	Between Groups	10.5	2	5.2667	4.9375	0.0273	3.8853
22	Within Groups	12.8	12	1.0667			
23							
24	Total	23.3	14				
25							

Figure 5.2 A worksheet with results of **Analysis of Variance** for a single factor for data given in Example 5.2.

	A	B	C	D	E	F	G
26	At 1% level						
27							
28	Anova: Single Factor						
29							
30	SUMMARY						
31	*Groups*	*Count*	*Sum*	*Average*	*Variance*		
32	Column 1	5	41	8.2	0.7		
33	Column 2	5	38	7.6	0.8		
34	Column 3	5	31	6.2	1.7		
35							
36							
37	ANOVA						
38	*Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
39	Between Groups	10.5	2	5.2667	4.9375	0.0273	6.927
40	Within Groups	12.8	12	1.0667			
41							
42	Total	23.3	14				

Figure 5.3 Continuation of the worksheet with results of **Analysis of Variance** for a single factor for data given in Example 5.2.

5.3 Analysis of Variance for a Two-Factor Design without Replication

When we are interested in evaluating samples for sensory characteristics using same judges with samples obtained from multiple treatments, analysis of variance for a two-factor design without replication is useful. This analysis helps in determining if there are significant differences among the various treatments as well as if any significant differences exist among the judges themselves.

Problem Statement:

Three types of ice cream were evaluated by 11 judges. The judges assigned the following scores.

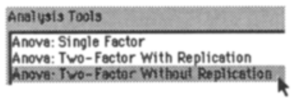
Judge	Ice Cream A	Ice Cream B	Ice Cream C
A	16	14	15
B	17	15	17
C	16	16	16
D	18	14	16
E	16	14	14
F	17	16	17
G	18	14	15
H	16	15	16
I	17	14	14
J	18	13	16
K	17	15	15

Approach:

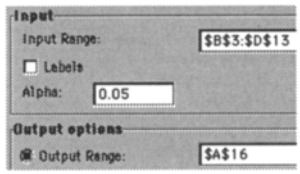
We will use the built-in analysis pack available in the Excel command called **Data Analysis....** Three sets of results will be obtained for the 5% level, the 1% level, and the 0.1% level.

Programming the Worksheet:

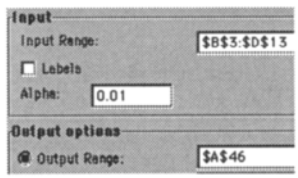
1. Open a new worksheet expanded to full size.
2. In cell A1:D14, type the text labels and data values, as shown in Fig. 5.4.
3. In cell A15, type **At 5% level**. Press **Enter**.
4. Choose the menu items **Tools, Data Analysis....** A dialog box will open.
5. Double click on **Anova: Two-Factor Without Replication**. A new dialog box will open.



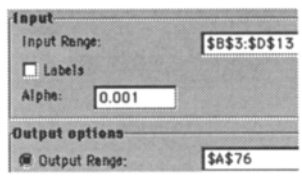
6. Type entries in edit boxes as shown.



7. The results will be displayed in cells A16:G42, as shown in Figures 5.4 and 5.5.
8. In cell A44, type **At 1% level**. Press **Enter**.
9. Repeat steps 4 and 5. In the new dialog box, change the edit box for **Output Range** to **$A$46** and **Alpha** to **0.01**.



10. The results will be displayed in cells A46:G72 as shown in Figures 5.5 and 5.6.
11. In cell A74, type **At 0.1% level**. Press **Enter**.
12. Repeat steps 4 and 5. In the new dialog box, change the edit box for **Output Range** to **$A$76** and **Alpha** to **0.001**.



13. The results will be displayed in cells A76:G102, as shown in Figures 5.6 and 5.7.

Discussion:

The difference among ice cream types is determined by examining the F values. The F value is calculated as 19.73 as displayed in cell E39. This value is greater than 3.49 for the 5% level, 5.85 at the 1% level, and 9.95 at the 0.1% level. The ice cream types are significantly different at $p<0.001$. For judges, the calculated F value is 1.36 as displayed in cell E38. This value is lower than the critical F values of 2.35 at the 5 % level, 3.37 at the 1% level, and 5.08 at the 0.1% level. Thus the judges showed no significant difference in their mean scores.

Worksheet Comments:

In this worksheet we used the Excel function **Analysis of Variance Two Factors Without Replication**.

	A	B	C	D	E
1	Given:				
2	Judge	Ice Cream A	Ice Cream B	Ice Cream C	
3	A	16	14	15	
4	B	17	15	17	
5	C	16	16	16	
6	D	18	14	16	
7	E	16	14	14	
8	F	17	16	17	
9	G	18	14	15	
10	H	16	15	16	
11	I	17	14	14	
12	J	18	13	16	
13	K	17	15	15	
14	Solution:				
15	At 5% level				
16	Anova: Two-Factor Without Replication				
17					
18	*SUMMARY*	*Count*	*Sum*	*Average*	*Variance*
19	Row 1	3	45	15	1
20	Row 2	3	49	16.3	1.3
21	Row 3	3	48	16.0	0.0
22	Row 4	3	48	16.0	4.0
23	Row 5	3	44	14.7	1.3
24	Row 6	3	50	16.7	0.3
25	Row 7	3	47	15.7	4.3
26	Row 8	3	47	15.7	0.3
27	Row 9	3	45	15.0	3.0
28	Row 10	3	47	15.7	6.3
29	Row 11	3	47	15.7	1.3
30					
31	Column 1	11	186	16.9	0.7
32	Column 2	11	160	14.5	0.9
33	Column 3	11	171	15.5	1.1

Figure 5.4 A worksheet for data given in Example 5.3.

	A	B	C	D	E	F	G
35							
36	ANOVA						
37	*Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
38	Rows	10.67	10	1.07	1.36	0.27	2.35
39	Columns	30.97	2	15.48	19.73	1.9E-05	3.49
40	Error	15.70	20	0.78			
41							
42	Total	57.33	32				
43							
44	At 1% level						
45							
46	Anova: Two-Factor Without Replication						
47							
48	*SUMMARY*	*Count*	*Sum*	*Average*	*Variance*		
49	Row 1	3	45	15	1		
50	Row 2	3	49	16.33333	1.33333		
51	Row 3	3	48	16	0		
52	Row 4	3	48	16	4		
53	Row 5	3	44	14.66667	1.33333		
54	Row 6	3	50	16.66667	0.33333		
55	Row 7	3	47	15.66667	4.33333		
56	Row 8	3	47	15.66667	0.33333		
57	Row 9	3	45	15	3		
58	Row 10	3	47	15.66667	6.33333		
59	Row 11	3	47	15.66667	1.33333		
60							
61	Column 1	11	186	16.90909	0.69091		
62	Column 2	11	160	14.54545	0.87273		
63	Column 3	11	171	15.54545	1.07273		
64							

Figure 5.5 Continuation of the worksheet for data given in Example 5.3.

Sensory_5.3

	A	B	C	D	E	F	G
65							
66	ANOVA						
67	*Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
68	Rows	10.66667	10	1.066667	1.36	0.268	3.37
69	Columns	30.9697	2	15.48485	19.73	2E-05	5.85
70	Error	15.69697	20	0.784848			
71							
72	Total	57.33333	32				
73							
74	At 0.1% level						
75							
76	Anova: Two-Factor Without Replication						
77							
78	*SUMMARY*	*Count*	*Sum*	*Average*	*Variance*		
79	Row 1	3	45	15	1		
80	Row 2	3	49	16.33333	1.33333		
81	Row 3	3	48	16	0		
82	Row 4	3	48	16	4		
83	Row 5	3	44	14.66667	1.33333		
84	Row 6	3	50	16.66667	0.33333		
85	Row 7	3	47	15.66667	4.33333		
86	Row 8	3	47	15.66667	0.33333		
87	Row 9	3	45	15	3		
88	Row 10	3	47	15.66667	6.33333		
89	Row 11	3	47	15.66667	1.33333		
90							
91	Column 1	11	186	16.90909	0.69091		
92	Column 2	11	160	14.54545	0.87273		
93	Column 3	11	171	15.54545	1.07273		

Figure 5.6 Continuation of the worksheet for data given in Example 5.3.

	A	B	C	D	E	F	G
95							
96	ANOVA						
97	*Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
98	Rows	10.66667	10	1.06667	1.36	0.268	5.08
99	Columns	30.9697	2	15.48485	19.73	2E-05	9.95
100	Error	15.69697	20	0.78485			
101							
102	Total	57.33333	32				

Figure 5.7 Continuation of the worksheet for data given in Example 5.3

5.4 Use of Linear Regression in Analyzing Sensory Data

Simple regression analysis involves determining the statistical relationship between two variables. One of the uses of such analysis is in predicting one variable on the basis of the other. In this example, we will use the regression analysis available in the **Add-in** package in Excel to determine linear regression between two variables.

Problem Statement:

A sensory study was conducted to determine the increase in off-flavor with storage time in a frozen vegetable. Sensory scores obtained at 0, 1, 2, 3, 4 and 6 month times were 1.5, 2, 2, 3, 2.5, and 3.5, respectively. Assuming that these data can be linearly correlated, determine the regression coefficient and predict the off-flavor score at 5 months of storage.

Approach:

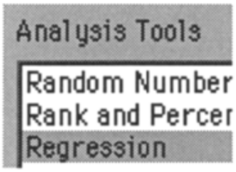
We will use the package **Regression** available as an **Add-in** item in Excel. If you have not installed the package **Add-in**, see section 1.24 for details. We will use this package to obtain required statistical relationships. We assume that a linear relationship exists between the off-flavor score and time (in months) with the equation

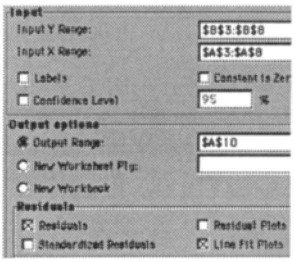
$$y = mx + b \ ,$$

where y is off-flavor score, x is time in months, m is slope and b is intercept.

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cells A1:B8, enter the text labels and data values as shown in Fig. 5.8.





3. Choose the menu items **Tools**, **Data Analysis....** A dialog box will open.
4. Double click on **Regression**.
5. A new dialog box will open. Enter the range of cells for Y and X as shown. Check boxes for **Residuals** and **Line Fit Plots**. Click **OK**.
6. The results will be displayed as shown in Fig. 5.8.
7. In cell A41, type **Off-flavor at 5 months**
8. In cell B41, type the following formula:
   =B26+5*B27
9. The predicted result of off-flavor score at 5 months of duration will be displayed in cell B41 as shown in Fig. 5.9.

Discussion:

The r^2 value is calculated as 0.85, the standard error is 0.318. The intercept is 1.5786 and the slope is 0.3143. The linear equation is $y = 1.5786 + 0.3143 \times x$. The residual output gives the predicted values for the off-flavor score at different time intervals. These data are also shown in the chart. The predicted and calculated values are shown. The predicted value at 5 months of storage duration is calculated as 3.15.

Worksheet Comments:

In this worksheet, we used the function **Regression** to conduct linear regression analysis.

	A	B	C	D	E	F	G
1	Given:						
2	Month	Off-flavor score					
3	0	1.5					
4	1	2					
5	2	2					
6	3	3					
7	4	2.5					
8	6	3.5					
9							
10	SUMMARY OUTPUT						
11							
12	*Regression Statistics*						
13	Multiple R	0.922490656					
14	R Square	0.850989011					
15	Adjusted R Square	0.813736264					
16	Standard Error	0.31763636					
17	Observations	6					
18							
19	ANOVA						
20		*df*	*SS*	*MS*	*F*	*Significance F*	
21	Regression	1	2.3047619	2.3047619	22.8436578	0.00877872	
22	Residual	4	0.40357143	0.10089286			
23	Total	5	2.70833333				
24							
25		*Coefficients*	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
26	Intercept	1.578571429	0.21809121	7.23812498	0.00193334	0.9730519	2.18409095
27	X Variable 1	0.314285714	0.06575697	4.77950393	0.00877872	0.13171471	0.49685672
28							

Figure 5.8 A worksheet with data given in Example 5.4.

	A	B	C
30			
31	RESIDUAL OUTPUT		
32			
33	*Observation*	*Predicted Y*	*Residuals*
34	1	1.578571429	-0.0785714
35	2	1.892857143	0.10714286
36	3	2.207142857	-0.2071429
37	4	2.521428571	0.47857143
38	5	2.835714286	-0.3357143
39	6	3.464285714	0.03571429
40			
41	off-flavor at 5 months	3.15	

Figure 5.9 Continuation of the worksheet with data given in Example 5.4.

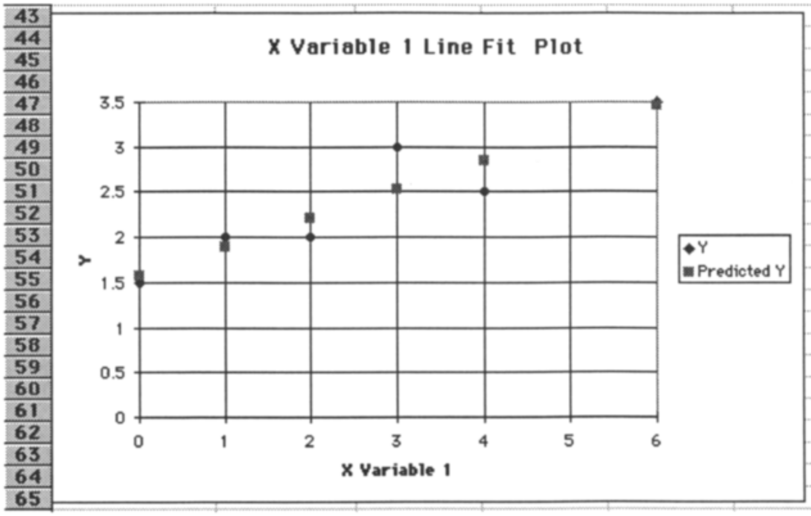


Figure 5.10 A plot of linear regression of data given in Example 5.4.

Chapter SIX

Mechanical Transport of Liquid Foods

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6.1 Measuring Viscosity of Liquid Foods Using a Capillary Tube Viscometer

Capillary tube viscometers are commonly used in determining the viscosity of liquid foods. The experimental procedure involves determining the volumetric flow rate of a given liquid as it flows through the viscometer under a known pressure drop at constant temperature. The experiment is repeated to obtain flow rates under a range of different pressure drops. The data are then analyzed to obtain an average value of the viscosity.

Problem Statement:

The following data were obtained from a capillary viscometer being used for determining the viscosity of a liquid food at 35°C.

Pressure Drop (Pa)	Volumetric Flow Rate ($\times 10^{-6} m^3/s$)
12	1.95
14	2.25
16	2.98
18	3.62
20	4.20
22	4.40

The tube radius is 2 cm and its length is 30 cm. Calculate the average value of viscosity and the standard deviation.

Approach:

We will calculate the viscosity using Eq. 2.16 in Singh and Heldman (1993, p. 54). This equation gives a relationship between the pressure drop and the volumetric flow rate through a capillary tube viscometer,

$$\mu = \frac{\pi \Delta P R^4}{8 L \dot{V}},$$

where μ is the viscosity (Pa.s), ΔP is the pressure drop (Pa), R is the radius (m), L is the length (m), and $\dot{V}$ is the volumetric flow rate (m^3/s).

> You can cancel any action before clicking the **OK** button by either pressing the **ESC** (in Windows) key or pressing **Command** and .(period) together. If you are in the middle of entering a formula and you want to cancel, you may click on the **Close** button, [X], in the formula bar.

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cells A1:D5, B6:C11 type the text labels and data values, as shown in Fig. 6.1.
3. In cell D6, type the following formula:
   =PI()*B6*$B$2^4/8/$B$3/C6/10^-6
4. Copy the contents of cell D6 into cells D7:D11 using **AutoFill**.
5. In cells A12, C13:C14, type the text labels as shown in Fig. 6.1.
6. In cell D13, type the following formula:
   =AVERAGE(D6:D11)
7. In cell D14, type the following formula:
   =STDEV(D6:D11)
8. The results of calculations will be displayed as shown in Fig. 6.1.

Discussion:

The average value of viscosity from six experimental determinations is 1.134 Pas. The standard deviation is 0.132.

Worksheet Comments:

In this worksheet we used the mathematical function *PI()* statistical functions *AVERAGE()* and *STDEV()*. When using the *PI()* function, the syntax requires that you must include empty brackets as shown. Excel returns the numerical value of π accurate up to 15 digits. Although we typed the function names in cells D13 and D14, respectively, an alternative procedure is to use the **Function Wizard** as described in section 1.8e.

In the formula entered in cell D6, we made use of the absolute reference for items given in cells B2 and B3. This was necessary to maintain correct references when copying the contents of cell D6 into D7:D11.

Use the **Decrease Decimal** button, , to reduce the number of signigicant digits.

	A	B	C	D
1	**Given**			
2	Radius of Capillary	0.02	m	
3	Length of Capillary	0.3	m	
4	**Solution**			
5		Pressure Drop	Volumetric Flow Rate	Viscosity
6		12	1.95	1.289
7		14	2.25	1.303
8		16	2.98	1.125
9		18	3.62	1.041
10		20	4.2	0.997
11		22	4.4	1.047
12	**Answer**			
13			Average Viscosity	1.134
14			Standard Deviation	0.132

Figure 6.1 A worksheet for data given in Example 6.1.

6.2 Using a Pitot Tube to Measure Velocity of Water in a Pipe

The Pitot tube is one of the most common convenient instruments used in measuring velocity profiles in a fluid flowing through a pipe. When a Pitot tube is placed in a pipe, there is a measurable pressure difference between the impact head and the static head. This pressure difference is usually measured by connecting the Pitot tube with a U-shaped mercury manometer. The observed difference between the heights of the mercury columns in the two legs of the manometer can be converted into fluid velocity at the location where the Pitot tube is positioned in the pipe. In this example, we will use a worksheet to determine the water velocities with different readings of a manometer. The data will be plotted on a grid paper such that they may be used as a quick reading aid.

Problem Statement:

A Pitot tube is being used to measure water flow rates. It is desired to determine the relationship between the manometer reading and the maximum water velocity at the central axis of the pipe. This relationship should cover a range of manometer readings from 10 to 150 mm of mercury. The density of the mercury used in the manometer is 13,600 kg/m^3, the density of water is 998 kg/m^3, and the tube coefficient is assumed to be 1.0.

Approach:

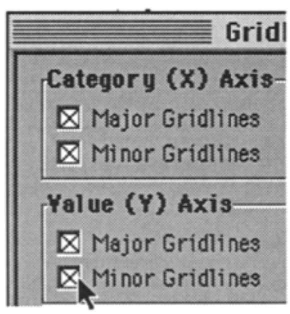
We will use Eq. 2.76, given in Singh and Heldman (1993, p. 85). This equation provides a relationship between maximum velocity and the change in height of a manometer fluid in a U-shaped manometer. The equation is

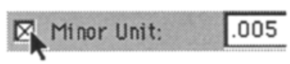
$$u = C\left\{\frac{2g}{\rho}(\rho_m - \rho)\Delta Z_m\right\}^{1/2},$$

where u is the velocity at any location in a pipe (m/s); g is the acceleration due to gravity, 9.81 (m/s^2); ρ is the density of water (kg/m^3); ρ_m is the density of mercury (kg/m^3); ΔZ_m is the difference in the heights of mercury in the two manometer columns, m.

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cell A1:B7, type the text labels and data values as shown in Fig. 6.2.
3. In cell A8, type: **0.01**
4. In cell A9, type: **0.02**
5. Using **AutoFill**, fill the series in cells A10:A22.
6. In cell B8, type the formula:
   =$B$4*(2*9.81/$B$3*($B$2-$B$3)*A8)^0.5
7. Copy the contents of cell B8 into cells B9:B22. The results will be displayed as shown in Fig. 6.2.
8. To draw a chart, we will use **ChartWizard**.
9. Highlight cells A8:B22.
10. Click on the **ChartWizard** button in the tool bar. Click on cell A24.
11. In step 2 of the **ChartWizard**, select **XY (Scatter)** chart.
12. Click **Finish**. The chart will be displayed as shown in Fig. 6.3.
13. To create detailed grid lines as shown in Fig. 6.3, first make the chart active by double-clicking anywhere inside the chart, then select the menu items **Insert**, **Gridlines....** In the dialog box, check the boxes for both major gridlines and minor gridlines. To add more divisions of the x-axis, double click anywhere on the x-axis values. A dialog box named **Format Axis** will open. Select the tab **Scale** select the check boxes **Minor unit**, and type **0.005** in the list box. Click **OK**. This will make the division of





x-axis into 0.005 units. Similarly, the spacing between grid lines on the y-axis may be changed if desired.

Discussion:

The grid sheet as shown in Fig. 6.3 may be used as a handy aid for quick conversion of manometer reading into velocity of water in a pipe.

Worksheet Comments:

In this worksheet, we used the **AutoFill** command to create a series. By entering numbers in both cells A8 and A9, we instructed Excel on both starting value and the interval for the series. We used an absolute reference in cell B8 to use given data in cells B2:B4.

	A	B
1	Given:	
2	Density of mercury (kg/m^3)	13600
3	Density of water (kg/m^3)	998
4	Tube coefficient	1
5		
6	Solution	
7	Manometer reading	Water velocity
8	0.01	1.574
9	0.02	2.226
10	0.03	2.726
11	0.04	3.148
12	0.05	3.520
13	0.06	3.855
14	0.07	4.164
15	0.08	4.452
16	0.09	4.722
17	0.1	4.977
18	0.11	5.220
19	0.12	5.452
20	0.13	5.675
21	0.14	5.889
22	0.15	6.096

Figure 6.2 A worksheet for data given in Example 6.2.

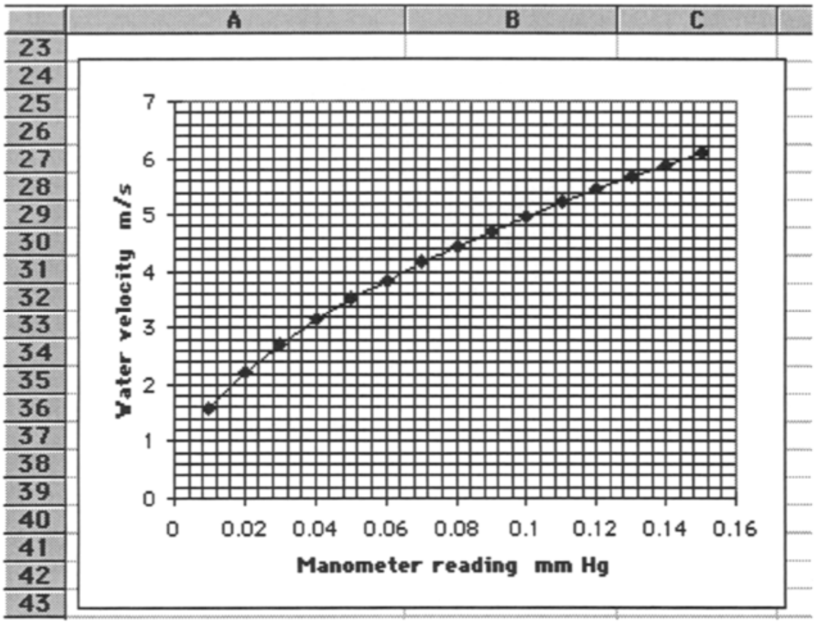


Figure 6.3 A chart showing water velocity as a function of manometer reading.

6.3 Rheological Properties of Power Law Fluids

Many liquid foods exhibit non-Newtonian characteristics. Power law fluids, also called shear thinning fluids, are most common. The rheological properties of these fluids are measured using viscometers. In this example, a coaxial viscometer is used to determine the relationship between shear stress and shear rate. The rheological properties, namely, consistency coefficient and flow behavior index, are obtained from the shear stress–shear rate data. We will develop a worksheet to enter the experimental data and obtain the rheological properties.

Problem Statement:

An experiment was conducted to determine the rheological properties of banana puree using a coaxial cylinder viscometer. The following data were obtained:

Shear rate	Shear Stress
0.001	0.000106
0.0015	0.000122
0.002	0.000137
0.003	0.000162
0.004	0.00018
0.005	0.000201
0.006	0.00021
0.007	0.000221

Determine the consistency coefficient and the flow behavior index from the experimental data. Plot the shear stress and shear rate data to show the shear thinning characteristics of the fluid.

Approach:

Non-Newtonian fluids follow the general Hershel Bulkley model, as given by Eq. 2.30 in Singh and Heldman (1993, p. 61). For power law fluids, the Herschel Bulkley model is modified as shown in the equation

$$\sigma = K\left(\frac{du}{dy}\right)^n,$$

where σ is the shear stress (Pa), *du/dy* is the shear rate (1/s), *K* is the consistency coefficient (Pas), and *n* is the flow behavior index.
The above equation may be simplified by taking the logarithm of both sides, thus

$$\ln\sigma = \ln K + n\ln\left(\frac{du}{dy}\right).$$

Thus if we plot ln σ vs ln (du/dy), we should get a straight line. The intercept will give a value of *K* and the slope provides the flow behavior index, *n*.

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cells A1:C10 and D2:E2, type the text labels and data values as shown in Fig. 6.4.
3. In cell D3, type the following formula:
   =LOG(B3)
4. Copy the contents of cell D3 into cells D4:D10 using the **AutoFill** command.
5. In cell E3, type the following formula:
   =LOG(C3)
6. Copy the contents of cell E3 into cells E4:E10 using the **AutoFill** command.
7. In cells D12:D16, type the text labels as shown in Fig. 6.4.
8. In cell E12, type the following formula:
   =SLOPE(E3:E10,D3:D10)
9. In cell E13, type the following formula:
   =E3
10. In cell E15, type the following formula:
    =10^(E13-E12*D3)
11. In cell B16, type the following formula:
    =E12

> The cell may be cleared by making the cell active and then selecting the menu items **Edit** and **Clear** to open a submenu. The submenu allows you to clear either notes, contents, formats, or all of the preceding three from the cell.

12. Select cells B3:C10. Click on the **ChartWizard** button, , and create an **XY (Scatter)** chart, as shown in Fig. 6.5.

Discussion:

The consistency coefficient for this liquid food is determined to be 0.00154 Pas and the flow behavior index is 0.387.

Worksheet Comments:

In this worksheet, we used the functions *LN(),* and *SLOPE().* The function *SLOPE()* uses linear regression analysis. If needed, you can obtain the regression coefficient to obtain the fit of data points to a straight line. In our example, you may type **=RSQ(E3:E10,D3:D10)** in cell E14, and you will obtain the regression coefficient as 0.998

	A	B	C	D	E
1	Given:				
2		Shear rate	Shear Stress	log(shear rate)	log(shear stress)
3		0.001	0.000106	-3.000	-3.975
4		0.0015	0.000122	-2.824	-3.914
5		0.002	0.000137	-2.699	-3.863
6		0.003	0.000162	-2.523	-3.790
7		0.004	0.00018	-2.398	-3.745
8		0.005	0.000201	-2.301	-3.697
9		0.006	0.00021	-2.222	-3.678
10		0.007	0.000221	-2.155	-3.656
11					
12				slope	0.387
13				intercept	-3.975
14					
15				K	0.00154
16				n	0.387

Figure 6.4 A worksheet for data given in Example 6.3.

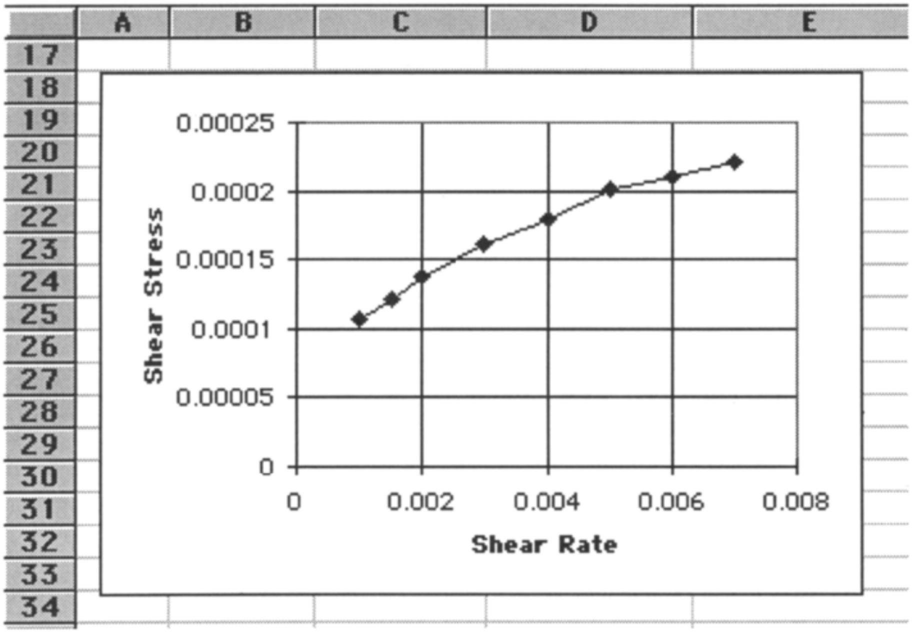


Figure 6.5 A chart showing the relationship between shear stress and shear rate for a non-Newtonian fluid.

6.4 Fluid Flow and Reynolds Number

In problems involving fluid flow, the magnitude of Reynolds number is used as an indicator of the flow conditions. For example, if the Reynolds number is less than 2100, the flow is called laminar. A Reynolds number greater than 10,000 indicates a turbulent flow. Values of Reynolds number between 2100 and 10,000 signify transitional flow. In this worksheet, we will develop a table of Reynolds numbers for flow of water through a pipe. This table will be created with the input of the diameter and the water velocity. The results will be useful to determine at what velocity the flow becomes turbulent.

Problem Statement:

A cylindrical pipe is being used to transport water. The viscosity of the water is 0.000992 Pas and the density is 998 kg/m^3. Develop a table of Reynolds numbers with velocity changing from 0.01 to 0.25 m/s and internal diameter changing from 1 to 10 cm. Plot the results to determine critical values of the pipe diameter for each velocity when the flow changes into turbulent regime.

Approach:

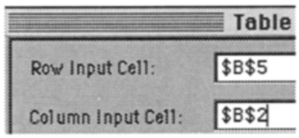
We will use Eq. 2.33 in Singh and Heldman (1993, p. 63). This equation is

$$N_{\mathrm{Re}} = \frac{\rho D \bar{u}}{\mu} ,$$

where $\bar{u}$ is the mean velocity (m/s), ρ is the density (kg/m^3), D is the diameter (m), and μ is the viscosity (Pas). We will use the **Table...** command in Excel to create a table with two functions.

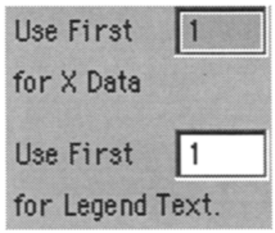
Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cells A1:B7, type the text labels and data values as shown in Fig. 6.6.
3. In cell B8, type the following formula:
   =B4*$B$5*$B$2/B3
4. In cells C8:H8, type the data values as shown in Fig. 6.6.
5. In cell E7, type **Velocity**.
6. In cells B9:B18, enter a series using the **Autofill** command, from 0.01 to 0.1 with an increment of 0.01.
7. Highlight cells B8:H18 by dragging the pointer.
8. Choose the menu commands, **Data**, **Table....** A dialog box will open.
9. In the edit box for **Row Input Cell:** type **$B$5**.
10. In the edit box for **Column Input Cell:** type **$B$2**. Click **OK**.



11. A table will be created as shown in Fig. 6.6.
12. You can hide the contents of cell B8 to unclutter the table, by first selecting cell B8, then choosing the menu commands **Format**, **Cells....** In the dialog box select tab **Number**, type **;;;** in the **Code** box. Click **OK**

13. Select cells B8:H18, click on the **ChartWizard** button and create an **XY (Scatter)** chart as shown in Fig. 6.7. In step 4 of **ChartWizard**, use first **1** column for X data and also first **1** row for legend text.



Discussion:

The results table is useful to determine the various Reynolds numbers for different velocities and pipe diameters. From Fig. 6.7, the values of velocity and pipe diameter that result in turbulent flow can be obtained. For example, for a pipe diameter of 0.05 m, the velocity must be greater than 0.20 m/s to assure turbulent flow. If the pipe diameter is 0.07 m then the velocity must be greater than about 0.15 m/s.

Worksheet Comments:

In this worksheet, we used the **Autofill** command to enter a series. We also used the **Table...** command with input of two functions. Tables generated by Excel are useful to determine the results obtained by changing two variables.

	A	B	C	D	E	F	G	H
1	**Given**							
2	Pipe diameter, m	0.01						
3	Viscosity, Pas	0.000992						
4	Density of water, kg/m3	998						
5	velocity, m/s	0.1						
6								
7	**Solution**				Velocity			
8			0.01	0.05	0.10	0.15	0.20	0.25
9		0.01	101	503	1006	1509	2012	2515
10		0.02	201	1006	2012	3018	4024	5030
11		0.03	302	1509	3018	4527	6036	7545
12		0.04	402	2012	4024	6036	8048	10060
13		0.05	503	2515	5030	7545	10060	12576
14		0.06	604	3018	6036	9054	12073	15091
15		0.07	704	3521	7042	10564	14085	17606
16		0.08	805	4024	8048	12073	16097	20121
17		0.09	905	4527	9054	13582	18109	22636
18		0.1	1006	5030	10060	15091	20121	25151

Figure 6.6 A worksheet for data given in Example 6.4.

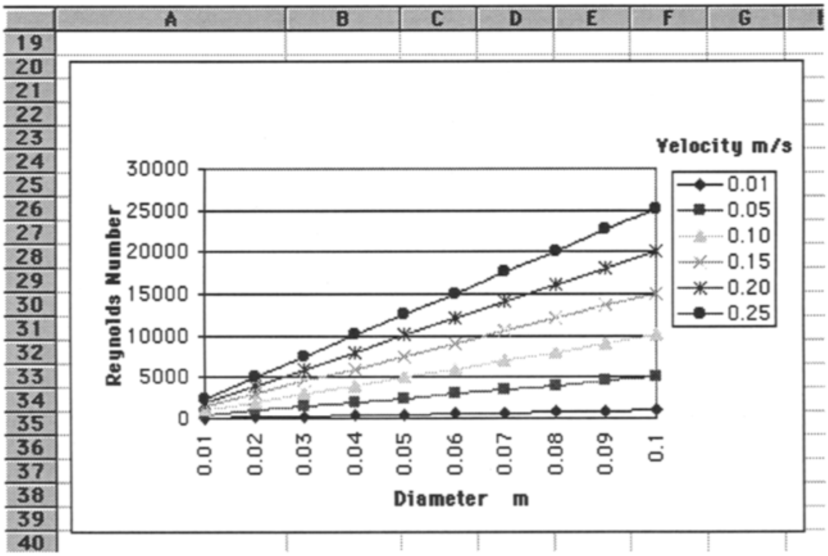


Figure 6.7 A chart showing the relationship between Reynolds number and pipe diameter for different fluid velocities.

6.5 Friction Factors for Water Flow in a Pipe

In designing pumping systems, we require values for friction factors for the liquid flow in a pipe. The friction factors are generally obtained from a diagram commonly referred to as Moody diagram. When the water flow in a pipe is within the laminar region (Reynolds number < 2100), the friction factor varies linearly with Reynolds number. In the turbulent regime, the relationship between friction factor and Reynolds number is nonlinear. In this example, we will use appropriate equations to calculate friction factor from Reynolds number and use the calculations to construct a chart similar to the Moody diagram.

Problem Statement:

Develop a chart that shows the dependence of friction factor on Reynolds number for water flowing in a smooth pipe.

Approach:

In the laminar regime, the friction factor varies linearly with Reynolds number (Singh and Heldman,1993, p. 68). The mathematical expression that describes this relationship is

$$f = \frac{N_{\mathrm{Re}}}{16} \; ,$$

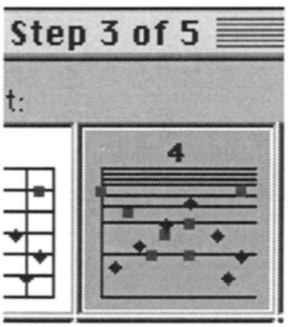
where f is the friction factor and N_{Re} is the Reynolds number. In the turbulent regime, for Reynolds number greater than 2100, the following equation known as Blassius equation may be used:

$$f = 0.0396 \times N_{\mathrm{Re}}^{-0.25} \; .$$

These two equations will be programmed in a worksheet and friction factors will be calculated for Reynolds numbers varying from 100 to 52,000. We will create a chart displaying the relationship between friction factor and Reynolds number as a semilog plot.

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cells A1:B1, type the text labels as shown in Fig. 6.8.
3. In cell A2, type **100** and using **AutoFill** command create a series with an increment of **400** in cells A2:A7.
4. Type **4000** in cell A8 and using **AutoFill** command create a series with an increment of **4000** in cells A8:A20
5. In cell B2, type the following formula:
   =16/A2
6. Copy the contents of cell B2 into cells B3:B7.
7. In cell B8 type the following formula:
   =0.0396*A8^-0.25
8. Copy the contents of cell B8 into cells B9:B20.
9. Using data in cells A2:B20, create a chart as shown in Fig. 6.9.
10. You will need to convert the scale for the y-axis into a log scale. If you use the **ChartWizard** to create the chart, then in step 3, when selecting the format for the **XY(Scatter) chart**, click on the fourth box that shows the format for a semilog plot.



Discussion:

As expected, the semilog plot of friction factor vs Reynolds number is linear in the laminar region and nonlinear in the turbulent regime. This plot is useful to obtain friction factor for situations involving smooth pipes. However, if the internal surfaces of the pipes are characterized by different degrees of roughness, then the Colebrook equation given as Eq. 2.53 in Singh and Heldman (1993, p. 70) may be used.

Worksheet Comments:

In this worksheet, we used two equations to obtain the functional relationship between friction factor and Reynolds number depending upon the flow regime. We used the semilog format for the chart because the friction factor changes by several orders of magnitude.

	A	B
1	Reynolds Number	Friction Factor
2	100	0.16
3	500	0.032
4	900	0.017777778
5	1300	0.012307692
6	1700	0.009411765
7	2100	0.007619048
8	4000	0.004979
9	8000	0.004187
10	12000	0.003784
11	16000	0.003521
12	20000	0.003330
13	24000	0.003182
14	28000	0.003061
15	32000	0.002961
16	36000	0.002875
17	40000	0.002800
18	44000	0.002734
19	48000	0.002675
20	52000	0.002622

Figure 6.8 A worksheet for data given in Example 6.5.

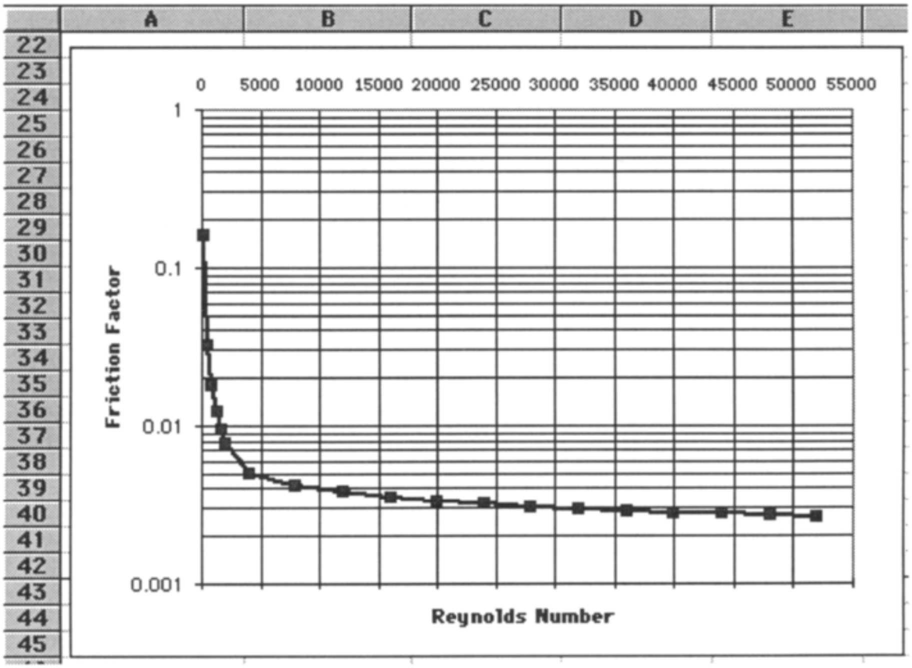


Figure 6.9 A plot of friction factor as a function of Reynolds number.

Chapter SEVEN

Steady State Heat Transfer in Food Processing

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7.1 Reducing Heat Transfer through a Wall Using Insulation

Insulation materials are commonly used to reduce the amount of heat transfer through a wall. Under steady state conditions, the rate of heat transfer through a wall depends upon the temperature difference between the two sides of the wall, the thermal conductivity of the material, and the thickness of the wall. In this example, we will determine the thermal conductivity of the insulating material for different values of acceptable temperature gradients across the insulating wall. Such information is necessary when selecting insulating materials.

Problem Statement:

A 10 square meter wall is to be insulated with some insulating material. The maximum rate of heat transfer allowed through the entire insulating wall is 100 W. The maximum thickness of the insulating wall is 10 cm. Determine the thermal conductivity of the insulating wall if the permitted temperature gradient across the wall is 10°C. Develop a worksheet to determine the thermal conductivities of the insulation if the permissible temperature gradient is increased from 10 to 100°C in increments of 10°C.

Approach:

We will use Fourier's law of heat conduction for slab geometry to determine the rate of heat transfer in a rectangular wall. An expression is available as Eq. 4.9 in Singh and Heldman (1993, p. 143) as follows:

$$q = -\frac{kAdT}{dx},$$

where q is the rate of heat transfer through the rectangular wall, W; k is the thermal conductivity of the material, W/m°C; A is the area of the wall, m^2; dT is the temperature gradient across the wall, °C; dx is the wall thickness, m.

This equation may be rearranged as follows:

$$k = \frac{qdx}{AdT} \ .$$

We will program the preceding equation in the worksheet to obtain thermal conductivity, k, as a function wall thickness, x.

Programming the Worksheet:

> To create a series with skipping values, type the first two numbers of the series, then use the fill handle to create the series.

1. Open a new worksheet expanded to full size.
2. Type the data and text labels in cells A1:B7 as shown in Fig. 7.1.
3. Type **10** in cell A8, and using **AutoFill** create a series in cells A9:A17 with an increment of 10.
4. In cell B8, enter the following formula: **=$B$2*$B$3/($B$4*A8)**
5. Copy the contents of the cell B8 into cells B9:B17 using the **AutoFill** command.
6. Select cells A8:B17, click on the **ChartWizard** button and create an **XY (Scatter)** chart as shown in Fig. 7.2.

Discussion:

The results show a non linear dependence of the thermal conductivity on the temperature gradient through the wall. As stated in the problem, if the rate of heat transfer is to be maintained at a fixed value, 100 W in this example, then as a higher temperature gradient is allowed through the wall, a lower thermal conductivity of the insulating material becomes necessary. For example, for a 50°C temperature difference across the wall, the thermal conductivity of the insulating material must be 0.02 W/mC. What-if analysis may be done to view the required thermal conductivity value, e.g., what if a higher heat transfer rate, say 200 W, is permitted. This may be accomplished by typing 200 in cell B2 and viewing the results in the chart.

Worksheet Comments:

In this worksheet, we created a series and copied formulas from one cell into others.

	A	B	C
1	Given:		
2	Heat Loss (W)	100	
3	Maximum thickness m	0.1	
4	Area (m^2)	10	
5			
6	Solution:		
7	Temperature gradient C	Thermal Conductivity	
8	10	0.1000	
9	20	0.0500	
10	30	0.0333	
11	40	0.0250	
12	50	0.0200	
13	60	0.0167	
14	70	0.0143	
15	80	0.0125	
16	90	0.0111	
17	100	0.0100	

Figure 7.1 Worksheet for Example 7.1.

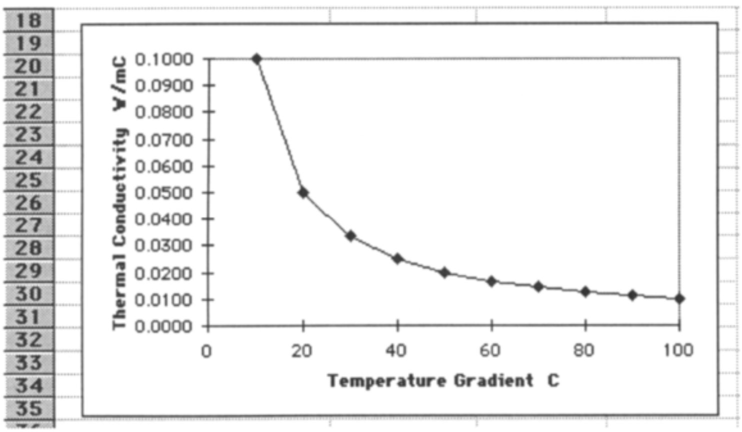


Figure 7.2 Thermal conductivity vs temperature gradient for data given in Example 7.1.

7.2 Log Mean and Average Areas in Cylindrical Pipes

In heat transfer in cylindrical pipes, as heat transfers in the radial direction, the area "seen" by the heat flow continues to increase. Thus, for a pipe with a certain finite thickness, the circumferential area "seen" by the heat transferring to the outside wall is variable. When Fourier's law in cylindrical coordinates is used to solve this problem, the integrated solution requires calculation of a logarithmic mean area. If instead of logarithmic mean, one uses an arithmetic average, between the outside area and inside area of the pipe, a certain error is introduced. In this worksheet, we will determine how much error is incurred when arithmetic average is used instead of the logarithmic mean.

Problem Statement:

Calculate the percent error involved in using arithmetic average area instead of logarithmic mean area for a pipe with an internal diameter of 2 cm and a thickness of 5 mm. What will be the error for the same diameter pipe, but thicknesses of 10, 15, 20, 25, and 30 mm?

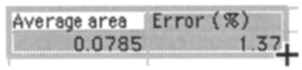
Approach:

We will calculate the arithmetic mean and logarithmic mean using a worksheet. We will use these areas to calculate the percent error. Then we will copy the formulas into other cells to determine the percent error for other thickness of pipe.

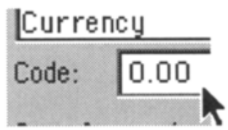
Programming the Worksheet:

1. Open a new worksheet maximized to full screen.
2. In cells A1:F5, type the text labels and data values as shown in Fig. 7.3
3. In cell B6, type the following formula:
   =PI()*$B$2

4. In cell C6, type the following formula:
   =PI()*($B$2+2*A6)
5. In cell D6, type the following formula:
   =(C6-B6)/LN(C6/B6)
6. In cell E6, type the following formula:
   =(C6+B6)/2
7. In cell F6, type the following formula:
   =(E6-D6)/D6*100
8. In cell A6, type **0.005**.
9. Insert thickness values in cells A7:A11 as shown in Fig. 7.3.
10. To complete the worksheet, we will use **AutoFill**.
    - Select cells B6:F6.
    - Point at the fill handle, the cursor will change to a solid cross.



    - Drag the solid cross to cell F11, this will fill cells B7:F11.
11. Select cells F6:F11, and change the format for numbers to two significant digits using the menu items **Format**, **Cells...**, select tab **Number** and type **0.00** in the **Code** box.



12. The results will be displayed as shown in Fig. 7.3.

Discussion:

The use of arithmetic average area instead of logarithmic mean area results in an error of 1.37% for a pipe of 2 cm diameter and 5 mm thickness. However, the error increases to 15.52% when the thickness for the 2 cm diameter pipe is 30 mm. Therefore, for thick pipes, it is advisable to use logarithmic mean areas.

Worksheet Comments:

In this worksheet, we used the **AutoFill** command to copy formulas into several cells. This shows the usefulness of the **AutoFill** feature in copying formulas to several cells with a single command.

	A	B	C	D	E	F
1	Given					
2	Diameter (m)	0.02				
3						
4	Solution					
5	Thickness	Inside Area	Outside Area	Log mean area	Average area	Error (%)
6	0.005	0.0628	0.0942	0.0775	0.0785	1.37
7	0.01	0.0628	0.1257	0.0906	0.0942	3.97
8	0.015	0.0628	0.1571	0.1029	0.1100	6.90
9	0.02	0.0628	0.1885	0.1144	0.1257	9.86
10	0.025	0.0628	0.2199	0.1254	0.1414	12.75
11	0.03	0.0628	0.2513	0.1360	0.1571	15.52

Figure 7.3 Worksheet for Example 7.2.

7.3 Selecting Insulation to Reduce Heat Loss from Cylindrical Pipes

Cylindrical pipes are commonly used in the food industry to transport steam, a variety of liquid foods, and chemicals. When the liquids or vapors being transported are hot, the heat transfer from the pipes must be minimized to conserve energy. A common approach to minimize heat loss is to install insulation on the pipe. In this worksheet, we will calculate heat loss from a given set of conditions. Then we will determine a new thermal conductivity of insulation that will reduce the heat loss to a prescribed value.

Problem Statement:

A steel pipe is being used to transport heated oil from a heat exchanger to a vessel. The pipe has an internal diameter of 8 cm and its thickness is 2 cm. The thermal conductivity of steel is 17 W/m°C. The temperature of the inside surface of the pipe is 130°C. The thermal conductivity of the insulation is 0.5 W/m°C. The temperature of the outside surface of the insulation must not be greater than 25°C. Calculate the rate of heat transfer through the pipe walls under steady state conditions. If your goal is to reduce this heat transfer by 90%, what will be the required thermal conductivity of insulation?

Approach:

Since steady state conditions prevail, we will use Eq. 4.36 given by Singh and Heldman (1993, p. 157). The equation is as follows:

$$q_r = \frac{T_1 - T_3}{\left(\frac{\Delta r}{kA_{lm}}\right)_{1-2} + \left(\frac{\Delta r}{kA_{lm}}\right)_{2-3}} .$$

Where T_1 and T_3 are the temperature (°C) of the inside pipe surface and outside surface of the insulation, respectively, Δr is the thickness (m), k is the thermal conductivity (W/m°C), and A_{lm} is the log mean area (m^2); 1–2 and 2–3 refer to the steel pipe thickness and insulation thickness, respectively.

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cell A1:B9, type the text labels and data values as shown in Fig. 7.4.
3. In cells A11: A17, type the text labels as shown in Fig. 7.4.
4. In cell B12, type the following formula:
   = B3/2
5. In cell B13, type the following formula:
   = B12+B2
6. In cell B14, type the following formula:
   =B13+B5
7. In cell B15, type the following formula:
   =2*PI()*(B13-B12)/LN(B13/B12)
8. In cell B16, type the following formula:
   =2*PI()*(B14-B13)/LN(B14/B13)
9. In cell B17, type the following formula:
   =(B7-B8)/(((B13-B12)/B4/B15)+((B14-B13)/B16/B6))
10. Your worksheet should look like Fig. 7.4.
11. To determine the insulation thickness for a reduced heat loss, we will use the **Goal Seek** command. Select cell B17.
12. Choose the menu commands **Tool**, **Goal Seek....** A dialog box will open.
13. In the exit box **Set cell:** type: **$B$17**, or first click inside the edit box then click on cell B17.
14. In the edit box **To value:**, type: **63.102**
15. In the edit box **By changing cell:**, type **$B$6** as shown in Fig. 7.5. Click **OK**.

16. The result will be shown in cell B17 in the worksheet (Fig. 7.6).

Discussion:

The heat loss from the pipe with given conditions is 631.02 W. To reduce this value by 90%, the heat loss must be 63.102 W; using the **Goal Seek** command, we determine, as expected intuitively, that the new insulation must have a thermal conductivity of 0.049 W/m°C.

Worksheet Comments:

In this worksheet, we used the **Goal Seek** command to determine the value of a dependent variable, namely, thermal conductivity of the insulation. Note that when using the **Goal Seek** command, your "goal" cell must have a formula in it, and the cell where you change the value must be referenced by that formula. For example, in our case, the "goal" cell was B17 and the reference cell was B6.

	A	B
1	Given	
2	Thickness of pipe, m	0.02
3	Inside diameter,m	0.08
4	k_steel, W/mC	17
5	Thickness of insulation, W/mC	0.04
6	k_insulation, W/mC	0.5
7	Temp inside pipe surface, C	130
8	Temp outside insulation, C	25
9	Pipe length, m	1
10		
11	Solution	
12	Inside radius, m	0.04
13	Interfacial radius, m	0.06
14	Outside radius, m	0.1
15	A_logmean12, m^2	0.31
16	A_logmean23, m^2	0.49
17	Rate of Heat transfer, W	631.02

Figure 7.4 Worksheet for Example 7.3.

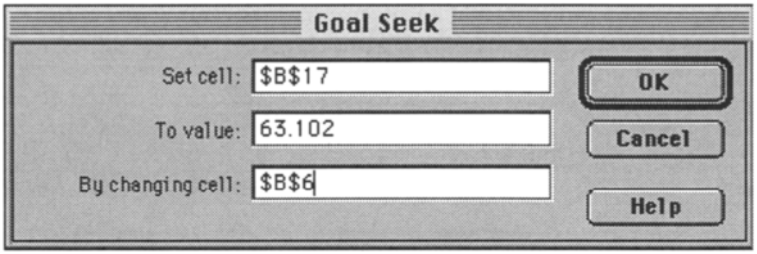


Figure 7.5 **Goal Seek** command used in Example 7.3.

	A	B
1	Given	
2	Thickness of pipe, m	0.02
3	Inside diameter,m	0.08
4	k_steel, W/mC	17
5	Thickness of insulation, W/mC	0.04
6	k_insulation, W/mC	0.049
7	Temp inside pipe surface, C	130
8	Temp outside insulation, C	25
9	Pipe length, m	1
10		
11	Solution	
12	Inside radius, m	0.04
13	Interfacial radius, m	0.06
14	Outside radius, m	0.1
15	A_logmean12, m^2	0.31
16	A_logmean23, m^2	0.49
17	Rate of Heat transfer, W	63.10

Figure 7.6 Worksheet after using the **Goal Seek** command.

7.4 Convective Heat Transfer Coefficient in Laminar Flow Conditions

Convective heat transfer coefficient (h value) is influenced by the velocity of the fluid at the surface of an object. Within laminar flow conditions, an increase in fluid velocity should increase the h value. This example is used to determine the extent of increase in h value with increasing fluid velocity.

Problem Statement:

Water is flowing in a pipe at a mass flow rate of 0.02 kg/s. The inlet temperature of the water is 20°C, while the exit temperature is 60°C. The inside diameter of the pipe is 0.025 m and the inside pipe surface temperature is 90°C. Calculate the convective heat transfer coefficient. Develop a plot of convective heat transfer coefficient as a function of mass flow rate if the flow rate is increased to 0.08 kg/s in increments of 0.02 kg/s.

Approach:

We will develop a worksheet where the given information and property data are obtained from table A.4.1 (p. 460) and Eq. 4.39 in Singh and Heldman (1993, p. 161). The equation is as follows:

$$N_{Nu} = 1.86\left(N_{\mathrm{Re}} \times N_{\mathrm{Pr}} \times \frac{D}{L}\right)^{0.33}\left(\frac{\mu_b}{\mu_w}\right)^{0.14},$$

where N_{Nu} is the Nusselt number; N_{Re} is the Reynolds number; N_{Pr} is the Prandtl number; D is the characteristic dimension or diameter of the pipe (m); L is the length of the pipe (m); μ_b is the bulk fluid viscosity evaluated at the average bulk fluid temperature, (Pas); μ_w is the fluid viscosity evaluated at the pipe wall temperature (Pas). This equation is valid only if $\left(N_{Re} \times N_{Pr} \times \frac{D}{L}\right) > 100$. We will check this condition in the worksheet.

> When you copy and paste a cell with a relative reference, the references change, but if you use cut and paste, the relative references do not change.

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cells A1:B14 and cells A15:A18, enter text labels and data values as shown in Fig. 7.7.
3. In cell B15, type the following formula to calculate the Reynolds number:
   =4*B2/PI()/B12/B5
4. In cell B16, type the following formula to calculate the conditional equation:
   =B15*B13*0.025
5. In cell B17, type the following formula to calculate the Nusselt number:
   =1.86*B16^0.33*(B12/B14)^0.14
6. In cell B18, type the following formula to calculate h value from the calculated Nusselt number.
   =B17*B11/B5
7. In cell C2, type **0.04**.
8. In cell D2, type **0.06**.
9. In cell E2, type **0.08**.
10. Using the **AutoFill** command, copy the contents of cell B3:B18 into cells C3:E18.
11. To create a chart, select cells B2:E2, and B18:E18.
12. Click on the **ChartWizard** button and create a chart using **XY (Scatter)** as the chart type in step 2. The chart will be as shown in Fig. 7.8.

Discussion:

The figure shows a nonlinear increase in convective heat transfer coefficient with an increase in mass flow rate of the fluid. As shown in Fig. 7.8, a fourfold increase in the mass flow rate results in about 160% increase in the convective heat transfer coefficient. This implies that the rate of heat transfer will also increase by a similar percentage when the mass flow rate is quadrupled.

Worksheet Comments:

In this worksheet, we used the arithmetic function *PI()*, the **AutoFill** command, and the **ChartWizard** to create a chart.

	A	B	C	D	E
1	Given				
2	Water flow rate, kg/s	0.02	0.04	0.06	0.08
3	Inlet temperature	20	20	20	20
4	Exit temperature, C	60	60	60	60
5	Inside diameter, m	0.025	0.025	0.025	0.025
6	Inside Pipe surface temperature, C	90	90	90	90
7					
8	Solution				
9	Density, kg/m^3	992.2	992.2	992.2	992.2
10	Specific Heat,kJ/kgC	4.175	4.175	4.175	4.175
11	Thermal conductivity, W/mC	0.633	0.633	0.633	0.633
12	Viscosity, Pas	0.000658026	0.00065803	0.00065803	0.00065803
13	Prandtl Number	4.3	4.3	4.3	4.3
14	Viscosity at 90 C, Pas	0.000308909	0.00030891	0.00030891	0.00030891
15	Reynold Number	1547.95	3095.90	4643.85	6191.80
16	N_Re*N_Pr*D/L	166.40	332.81	499.21	665.62
17	N_Nu	11.18	14.05	16.07	17.67
18	h	283.10	355.86	406.81	447.32

Figure 7.7 Worksheet for Example 7.4.

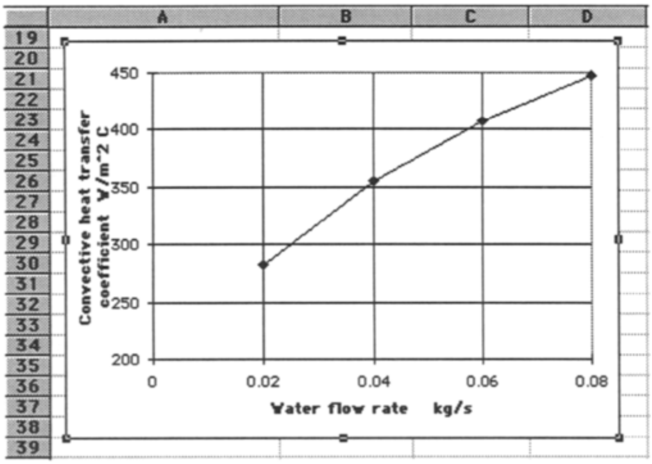


Figure 7.8 Convective heat transfer coefficient for different water flow rates.

7.5 Convective Heat Transfer Coefficient in Turbulent Flow Conditions

When a fluid is flowing inside a pipe under turbulent conditions, we can expect convective heat transfer coefficient to be considerably larger than that for laminar flow conditions. Within the turbulent flow conditions, an increase in flow rate should result in an increased convective heat transfer coefficient.

Problem Statement:

Water is flowing in a pipe at a mass flow rate of 0.2 m/s, The inlet temperature of the fluid is 20°C, while the exit temperature is 60°C. The inside diameter of the pipe is 0.025 m and the pipe surface temperature is 90°C. Determine the convective heat transfer coefficient. Determine the percent increase in convective heat transfer coefficient if the mass flow rate is increased from 0.2 to 1.0 kg/s in increments of 0.2 kg/s.

Approach:

We will use a worksheet to program equations for calculating convective heat transfer coefficient under turbulent conditions. We will also check to make sure that turbulent conditions prevail. We will use equation 4.40 (p. 163) and Table A.4 (p. 460) from Singh and Heldman(1993). The equation describing heat transfer under turbulent conditions is

$$N_{Nu} = 0.023 N_{\mathrm{Re}}^{0.8} \times N_{\mathrm{Pr}}^{0.33} \times \left(\frac{\mu_b}{\mu_w} \right)^{0.14},$$

where N_{Nu} is the Nusselt Number, N_{Re} is the Reynolds number, N_{Pr} is the Prandtl number, μ_b is the fluid viscosity at bulk fluid temperature (Pas), and μ_w is the fluid viscosity at wall temperature (Pas).

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cells A1:B14 and A15:A19, type the text labels and data values as shown in Fig. 7.9.
3. In cell B15, type the following formula:
   =4*B2/PI()/B12/B5
4. In cell B16, type the following formula:
   =0.023*(B15^0.8)*(B13^0.33)*(B12/B14)^0.14
5. In cell B17, type the following formula:
   =B16*B11/B5
6. In cell B18, type **0**.
7. In cell B19, type **0**.
8. In cell C18 , type the following formula:
   =(C2-$B$2)/$B$2*100
9. In cell C19, type the following formula:
   =(C17-$B$17)/$B$17*100
10. Using the **AutoFill** command, copy the contents of cells B15:B17 into cells C15:F17.
11. Using the **AutoFill** command, copy the contents of cells C18:C19 into cells D18:F19
12. The results will be displayed as in Fig. 7.9.
13. Using cells B18:F19 and the **ChartWizard**, create an **XY (Scatter)** diagram as shown in Fig. 7.10.

> The hierarchy of mathematical operations is as follows: Addition, Subtraction, Negation, Multiplication, Division, Exponential, and Percentage. The respective symbols for these operations are +,-,-,*,/,^,%.

Discussion:

The results of this worksheet show that by increasing the flow rate by 400% the increase in the convective heat transfer coefficient is 262%.

Worksheet Comments:

In this worksheet, we programmed the equations and the property data to determine convective heat transfer coefficient. The results were used in creating an **XY (Scatter)** diagram.

	A	B	C	D	E	F
1	Given					
2	Water flow rate, kg/s	0.2	0.4	0.6	0.8	1
3	Inlet temperature	20	20	20	20	20
4	Exit temperature, C	60	60	60	60	60
5	Inside diameter, m	0.025	0.025	0.025	0.025	0.025
6	Inside Pipe surface temperature, C	90	90	90	90	90
7						
8	Solution					
9	Density, kg/m^3	992.2	992.2	992.2	992.2	992.2
10	Specific Heat, kJ/kgC	4.175	4.175	4.175	4.175	4.175
11	Thermal conductivity, W/mC	0.633	0.633	0.633	0.633	0.633
12	Viscosity, Pas	0.00065803	0.00065803	0.00065803	0.00065803	0.00065803
13	Prandtl Number	4.3	4.3	4.3	4.3	4.3
14	Viscosity at 90 C, Pas	0.00030891	0.00030891	0.00030891	0.00030891	0.00030891
15	Reynold Number	15479.5	30959.0	46438.5	61918.0	77397.5
16	N_Nu	93.0	161.9	224.0	282.0	337.1
17	h	2355.2	4100.6	5671.7	7139.5	8534.8
18	Percent increase in flow rate	0	100	200	300	400
19	Percent increase in h	0	74.1	140.8	203.1	262.4

Figure 7.9 Worksheet for Example 7.5.

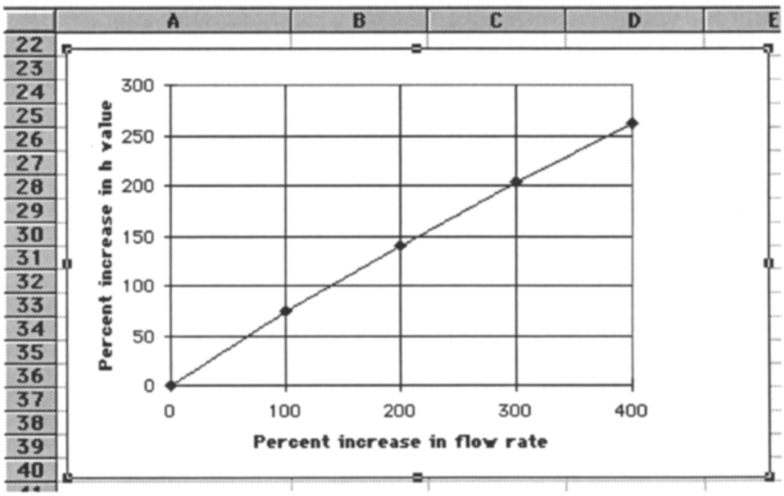


Figure 7.10 Percent increase in convective heat transfer coefficient with flow rate for data given in Example 7.5.

Chapter EIGHT

Transient Heat Transfer in Food Processing

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8.1 Predicting Temperature in a Liquid Food Heated in a Steam-Jacketed Kettle

Steam-jacketed kettles are commonly used in food processing to heat liquid foods such as juices, slurries, and sauces. Usually a mixer installed in the kettle provides a complete mixing of the liquid. In some cases, mixers with special blades provide a continuous sweeping action on the inside of kettle. In this example, we will use a mathematical model that predicts temperature in the kettle as a function of time.

Problem Statement:

Develop a temperature profile for a 0.26 m^3 batch of apple juice being heated in a steam-jacketed kettle. The outside convective heat transfer coefficient is 5000 $W/m^{2\circ}C$. The contact area between the juice and the inside surface of the kettle is 1.57 m^2; the density of the juice is 980 kg/m^3; the specific heat is 3.95 kJ/kg°C. The initial temperature of the juice is 25°C and the steam is available at 95°C. Examine the influence of changing the external convective heat transfer coefficient on the temperature profile.

Approach:

The juice in the kettle is continuously mixed, therefore temperature does not change with location inside the kettle. We will use Eq. 4.80, p. 191, in Heldman and Singh (1993). The equation is as follows:

$$\frac{T_a - T}{T_a - T_i} = e^{-(hA/\rho c_p V)t} \quad .$$

Where T_a is the surrounding medium temperature, °C; T is the unknown temperature, °C; T_i is the uniform initial temperature,

°C ; h is the convective heat transfer coefficient, W/m^2°C; A is the area, m^2; ρ is the density kg/m^3; V is the volume, m^3; t is the time, s.

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cells A1:B11, type the text labels and data values as shown in Fig. 8.1.
3. In cells A12:A24, insert a series, starting with 0 and an increment of 50.
4. In cell B12, type the following formula: **=B$8-(B$8-B$7)*EXP(-B$4*B$3*A12/B$5/B$6/1000/B$2)**
5. Copy the contents of cell B12 into cells B13:B24.
6. Using the data in cells A12:B24, create an **XY (Scatter)** diagram as shown in Fig. 8.2
7. Change the heat transfer coefficient in cell B4 and view the chart changing to reflect new temperature profile. Note that as the convective heat transfer coefficient increases, the profile becomes more steep, indicating a faster increase in temperature.

Discussion:

The convective heat transfer coefficient has a major influence on the rate of temperature increase in a liquid food being heated in a steam kettle. If hot water, instead of steam, is used in the jacketed space, the heat transfer coefficient will be much lower, indicating a reduced rate of temperature increase.

Worksheet Comments:

In this worksheet, we established a link between data in a cell and the chart. Thus, by changing a number in the cell that is used in calculations, we can immediately view the results on a chart.

	A	B
1	Given:	
2	Volume (m^3)	0.26
3	Area (m^2)	1.57
4	Heat transfer coefficient W/m^2 C)	5000
5	Density (kg/m^3)	980
6	Specific Heat (kJ/kg C)	3.95
7	Initial Temperature (C)	25
8	Steam Temperature (C)	95
9		
10	Solution:	
11	Time	Temperature
12	0	25.0
13	50	47.6
14	100	62.9
15	150	73.3
16	200	80.3
17	250	85.0
18	300	88.3
19	350	90.4
20	400	91.9
21	450	92.9
22	500	93.6
23	550	94.0
24	600	94.4

Figure 8.1 A worksheet for data given in Example 8.1.

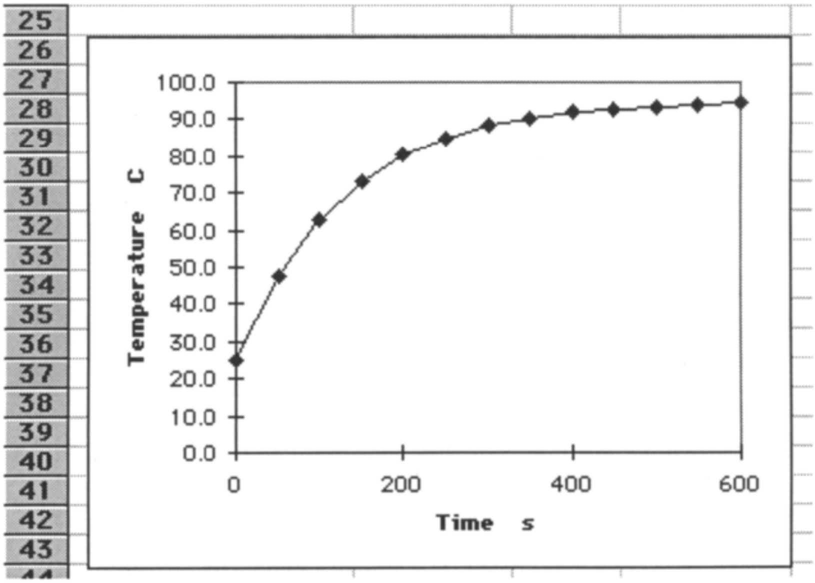


Figure 8.2 A plot of temperature history of a liquid food heated in a steam kettle.

8.2 Transient Heat Transfer in Spherical-Shaped Foods

When spherical-shaped foods are heated or cooled, the transient part of the heating or cooling process may be described by using an analytical solution of the governing partial differential equation. In this example, we will consider the cooling of a strawberry when placed in a stream of cold water.

Problem Statement:

Determine the cooling of a strawberry initially at 25°C in cold water at 2°C. Assume that the convective heat transfer coefficient is large, therefore the surface resistance to heat transfer is negligible. The diameter of the strawberry is 3 cm; the thermal conductivity is 0.35 W/m°C; the specific heat capacity, c_p, is 3.6 kJ/kg°C; the density is 900 kg/m^3.

Approach:

For this example, we will use a series solution of the governing transient heat transfer equation obtained for a sphere. This solution is given by Singh and Heldman (1993), as Eq. 4.86 on p. 204. The equation is as follows:

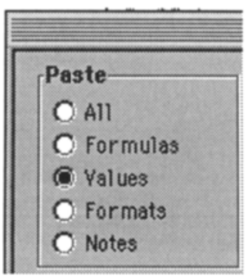
$$T = T_a + (T_a - T_i)\frac{2}{\pi}\left(\frac{D}{r}\right)\sum_{n=1}^{\infty}\frac{(-1)^{n+1}}{n}e^{(-n^2\pi^2\alpha t/D^2)}\sin(n\pi r/D) \ .$$

Where T is the unknown temperature, °C; T_a is the surrounding medium temperature, °C; T_i is the initial temperature, °C; D is the radius; r is radial location, m; n is the series counter; $\alpha t/D^2$ is the Fourier number; α is the thermal diffusivity, m^2/s; t is the time, s.

In this preceding equation, the radial location, r, appears in the denominator in the right-hand side. Therefore, this equation can not be used to determine the temperature at the center location. To avoid this numerical problem, when calculating temperature at the geometric center we will instead use a very small distance away from the center, e.g. $r/D = 0.0001$. Thus, we will obtain a temperature that may be considered to be, practically, the center temperature.

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cells A1:B11, type the text labels and data values as shown in Fig. 8.3.
3. In cells A12:A15, type the text labels as shown in Fig. 8.3.
4. In cells A16: A45, create a series starting from 1 to 30, with an increment of 1 using the **AutoFill** command.
5. In cell B12, type the following formula: **=SUM(B16:B45)*2/PI()*(1/$B$10)**
6. In cell B14:B15, type the text label as shown.
7. In cell B16, type the following formula: **=((-1^(A16+1))/A16*EXP(-A16*A16*PI()*PI()*$B$9)*SIN(A16*PI()*$B$10))**
8. Copy the contents of cell B16, into cells B17:B45.
9. In cells C11:F11, type the text labels as shown.
10. In cell C12: C16, type the data values as shown.
11. In cell D12, type the following formula: **=B$3*C12/B$5/B$4/1000/((B$2/100)^2)**
12. Copy the contents of cell D12 into cells D13:D16.
13. Select cell D12. Copy by using the menu items **Edit**, **Copy** or use the **Command+C** (**Ctrl+C** in Windows) keys.
14. Select cell B9. Select the menu items **Edit**, **Paste Special...**, a dialog box will open, select option **Values** under **Paste**. Click **OK**.
15. Select cell B12, copy by using menu items **Edit**, **Copy** or use the **Command+C** (**Ctrl+C** in Windows) keys.



16. Select cell E12. Select the menu items **Edit**, **Paste Special...**; a dialog box will open. Select option **Values** under **Paste**. Click **OK**.
17. Use steps 13 through 16, and paste values for Temperature Ratio in cells E13:E16.
18. In cell F 12, type the following formula: **=$B$7-E12*($B$7-$B$6)**
19. Copy the contents of cell F12 into cells F13:F16.
20. Using the values in cells C12:C16 and F12:F16, create an **XY (Scatter)** chart as shown in Fig. 8.5.

Discussion:

The decrease in temperature at the center of strawberry when placed in a stream of cold water is shown in Fig. 8.5.

Worksheet Comments:

In this worksheet, we created a series of 30 terms and obtained a summation of the series. We used the **Paste Special...** command to paste only the values instead of the entire cell contents. This is necessary when the target cell requires only a numerical value which is then used in subsequent computations. If we had used the regular **Paste** command, a formula will be pasted, giving erroneous results.

	A	B	C	D	E	F
1	Given:					
2	Diameter	3				
3	k	0.35				
4	cp	3.6				
5	density	900				
6	T_i	25				
7	T_a	2				
8						
9	Fourier Number =	0.012				
10	r/D =	0.00001				
11	Results		Time	Fourier Number	Temp Ratio	Temp
12	Temperature Ratio =	1.000	100	0.01200	1.0000	25.0
13			1000	0.12003	0.5943	15.7
14		Terms of Series	2000	0.24005	0.1869	6.3
15	n	term_n	3000	0.36008	0.0572	3.3
16	1	2.79071E-05	4000	0.48011	0.0175	2.4

Figure 8.3 A worksheet for data given in Example 8.2.

	A	B
17	2	-1.95596E-05
18	3	1.08174E-05
19	4	-4.72051E-06
20	5	1.6254E-06
21	6	-4.4161E-07
22	7	9.46718E-08
23	8	-1.60143E-08
24	9	2.13747E-09
25	10	-2.25111E-10
26	11	1.87067E-11
27	12	-1.2266E-12
28	13	6.34624E-14
29	14	-2.59079E-15
30	15	8.34554E-17
31	16	-2.12119E-18
32	17	4.25414E-20
33	18	-6.73206E-22
34	19	8.406E-24
35	20	-8.282E-26
36	21	6.43852E-28
37	22	-3.9495E-30
38	23	1.91163E-32
39	24	-7.30078E-35
40	25	2.20009E-37
41	26	-5.23137E-40
42	27	9.81513E-43
43	28	-1.45305E-45
44	29	1.69735E-48
45	30	-1.56447E-51

Figure 8.4 Continuation of a worksheet for data given in Example 8.2.

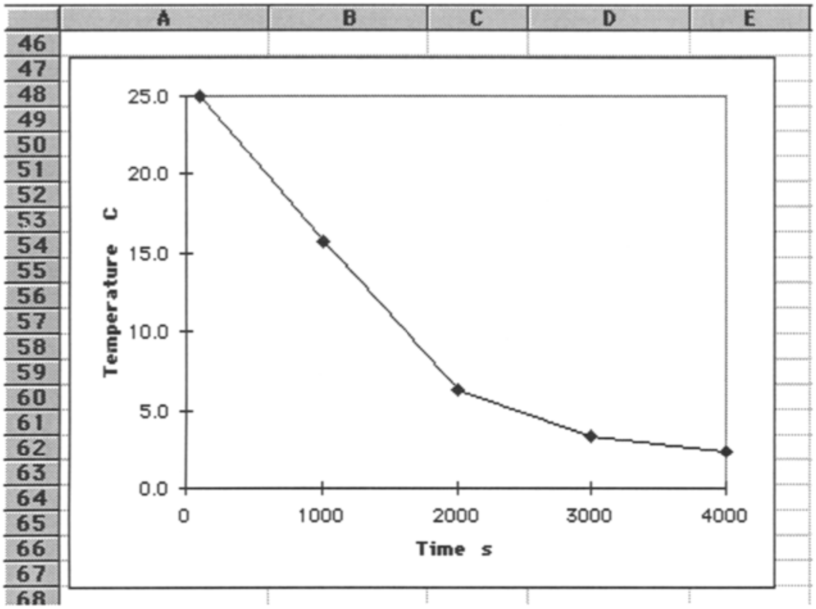


Figure 8.5 A plot of temperature at the geometric center of a sphere.

8.3 Prediction of Temperature in an Infinite Cylinder during Heating or Cooling Processes

To predict temperature inside an infinite cylinder during heating or cooling processes, we can use analytical solutions of the governing partial differential equation. These solutions involve summation of several terms of an infinite series. As the number of terms in a series increases, the values of the higher order terms decrease and become negligible. In this example, we will program a series solution that involves an infinite cylinder.

Problem Statement:

Program the analytical solution of transient heat conduction in an infinite cylinder when the surface resistance to heat transfer is considered to be negligible. Determine the temperature ratio when the Fourier number is 0.2 and the location is one-tenth of the radius from the geometric center.

Approach:

We will use a series solution of a partial differential equation that describes transient heat transfer in a solid infinite cylinder. The solution is given in Singh and Heldman (1993), equation 4.84, p. 204, as shown in the following equation:

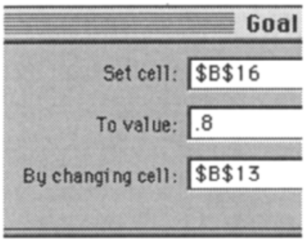
$$T = T_a + 2(T_i - T_a)\sum_{n=0}^{\infty} \frac{e^{-\lambda_n^2 \alpha t / D^2} J_o(\lambda_n r / D)}{\lambda J_1(\lambda_n)} .$$

Where T is the unknown temperature, °C; T_a is the surrounding medium temperature, °C; T_i is the initial temperature, °C; D is the radius, m; r is the radial location, m; n is the series counter; $\alpha t/D^2$ is the Fourier number; α is the thermal diffusivity, m^2/s;

J_o is the Bessel function of zero order; J_1 is the Bessel function of first order; λ_n is the root; t is the time, s.

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cells A1:F1, type the text labels as shown in Fig. 8.6.
3. In cells A2: A11 create a series, beginning with 0 to 9 with an interval of 1 using the **AutoFill** command.
4. In cells B2:B11, type the data values as shown. Note that all significant digits must be typed.
5. In cells A12:A16, type the text labels as shown in Fig. 8.6.
6. In cell B13:B14, type the data values as shown in Fig. 8.6.
7. In cell C2, type the following formula:
   =$B$14*B2
8. Copy the contents of cell C2 into cells C3:C11 using the **AutoFill** command.
9. In cell D2, type the following formula:
   =BESSELJ(C2,0)
10. Copy the contents of cell D2 into cells D3:D11 using the **AutoFill** command.
11. In cell E2, type the following formula:
    =BESSELJ(B2,1)
12. Copy the contents of cell E2 into cells E3:E11 using the **AutoFill** command.
13. In cell F2, type the following formula:
    =EXP(-B2*B2*$B$13)*D2/(B2*E2)
14. Copy the contents of cell F2 into cells F3:F11 using the **AutoFill** command.
15. In cell B16, copy the following formula:
    =2*SUM(F2:F11)
16. If you want to determine a Fourier number for a known value of Temperature Ratio, you may use the **Goal Seek** command. For example, let us determine Fourier number if the desired temperature ratio is 0.8.



17. Choose the menu items **Tools**, **Goal Seek....** A dialog box will open.
18. Enter items in the edit boxes as shown. Click **OK**.
19. The calculations will yield a Fourier number of 0.11

Discussion:

The temperature ratio or the Fourier number may be determined using the worksheet developed in this worksheet.

Worksheet Comments:

In this worksheet, we used the functions *BESSELJ(), SUM(), EXP()*. These functions are available under **Engineering** functions when the **Function Wizard** is activated. If the **Engineering** functions are not available, then you must use **Add-Ins...** under the **Tools** menu to install as was previously shown in Section 1.24.

	A	B	C	D	E	F
1	n	lambda_n	(lambda_n)*r/D	Jo	J1	Terms in Series
2	0	2.4048255577	0.240482556	1	0.5191475	0.248314826
3	1	5.5200781103	0.552007811	1	-0.340265	-0.001111224
4	2	8.6537279129	0.865372791	1	0.2714523	1.09405E-07
5	3	11.7915344391	1.179153444	1	-0.23246	-2.08276E-13
6	4	14.9309177086	1.493091771	1	0.2065464	7.23804E-21
7	5	18.0710639679	1.807106397	0	-0.187729	-4.2727E-30
8	6	21.2116366299	2.121163663	0	0.1732659	3.49304E-41
9	7	24.3524715308	2.435247153	-0	-0.161702	1.22848E-54
10	8	27.4934791320	2.749347913	-0	0.1521812	-8.64967E-68
11	9	30.6346064684	3.063460647	-0	-0.144166	1.94123E-83
12	Input:					
13	Fourier Number	0.2				
14	Radial location/Diameter, r/D	0.1				
15	Result:					
16	Temperature Ratio	0.494				

Figure 8.6 A worksheet for data given in Example 8.3.

8.4 Predicting Transient Heat Transfer in an Infinite Slab during Heating or Cooling Processes

Heat transfer in an infinite slab occurs from only two opposing surfaces, the heat transfer from the other four sides of the slab is considered negligible. In food processing, many flat shaped objects may be approximated as an infinite slab. In this example, we will use the analytical solution of the governing heat transfer equation written for an infinite-slab shaped object. The solution assumes negligible resistance to convective heat transfer at the surface of the object.

Problem Statement:

Using the analytical solution for transient heat transfer in an infinite slab, program a worksheet that allows determining temperature at any location in the slab as a function of Fourier number.

Approach:

We will use a series type solution for the infinite slab geometry given by Singh and Heldman (1993), Eq. 2.85, p. 204. The series solution is as follows:

$$T = T_a + (T_i - T_a)\sum_{n=0}^{\infty}\frac{\left[2(-1)^n\right]e^{-\lambda_n^2 \alpha t / D^2}}{\lambda_n}\cos(\lambda_n x / D) \ .$$

Where T is the unknown temperature, °C; T_a is the surrounding medium temperature, °C; T_i is the initial temperature, °C; D is the half-thickness of slab, m; x is the spatial location, m; n is the series counter; $\alpha t/D^2$ is the Fourier number; α is the thermal diffusivity, m^2/s; λ_n is the root; t is the time, s.

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2) In cells A1:A5, B2:B3, C1:E2, type the text labels and data values as shown in Fig. 8.7.
3) In cell C3:C33, enter a series, starting with 0 to 30 with an interval of 1 using the **AutoFill** command.
4) In cell D3, type the following formula:
   =(2*C3+1)/2*PI()
5) Copy the contents of cell D3 into cells D4:D33.
6) In cell E3, type the following formula:
   =(2*(-1)^C3)*EXP(-D3*D3*$B$2)/D3*COS(D3*$B$3)
7) Copy the contents of cell E3 into cells E4:E33.
8) In cell B5, type the following formula:
   =SUM(E3:E33)

Discussion:

Excel supports numbers within the range -9.99999999999999^{307} to 9.99999999999999^{307}

The temperature ratio for a given Fourier number and x/D ratio is displayed in cell B5. In this worksheet, we used first 30 terms of the series solution. If you are using very small Fourier number, it may be useful to increase the number of terms in the series. This can be easily done by copying cells C3:C33 into the additional cells and modifying the summation term used in cell B5. Observe that in our example the final terms in the series are extremely small and negligible for example, for n=26, the quantity is 2.3378×10^{-303} as seen in cell C29.

Worksheet Comments:

In this worksheet, we used trigonometric functions and summation series to obtain results for the series solution. You can use the **Goal Seek** command to obtain Fourier number for a desired Temperature Ratio. See Example 8.3.

	A	B	C	D	E
1					Terms of Series
2	Fourier Number =	0.1	n	lambda_n	term_n
3	x/D =	0.3	0	1.570796327	0.886406913
4	Results		1	4.71238898	-0.007206103
5	Temperature Ratio =	0.8788	2	7.853981634	-0.000377119
6			3	10.99557429	1.00855E-06
7			4	14.13716694	-1.34254E-10
8			5	17.27875959	-5.68149E-15
9			6	20.42035225	7.51462E-20
10			7	23.5619449	-4.65354E-26
11			8	26.70353756	-1.25942E-33
12			9	29.84513021	1.23608E-40
13			10	32.98672286	-2.99193E-49
14			11	36.12831552	1.78239E-59
15			12	39.26990817	3.82637E-69
16			13	42.41150082	-3.54879E-80
17			14	45.55309348	1.51284E-92
18			15	48.69468613	1.9583E-105
19			16	51.83627878	-7.693E-119
20			17	54.97787144	1.3866E-133
21			18	58.11946409	1.0763E-149
22			19	61.26105675	-2.9965E-165
23			20	64.4026494	2.04E-182
24			21	67.54424205	-3.3953E-201
25			22	70.68583471	-2.0253E-219
26			23	73.82742736	5.1964E-239

Figure 8.7 A worksheet for data given in Example 8.4.

27			24	76.96902001	-6.1055E-260
28			25	80.11061267	-2.1716E-281
29			26	83.25220532	2.3378E-303
30			27	86.39379797	0
31			28	89.53539063	0
32			29	92.67698328	0
33			30	95.81857593	0

Figure 8.8 Continuation of a worksheet for data given in Example 8.4.

8.5 Predicting Transient Heat Transfer in a Finite Cylinder

Prediction of transient heat transfer in a finite cylinder requires the use of analytical solutions obtained for both infinite cylinders and infinite slabs. The temperature ratios determined for both the infinite shapes are multiplied with each other to calculate the temperature ratio for a finite cylinder. In food processing, this problem is often encountered in the canning process. The temperature of interest is mostly at the geometric center of a conduction heating food in a cylindrical can. The following worksheet is useful for this purpose.

Problem Statement:

Determine the temperature after 30 min at the geometric center of a 303 × 406 can when placed in boiling water at 100°C. The can contains a conduction heating food such as a yam. The initial uniform temperature of the can contents is 35°C. The thermal properties of the food are as follows: the thermal conductivity is 0.34 W/m°C; the density is 900 kg/m^3; the specific heat is 3.5 kJ/kg°C. Assume that the convective heat transfer coefficient is very large such that there is negligible resistance to heat transfer at the surface of the can.

Approach:

Using the convention used in the canning industry, the can dimensions are as follows:
Diameter = 3 3/16 inches = 0.081 m
Height = 4 6/16 inches = 0.11 m
We will create three worksheets: the first worksheet will be the main worksheet containing the given data and the calculated results, the second worksheet will be a template for the infinite cylinder and the third worksheet will be a template for the infinite slab.
From the templates we will calculate the temperature ratios, then we will use the following expression, Eq. 4.82, p. 198, given

by Singh and Heldman (1993) to determine the temperature ratio for a finite cylinder:

$$\left(\frac{T_a - T}{T_a - T_i}\right)_{\substack{\text{finite}\\ \text{cylinder}}} = \left(\frac{T_a - T}{T_a - T_i}\right)_{\substack{\text{infinite}\\ \text{cylinder}}} \times \left(\frac{T_a - T}{T_a - T_i}\right)_{\substack{\text{infinite}\\ \text{slab}}}.$$

Where T is the unknown temperature, °C; T_a is the surrounding medium temperature, °C; T_i is the initial temperature, °C.

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. Select Sheet2 tab, rename it using by pointing at the sheet tab while keeping the **Control** key pressed (in Excel for Windows, point at the sheet tab and press the right mouse button). A menu pad will open. Select **Rename....** A dialog box will open, type **Infinite Cylinder**. Click **OK**.
3. In cells A1:F1, type the text labels as shown in Fig. 8.9.
4. In cells A2:A11, create a series starting with 0 to 9 with an increment of 1.
5. In cells B2:B11, type the data values as shown in Fig. 8.9.
6. In cell C2, type the following formula:
   ='Finite Cylinder'!$B$4*B2
7. In cell D2, type the following formula:
   =BESSELJ(C2,0)
8. In cell E2, type the following formula:
   =BESSELJ(B2,1)
9. In cell F2, type the following formula:
   =EXP(-B2*B2*'Finite Cylinder'!$B$13)*D2/(B2*E2)
10. Copy the contents of cells C2:F2 into cells C3:F11 using the **AutoFill** command.
11. Select the sheet tab Sheet3. A new worksheet will open. Keeping **Control** key pressed point at the sheet tab name (in Excel for Windows, point at the sheet tab and press the right mouse button). A menu pad will open. Select **Rename....** A

dialog box will open. Type **Infinite Slab**. Click **OK**.

12. In cells A1:C2, type the text labels as shown in Fig. 8.10.
13. In cells A3:A33, create a series from 0 to 30 with an increment of 1 using the **AutoFill** command.
14. In cell B3, type the following formula: **=(2*A3+1)/2*PI()**
15. In cell C3, type the following formula. **=(2*(-1)^A3)*EXP(-B3*B3*'Finite Cylinder'!$B$14)/B3*COS(B3*'Finite Cylinder'!$B$4)**
16. Copy the contents of cell B3:C3 into B4:C33 using the **AutoFill** command.
17. Select the sheet tab Sheet1. A new worksheet will open. Keeping **Control** key pressed, point at the sheet tab name (in Excel for Windows, point at the sheet tab and press the right mouse button). A menu pad will open. Select **Rename....** A dialog box will open. Type **Finite Cylinder**. Click **OK**
18. Select sheet tab **Finite Cylinder**.
19. In cells A1:B12, type the text labels and data values as shown in Fig. 8.11.
20. In cells A13:A18, type the text labels as shown in Fig. 8.11.
21. In cell B13, type the following formula: **=B5*B8/B7/B6/1000/(B3/2)^2**
22. In cell B14, type the following formula: **=B5*B8/B7/B6/1000/(B2/2)^2**
23. In cell B15, type the following formula: **=2*SUM('Infinite Cylinder'!F2:F11)**
24. In cell B16, type the following formula: **=SUM('Infinite Slab'!C3:C33)**
25. In cell B17, type the following formula: **=B15*B16**
26. In cell B18, type the following formula: **=B10-B17*(B10-B9)**
27. The predicted temperature at 1800 s is shown in cell B18.

Discussion:

This worksheet uses results from both the infinite cylinder and infinite slab shape to predict temperature at the geometric center of a finite cylinder after a desired heating or cooling time. This worksheet is useful to investigate the relative effect of container height or diameter on the final temperature. You may change the diameter or height to different values other than those used in this example to explore how the dimensions of a finite cylinder influence the final results.

Worksheet Comments:

In this worksheet, we used three linked worksheets and programmed two different series.

	A	B	C	D	E	F
1	n	lambda_n	lambda_n)*r/	Jo	J1	Terms in Series
2	0	2.4048255577	0	1	0.5191475	0.40376518
3	1	5.5200781103	0	1	-0.3402648	-0.0144127
4	2	8.6537279129	0	1	0.2714523	5.9812E-05
5	3	11.7915344391	0	1	-0.2324598	-2.568E-08
6	4	14.9309177086	0	1	0.20654643	1.1038E-12
7	5	18.0710639679	0	1	-0.1877288	-4.683E-18
8	6	21.2116366299	0	1	0.17326589	1.947E-24
9	7	24.3524715308	0	1	-0.1617016	-7.9E-32
10	8	27.4934791320	0	1	0.15218121	3.1195E-40
11	9	30.6346064684	0	1	-0.144166	-1.197E-49
12						

Finite Cylinder | **Infinite Cylinder** | Infinite Slab | Sheet4 | Sheet5 | She

Figure 8.9 A worksheet for data given in Example 8.5 for an infinite cylinder case.

	A	B	C
1			Terms of Series
2	n	lambda_n	term_n
3	0	1.570796327	1.086641219
4	1	4.71238898	-0.101946747
5	2	7.853981634	0.004845533
6	3	10.99557429	-7.71683E-05
7	4	14.13716694	3.76641E-07
8	5	17.27875959	-5.44277E-10
9	6	20.42035225	2.28939E-13
10	7	23.5619449	-2.77608E-17
11	8	26.70353756	9.64587E-22
12	9	29.84513021	-9.56561E-27
13	10	32.98672286	2.6998E-32
14	11	36.12831552	-2.16429E-38
15	12	39.26990817	4.92046E-45
16	13	42.41150082	-3.16877E-52
17	14	45.55309348	5.77531E-60
18	15	48.69468613	-2.97672E-68
19	16	51.83627878	4.33632E-77
20	17	54.97787144	-1.78448E-86
21	18	58.11946409	2.07362E-96
22	19	61.26105675	-6.8019E-107
23	20	64.4026494	6.2962E-118
24	21	67.54424205	-1.6443E-129
25	22	70.68583471	1.2112E-141
26	23	73.82742736	-2.5161E-154
27	24	76.96902001	1.4738E-167
28	25	80.11061267	-2.4337E-181
29	26	83.25220532	1.1329E-195
30	27	86.39379797	-1.4863E-210
31	28	89.53539063	5.4959E-226
32	29	92.67698328	-5.7268E-242
33	30	95.81857593	1.6815E-258

Infinite Slab / Sheet4 / Sheet5

Figure 8.10 A worksheet for data given in Example 8.5 for an infinite slab case.

	A	B	C
1	Given:		
2	Height (m)	0.11	
3	Diameter (m)	0.081	
4	Location from center (m)	0	
5	Thermal Conductivity (W/mK)	0.34	
6	Specific heat (kJ/kgK)	3.5	
7	Density (kg/m^3)	900	
8	Time (s)	1800	
9	Initial Temperature (C)	35	
10	Heating Medium Temperature (C)	100	
11			
12	Solution:		
13	Fourier Number (Inifinite Cylinder)	0.118	
14	Fourier Number (Infinite Slab)	0.064	
15	T.R._(Infinite Cylinder)	0.779	
16	T.R._(Infinite Slab)	0.989	
17	T.R._(Finite Cylinder)	0.771	
18	Temperature (C)	49.9	
19			
20			
21			

Finite Cylinder / Infinite Cylinder / Infinite Slab

Figure 8.11 A worksheet for data given in Example 8.5.

8.6 Transient Heat Transfer in a Cube

Prediction of temperature at a desired location inside a cube requires the use of an infinite slab solution. Since a cube has the same length, width and height, the temperature ratios calculated from an infinite slab solution are multiplied three times to obtain the required temperature ratio.

Problem Statement:

Determine the temperature at the geometric center of a cube of an engineered food with a length of 4 cm when placed in a stream of cold water at 2°C for 720 s. The uniform initial temperature of the cube is 55°C. The thermal properties of the food are as follows: the thermal conductivity is 0.56 W/m°C; the specific heat is 3.4 kJ/kg°C; the density is 950 kg/m^3.

Approach:

We will create two linked worksheets, the first with given data and the second with a template for an infinite slab. We will calculate the Fourier number in the first worksheet. The template will be used to determine the temperature ratio for a known Fourier number and return the calculated value of temperature ratio to the first worksheet. The template will contain the series solution for an infinite slab geometry as presented previously in example 8.4.
Using the infinite slab template, we will calculate the temperature ratio, then we will use the following expression, slightly modified Eq. 4.83, p. 198 given by Singh and Heldman (1993) to determine the temperature ratio for a cube:

$$\left(\frac{T_a - T}{T_a - T_i}\right)_{\text{cube}} = \left(\frac{T_a - T}{T_a - T_i}\right)^3_{\substack{\text{infinite}\\ \text{slab}}} .$$

Where T is the unknown temperature, °C; T_a is the surrounding medium temperature, °C; T_i is the initial temperature, °C;

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. Select the tab **Sheet1** while keeping the **Control** key pressed (in Excel for Windows, point at the sheet tab and press the right mouse button). A menu pad will open. Select **Rename....** A dialog box will open. Type **Cube**. Click **OK**.
3. Select the tab **Sheet2** while keeping the **Control** key pressed (in Excel for Windows, point at the sheet tab and press the right mouse button). A menu pad will open. Select **Rename....** A dialog box will open. Type **Infinite Slab**. Click **OK**.
4. In cells A1:C2, type the text labels as shown in Fig. 8.12.
5. In cells A3:A33, create a series from 0 to 30 with an increment of 1 using the **AutoFill** command.
6. In cell B3, type the following formula:
   =(2*A3+1)/2*PI()
7. In cell C3, type the following formula:
   =(2*(-1)^A3)*EXP(-B3*B3*Cube!$B$12)/B3*COS(B3*Cube!$B$3)
8. Copy the contents of cell B3:C3 into cells B4:C33 using the **AutoFill** command.
9. Select the sheet tab **Cube**.
10. In cells A1:B11, type the text labels and data values as shown in Fig. 8.13.
11. In cell A12:A15, type the text labels as shown in Fig. 8.13.
12. In cell B12, type the following formula:
    =B4*B7/B6/B5/1000/(B2/2)^2
13. In cell B13, type the following formula:
    =SUM('Infinite Slab'!C3:C33)
14. In cell B14, type the following formula:
    =B13^3
15. In cell B15, type the following formula:
    =B9-B14*(B9-B8)

16. The result will be displayed in cell B15.

Discussion:

In this example, we calculated the temperature ratio for an infinite slab and raised to the power of 3. We can use this worksheet either for cooling or heating applications. We cannot use this method for predicting temperatures if the cooling range involves a phase change, e.g., the freezing process. In addition, this method is limited to conduction heating foods. We assumed that the surface resistance to heat transfer is negligible; i.e., the convective heat transfer coefficient is large.

Worksheet Comments:

We used linked worksheets to determine the temperature ratio from a calculated value of Fourier number. In the template, we created a series and used the sum of 30 terms in the series to obtain the temperature ratio. If necessary, you can easily increase the terms from 30 to any other number as desired.

	A	B	C
1			Terms of Series
2	n	lambda_n	term_n
3	0	1.570796327	0.589519191
4	1	4.71238898	-0.00041503
5	2	7.853981634	1.1108E-09
6	3	10.99557429	-7.47508E-18
7	4	14.13716694	1.15686E-28
8	5	17.27875959	-3.97782E-42
9	6	20.42035225	2.98751E-58
10	7	23.5619449	-4.85378E-77
11	8	26.70353756	1.69568E-98
12	9	29.84513021	-1.2687E-122
13	10	32.98672286	2.0273E-149
14	11	36.12831552	-6.9047E-179
15	12	39.26990817	5.0045E-211
16	13	42.41150082	-7.7103E-246
17	14	45.55309348	2.5228E-283
18	15	48.69468613	0
19	16	51.83627878	0
20	17	54.97787144	0
21	18	58.11946409	0
22	19	61.26105675	0
23	20	64.4026494	0
24	21	67.54424205	0
25	22	70.68583471	0
26	23	73.82742736	0
27	24	76.96902001	0
28	25	80.11061267	0
29	26	83.25220532	0
30	27	86.39379797	0
31	28	89.53539063	0
32	29	92.67698328	0
33	30	95.81857593	0

Cube | Infinite Slab | Sheet3 | S

Figure 8.12 A worksheet for data given in Example 8.6 for an infinite slab.

	A	B
1	Given:	
2	Height (m)	0.04
3	Location from center (m)	0
4	Thermal Conductivity (W/mK)	0.56
5	Specific heat (kJ/kgK)	3.4
6	Density (kg/m^3)	950
7	Time (s)	720
8	Initial Temperature (C)	55
9	Cooling Medium Temperature (C)	2
10		
11	Solution:	
12	Fourier Number (Infinite Slab)	0.312
13	T.R._(Infinite Slab)	0.589
14	T.R._(Finite Slab)	0.204
15	Temperature (C)	12.8
16		

Cube / Infinite Slab / Sheet3 / Sheet4

Figure 8.13 A worksheet for data given in Example 8.6 for a cube.

8.7 Transient Heat Transfer in a Semi-infinite Slab

When heating or cooling an object whose dimensions extend to infinity, we can use an analytical solution for heat transfer in a semi-infinite slab. In food processing, there are several examples of such situations. A pallet located in a cold room may be considered a semi-infinite slab. In this example, we will determine the temperature at a desired location when a semi-infinite object is cooled in a convective environment.

Problem Statement:

Consider the cooling of a lamb carcass that is 25 cm thick. Assume that the length and width of the carcass extends to infinity. We are interested in finding out the temperature of the carcass at a location 2 cm from the surface after 30 min of cooling. The initial temperature is 40°C; the surrounding air temperature is 1°C; the convective heat transfer coefficient is 30 W/m^2°C; the thermal conductivity is 0.4 W/m°C; the specific heat is 3550 J/kg°C; the density is 1040 kg/m^3.

Approach:

We will use an equation given as Eq. 88, p. 284 by Toledo (1991). The equation is as follows:

$$\frac{T - T_m}{T_o - T_m} = erf\left[\frac{x}{\sqrt{4\alpha t}}\right] + e^{hx/k + (h/k)^2 \alpha t}\left[erfc\left[\frac{x}{\sqrt{4\alpha t}} + \frac{h}{k}\sqrt{\alpha t}\right]\right].$$

Where T is the unknown temperature, °C; T_m is the surrounding medium temperature, °C, T_o is the initial temperature °C; x is the distance between the surface and the desired location in the object, m; α is the thermal diffusivity, m^2/s; t is the time, s; k is the thermal conductivity, W/m°C; h is the convective heat transfer coefficient, W/m^2°C.

Toledo (1991) gives the following criterion to check the validity of this method. The Fourier number for a given problem must be smaller than the critical Fourier number obtained from the following expression:

$$N_{Fo\ critical} = 0.00756\ N_{Bi}^{-0.3} + 0.02\ .$$

Where N_{Bi} is the Biot number. We will use this criteria in our worksheet to check the difference between the values of calculated and critical Fourier numbers.

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cells A1:A19, type the text labels as shown in Fig. 8.14.
3. In cells B2:B10, type the data values as shown in Fig. 8.14.
4. In cell B13, type the following formula:
   =B8/B7/B9
5. In cell B14, type the following formula:
   =B4/2/100
6. In cell B15, type the following formula:
   =B10*B5/100/B8
7. In cell B16, type the following formula:
   =0.00756*B15^(-0.3)+0.02
8. In cell B17, type the following formula:
   =(B8/(B7*B9))*B6*60/B14^2
9. In cell B18, type the following formula:
   =IF(B17<B16,ERF(B5/100/(4*B13*B6*60)^0.5)+EXP(B15+(B10/B8)^2*B13*B6*60)*(ERFC(B5/100/(4*B13*B6*60)^0.5+(B10/B8)*(B13*B6*60)^0.5)), "Method Invalid")
10. In cell B19, type the following formula:
    =B3+B18*(B2-B3)

Discussion:

The predicted temperature at any time and location may be calculated using this method. The only limitation is the criterion that the Fourier number is less than the critical Fourier number.

When the Fourier number exceeds the critical value, a message indicates that this method is invalid.

Worksheet Comments:

In this worksheet, we used two engineering functions, error function, *ERF()*, and complimentary error function, *ERFC()*. We also used the *IF()* function to test the validity of the method.

	A	B
1	Given:	
2	Initial Temperature (C)	40
3	Surrounding Air Temperature (C)	1
4	Thickness (cm)	25
5	Location from surface (cm)	2
6	Time (minutes)	30
7	Density (kg/m^3)	1040
8	Thermal Conductivity (W/mC)	0.4
9	Specific heat (J/kg K)	3550
10	Convective heat transfer coeffcient (W/m^2 C)	30
11		
12	Solution:	
13	Thermal Diffusivity	1.08E-07
14	Half thickness	0.125
15	Biot Number	1.500
16	Fo Critical	0.027
17	Fourier Number	0.012
18	Temperature Ratio	0.858
19	Temperature at desired location (C)	34.5

Figure 8.14 A worksheet for data given in Example 8.7.

Chapter NINE

Refrigeration, Freezing, and Cold Chain

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9.1 Pressure–Temperature Relations for Ammonia Used as a Refrigerant in a Vapor Compression Refrigeration System

In operating a refrigeration system, one relies on the pressure data obtained from two key pressure gauges. These gauges are used to determine the high and low pressures in the system.The low pressure gauge gives the suction pressure at the compressor, whereas the high pressure gauge is used to determine the compressor discharge pressure. These pressures are directly related to the temperatures of the refrigerant in the evaporator and the condenser. In this example, we will develop a worksheet that will convert pressure values obtained from a pressure gauge into temperatures for a given refrigerant.

Problem Statement:

Develop a worksheet to convert pressure into temperature for ammonia used as a refrigerant in a vapor compression refrigeration systesm. Construct a plot of temperature and pressure that may be used to read temperature values from the known pressure data.

Approach:

To construct this worksheet, we will use an empirical equation given by Cleland (1986) and cited as Equation 7.2 in Singh and Heldman (1993). The equation is

$$P_{sat} = e^{(a_1 + a_2/(T_{sat} + a_3))} ,$$

where P_{sat} is saturation pressure (kPa) and T_{sat} is saturation temperature (°C). Constants a_1, a_2, and a_3 are 22.11874, -2233.8226, and 244.2, respectively.

Programming the Worksheet:

1. We will construct two separate charts to depict a typical range of suction and discharge pressures in an ammonia refrigeration system.
2. Open a new worksheet expanded to full size.
3. In cells A1:D5, enter the text labels and numeric values as shown in Fig. 9.1.
4. In cell A6, type **70**, and using **AutoFill** create a series of numbers increasing with an increment of **10** in cells A7:A24.
5. Similarly, in cell C6, type **1300**, and using **AutoFill** create a series of numbers increasing with an increment of **50** in cells C7:C24.
6. In cell B6, type the following formula: **=($B$3/(LN(A6*1000)-$B$2))-$B$4**
7. In cell D6, type the following formula: **=($B$3/(LN(C6*1000)-$B$2))-$B$4**
8. Copy the contents of cell B6 into cells B7:B24 using **AutoFill**.
9. Copy the contents of cell D6 into cells D7:D24 using **AutoFill**.
10. Select cells A6:B24, click on the **ChartWizard** button and create an **XY (Scatter)** chart as shown in Fig. 9.2.
11. Select cells C6:D24, click on the **ChartWizard** button and create an **XY (Scatter)** chart as shown in Fig. 9.3.
12. To make sure that the scaling of the chart is as shown in Fig 9.2, double click on the y-axis, select tab **Scale** and enter for **Value (Y) axis crosses at: 50** for Fig. 9.2. Similarly for Fig. 9.3, use **1250** in the edit box for where the y-axis crosses the x-axis.

Discussion:

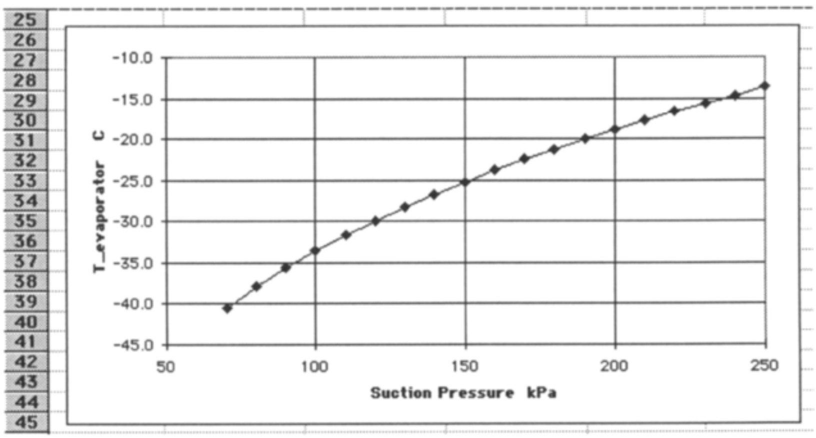
The results of the pressure–temperature relationship for ammonia are shown in Figs. 9.2 and 9.3. These charts may be used as a handy aid for determining the temperatures for the evaporator or the condenser when pressures are read from the pressure gauges.

Worksheet Comments:

In this worksheet, we programmed a formula for converting pressure into temperature and used the data to plot the relationships. We used the function *LN()* and absolute cell references to the empirical coefficients given in cells B2:B4. You may convert these charts to English units, e.g., psig (pounds per square inch, gauge pressure) and degrees Fahrenheit, as these units are still commonly used in the industry.

	A	B	C	D
1	Solution:			
2	constant1	22.11874		
3	constant2	-2233.8226		
4	constant3	244.2		
5	P_suction kPa	T_evaporator C	P_discharge kPa	T_condenser C
6	70	-40.4	1300	33.6
7	80	-37.9	1350	34.9
8	90	-35.6	1400	36.2
9	100	-33.6	1450	37.4
10	110	-31.7	1500	38.6
11	120	-29.9	1550	39.8
12	130	-28.2	1600	41.0
13	140	-26.7	1650	42.1
14	150	-25.2	1700	43.2
15	160	-23.8	1750	44.3
16	170	-22.5	1800	45.3
17	180	-21.2	1850	46.4
18	190	-20.0	1900	47.4
19	200	-18.8	1950	48.4
20	210	-17.7	2000	49.3
21	220	-16.7	2050	50.3
22	230	-15.6	2100	51.2
23	240	-14.6	2150	52.2
24	250	-13.7	2200	53.1

Figure 9.1 A worksheet for data given in Example 9.1.



Example 9.2 A chart showing relationship between evaporator temperature and suction pressure.

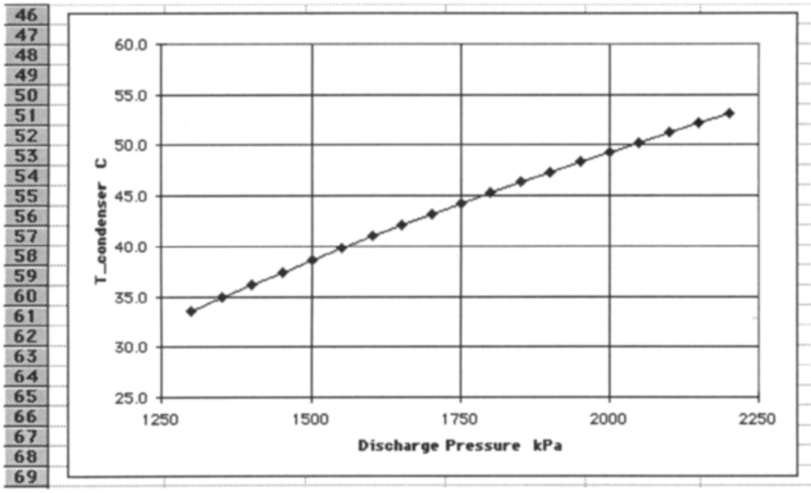


Figure 9.3 A chart showing relationship between condenser temperature and discharge pressure.

9.2 Pressure–Enthalpy Values of Ammonia when Used as a Refrigerant in a Vapor Compression Refrigeration System

Ammonia is widely used as a refrigerant in mechanical vapor compression refrigeration systems. Typical applications of ammonia systems are in operating industrial-scale freezers. In designing refrigeration systems, it is often necessary to determine the pressure–enthalpy data for a given refrigerant. These values are usually obtained from tables and charts available for different refrigerants. In this example, the mathematical relationships describing pressure–enthalpy data for ammonia will be programmed into a worksheet. This will simplify obtaining the required data for calculations involving the design and performance evaluation of refrigeration systems operating under ideal conditions.

Problem Statement:

Develop a worksheet that may be used to determine enthalpy values of ammonia for given values of evaporator and condenser temperatures. Assuming that the evaporator temperature is -20°C and the condenser temperature is 40°C, determine the enthalpy of saturated liquid at the entry to the expansion valve (H_1), the enthalpy of saturated vapor at the exit of the evaporator coils (H_2), and the enthalpy of superheated vapors at the exit of the compressor (H_3).

Approach:

We will use equations given by Cleland (1986) to develop this worksheet. These equations require a number of empirical coefficients that must be entered in a part of a worksheet. Additional information on the equations and empirical coefficients is provided in Singh and Heldman (1993, pp. 279-281).

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cells A1:A3, type text labels as shown in Fig. 9.4.
3. In cells C4:G9, type the numerical coefficients as shown in Fig. 9.4. It is important that each of these coefficients are typed with the number of significant digits shown, otherwise round-off errors will yield incorrect results.
4. In cells A10:A17, type the text labels as shown.
5. In cell B10, type the following formula: **=EXP(C4+D4/(B1+E4))/1000**
6. In cell B11, type the following formula: **=EXP(C4+D4/(B2+E4))/1000**
7. In cell B12, type the following formula: **=(F4+G4*B2+C5*B2^2+D5*B2^3)/1000**
8. In cell B13, type the following formula: **=(E5+F5*B1+G5*B1^2+C6*B1^3+D6)/1000**
9. In cell B14, type the following formula: **=EXP(E6+F6/(B1+273.15))*(G6+C7*B1+D7*B1^2+E7*B1^3)**
10. In cell B15, type the following formula: **=F7+G7*B1+C8*B1^2+D8*B1*B3+E8*B1^2*B3+F8*B1*B3^2+G8*B1^2*B3+C9*B3**
11. In cell B16, type the following formula: **=(B15/(B15-1))*(B10*B14*((B11/B10)^((B15-1)/B15)-1))**
12. In cell B17, type the following formula: **=B13+B16**
13. In cell B1, type **-20**
14. In cell B2, type **40**
15. In cell B3, type the following formula: **=B2-B1**
16. The results will be shown in cells B12, B13, and B17

You can fix the number of decimal points by using the menu commands **Tools**, **Options**, choosing **Edit** tab, and checking the **Fixed Decimal** check box. This is useful if you are entering currency values: you can type dollars and cents without a decimal point; Excel will introduce the decimal if you selected the fixed decimal point as two. Remember to deselect this option after you are finished with data entry

Discussion:

The results H_1, H_2, H_3 are useful in designing the refrigeration system as we will see in the following example. This worksheet is useful in determining the enthalpy values for any values of evaporator and condenser temperatures. You may also use the **Goal Seek** command to enter a desired value for say H_3 and determine the evaporator temperature that will give that entered value for H_3.

Worksheet Comments:

In this worksheet, we used numerical coefficients for empirically derived equations to obtain the required enthalpy values. Caution must be exercised when entering any empirical coefficients.

	A	B	C	D	E	F	G
1	T_evaporator (C)	-20		Coefficients from Cleland(1986)			
2	T_condenser (C)	40					
3	T_cond-T_evap (C)	60					
4			22.11874	-2233.8226	244.2	200000	4751.63
5			2.04493	-0.037875	1441467	920.154	-10.20556
6			-0.0265126	15689	-11.09867	2691.68	0.99675
7			0.000402288	2.6417E-06	-1.75152E-07	1.325798	0.0002452
8			3.10683E-06	1.13335E-05	-1.42736E-07	6.35817E-08	9.5979E-10
9			-0.000382295				
10	P_suction (kPa)	190.08					
11	P_discharge (kPa)	1557.67					
12	H_1 (kJ/kg)	390.91					
13	H_2 (kJ/kg)	1434.88					
14	v_saturated (m^3/kg)	0.62					
15	c	1.28					
16	delta_H (kJ/kg)	315.29					
17	H_3 (kJ/kg)	1750.17					

Figure 9.4 A worksheet for data given in Example 9.2.

9.3 Coefficient of Performance of a Vapor Compression Refrigeration System

The efficiency of a vapor compression refrigeration system is evaluated by calculating its coefficient of performance. The coefficient of performance is a ratio between the enthalpy removed by an evaporator and the enthalpy equivalent of the energy supplied by the compressor. In this example we will determine the coefficient of performance of a refrigeration system using ammonia as a refrigerant.

Problem Statement:

Determine the coefficient of performance for an ammonia vapor compression system, when the evaporator is maintained at -20°C and the condenser is at 45°C. The heating load is equivalent to 10 tons of refrigeration.

Approach:

For a refrigeration system operating under ideal conditions, coefficient of performance is calculated by determining the enthalpy values of refrigerant entering the evaporator, exiting the evaportor, and exiting the compressor. We will use the ammonia template presented earlier in Example 9.2 to determine the enthalpy values. The coefficient of performance will be determined using Eq.7.20 given by Singh and Heldman (1993, p. 284). The equation is as follows:

$$Coefficient\ of\ Performance = \frac{H_2 - H_1}{H_3 - H_2}\ .$$

Where, H_1 is the enthalpy of refrigerant entering the evaporator, kJ/kg; H_2 is the enthalpy of refrigerant exiting the evaporator, kJ/kg; H_3 is the enthalpy of refrigerant exiting the compressor, kJ/kg.

We will use two worksheets linked with each other to solve this problem. The ammonia template will be stored in one worksheet. The second worksheet will include the given data and formula for calculating the coefficient of performance (COP) value.

> When working with more than one window, press **Command+M** (**Ctrl+F6** in Windows) to go to the next window or **Command+Shift+M** (**Ctrl+Shift+F6** in Windows) to go to the previous window.

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. Rename the worksheet **COP calculations**.
3. Click on tab Sheet2. Rename the worksheet as **Ammonia Template**.
4. Open the worksheet developed in Example 8.2.
5. Copy cells A1:G17 from the worksheet in Example 8.2, and paste them into cells A1:G7 of the new worksheet named **Ammonia Template** in step 2.
6. In cell B1 type the following formula: **='COP calculations'!$B$2**
7. In cell B2, type the following formula: **='COP calculations'!$B$3**
8. Click on sheet tab **COP calculations**.
9. In cells A1:B4, type the text labels and data values as shown in Fig. 9.5.
10. In cells A6:A12, type the text labels as shown in Fig. 9.5.
11. In cell B7, type the following formula: **='Ammonia Template'!$B$12**
12. In cell B8, type the following formula: **='Ammonia Template'!$B$13**
13. In cell B9, type the following formula: **='Ammonia Template'!$B$17**
14. In cell B10, type the following formula: **=B4*303852/(24*3600*(B7-B6))**
15. In cell B11, type the following formula: **=B9*(B8-B7)**
16. In cell B12, type the following formula: **=(B7-B6)/(B8-B7)**
17. The results will be displayed in cell B12.

Discussion:

The coefficient of performance may be calculated for any combination of evaporator and condenser temperatures. Note that the load on the evaporator has no influence on the coefficient. This worksheet may be used to determine how the COP value changes when the evaporator or condenser temperature is changed.

Worksheet Comments:

In this worksheet, we developed a link between two worksheets. The main worksheet contains the given data and displays the calculated results. The template is used in the background using a second linked worksheet.

	A	B	C
1	Given:		
2	T_evaporator	-20	
3	T_condenser	45	
4	Tons of Refrigeration	10	
5			
6	Solution:		
7	H_1 (kJ/kg)	414.51	
8	H_2 (kJ/kg)	1434.88	
9	H_3 (kJ/kg)	1774.88	
10	Flow rate (kg/s)	0.03447	
11	Power (kW)	11.72	
12	COP	3.0	
13			

COP calculations / Ammonia Template

Figure 9.5 A worksheet for data given in Example 9.3.

	A	B	C	D	E	F	G
1	T_evaporator (C)	-20		Coefficients from Cleland(1986)			
2	T_condenser (C)	45					
3	Tcond-Tevap (C)	65					
4			22.11874	-2233.8226	244.2	200000	4751.63
5			2.04493	-0.037875	1441467	920.154	-10.20556
6			-0.0265126	15689	-11.09867	2691.68	0.99675
7			0.000402288	2.6417E-06	-1.75152E-07	1.325798	0.0002452
8			3.10683E-06	1.13335E-05	-1.42736E-07	6.35817E-08	9.5979E-10
9			-0.000382295				
10	P_suction (kPa)	190.08					
11	P_discharge (kPa)	1784.40					
12	H_1 (kJ/kg)	414.51					
13	H_2 (kJ/kg)	1434.88					
14	v_saturated (m^3/kg)	0.62					
15	c	1.27					
16	delta_H (kJ/kg)	340.00					
17	H_3 (kJ/kg)	1774.88					

COP calculations | Ammonia Template | Sheet3 | Sheet4

Figure 9.6 A worksheet for data given in Example 9.3.

9.4 Pressure–Enthalpy Relationships for Freon (R-12) Used as a Refrigerant in a Vapor Compression Refrigeration System

Although worldwide efforts are being made to eliminate the use of Freon 12 (dicholorodifluoromethane) as a refrigerant, because of its adverse effect on ozone, there is still large-scale industrial use of Freon systems. In this example, we will develop a worksheet that will assist us in evaluating the performance of refrigeration systems that utilize Freon.

Problem Statement:

Develop a pressure–enthalpy worksheet for Freon. Use this worksheet to determine the enthalpy of the refrigerant as it exits an evaporator, compressor, or condenser, when operating under ideal conditions. Consider that the evaporator temperature is -5°C and the condenser temperature is 40°C.

Approach:

We will use the empirical expressions provided by Cleland (1986) and cited in Singh and Heldman(1993). These expressions use certain numerical coefficients that must be entered into the worksheet.

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cells A1:G7, type the text labels and data values as shown in Fig. 9.7.

3. In cells A8:A15, type the text labels as shown in Fig. 9.7.
4. In cell B9, type the following formula:
   =EXP(C2+D2/(B2+E2))/1000
5. In cell B10, type the following formula:
   =EXP(C2+D2/(B3+E2))/1000
6. In cell B11, type the following formula:
   =(F2+G2*B3+C3*B3^2+D3*B3^3)/1000
7. In cell B12, type the following formula:
   =(E3+F3*B2+G3*B2^2+C4*B2^3+D4)/1000
8. In cell B13, type the following formula:
   =EXP(E4+F4/(B2+273.15))*(G4+C5*B2+D5*B2^2+E5*B2^3)
9. In cell B14, type the following formula:
   =F5+G5*B2+C6*B2^2+D6*B2*(B3-B2)+E6*B2^2*(B3-B2)+F6*B2*(B3-B2)^2+G6*B2^2*(B3-B2)+C7*(B3-B2)
10. In cell B15, type the following formula:
   =B12+(B14/(B14-1))*(B9*B13*((B10/B9)^((B14-1)/B14)-1))

Discussion:

The enthalpies of the refrigerant exiting evaporator, compressor and the condenser are calculated as shown in Fig. 9.7. These values are used in determining the performance as well as designing the size of the evaporator, the condenser, and the compressor. It should be noted that the values calculated in this worksheet are for ideal saturated conditions. If there is certain superheated refrigerant entering the compressor or subcooled refrigerant entering the expansion valve, then the values must be adjusted accordingly.

Worksheet Comments:

In this worksheet, we used empirical expressions involving numerical coefficients. It is important that the coefficients are entered carefully with all significant digits, as shown, otherwise the results will be erroneous.

	A	B	C	D	E	F	G
1	Given:				Coefficients		
2	T_evaporator (C)	-5	20.82963	-2033.5646	248.3	200000	923.88
3	T_condeser (C)	40	0.83716	0.0053772	187565	428.992	-0.75152
4			-0.0056695000	163994	-11.58643	2372.495	1.00755
5			0.000494025	-0.00000604777	-0.000000229472	1.086089	-0.00181486
6			-0.0000148704	0.00000220685	0.000000197069	-0.00000007865	-0.00000000196889
7			-0.000562656				
8	Solution:						
9	P_suction	260.76					
10	P_discharge	961.25					
11	H_1	238.64					
12	H_2	349.40					
13	v_saturated	0.06					
14	c_constant	1.07					
15	H_3 (kJ/kg)	372.47					

Figure 9.7 A worksheet for data given in Example 9.4.

9.5 Predicting Freezing Times in Foods Using Plank's Equation

Freezing times in foods are commonly predicted using Plank's equation. The Plank's equation has been developed for simplified geometrical-shaped objects such as a sphere, an infinite slab, and an infinite cylinder. Solutions are also available for finite objects such as a rectangular slab and a finite cylinder. In this example, we will use Plank's equation to determine the freezing time of a spherical-shaped food.

Problem Statement:

A spherical-shaped food object is being frozen in an air-blast freezer. The diameter of the object is 5 cm, its initial freezing point is -1.2°C, the thermal conductivity during the frozen state is 1.25 W/m°C, the total enthalpy to be removed during the freezing process is 260 kJ/kg K, and the density is 1000 kg/m^3. The air blast temperature is -30°C. The convective heat transfer coefficient is 50 W/m^{2}°C. Determine the time required to freeze this food object. Determine the influence of the object size, air temperature, and convective heat transfer coefficient on the freezing time by changing each of these three parameters. Obtain freezing times by varying the diameter as 1, 2, 5, and 10 cm, the air blast temperature as -20, -30, -40, -100, and -200 °C, and convective heat transfer coefficient as 5, 25, 75, and 200 W/m^{2}°C,

Approach:

We will use Plank's equation given by Singh and Heldman (1993, p. 312). The equation is

$$t_F = \frac{\rho H_L}{T_F - T_\infty}\left(\frac{Pa}{h_c} + \frac{Ra^2}{k}\right),$$

where ρ is the density (kg/m^3); H_L is the latent heat of fusion to be removed (kJ/kg); a is the object diameter (m); T_F is initial freezing temperature (°C); T_∞ is the air blast temperature (°C); h_c is the convective heat transfer coefficient (W/m^2°C); k is the thermal conductivity of frozen medium (W/m°C), P is a constant (1/6); R is a constant (1/24).

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cells A1:B8, type text labels and data values as shown in Fig. 9.8.
3. In cell A9, type **time, min**.
4. In cell B9, type the following formula: **=$B$5*$B$6/($B$3-$B$7)*($B$2*1/6/$B$8+$B$2*$B$2*1/24/$B$4)*1000/60**
5. In cells A11:B12, type the text labels as shown in Fig. 9.8.
6. In cells A13:A16, type data values as shown in Fig. 9.8.
7. In cell B13, type the following formula: **=$B$5*$B$6/($B$3-$B$7)*($B$2*1/6/A13+$B$2*$B$2*1/24/$B$4)*1000/60**
8. Using **AutoFill**, copy the contents of cell B13 into cells B14:B16.
9. In cells A18:B18, type the text labels as shown in Fig. 9.8.
10. In cells A19:A23, type the data values as shown in Fig. 9.8.
11. In cell B19, type the following formula: **=$B$5*$B$6/($B$3-A19)*($B$2*1/6/$B$8+$B$2*$B$2*1/24/$B$4)*1000/60**
12. Using **AutoFill**, copy the contents of cell B19 into cells B20:B23.
13. In cells A25:B25, type the text labels as shown in Fig. 9.9.
14. In cells A26:A29, type the data values as shown in Fig. 9.9.

15. In cell B26, type the following formula:
    =$B$5*$B$6/($B$3-$B$7)*(A26*1/6/$B$8+A26*A26*1/24/$B$4)*1000/60
16. Using **AutoFill**, copy the contents of cell B26 into cells B27:B29.
17. Create a chart to display the influence of convective heat transfer coefficient on the freezing time. Select cells A13:B16, click on the **ChartWizard** button,  and create an **XY (Scatter)** chart as shown in Fig. 9.10.
18. Create a chart to display the influence of air blast temperature on the freezing time. Select cells A19:B23, click on the **ChartWizard** button,  and create an **XY (Scatter)** chart as shown in Figure 9.11.
19. Create a chart to display the influence of object size on the freezing time. Select cells A26:B29, click on the **ChartWizard** button and create an **XY (Scatter)** chart as shown in Figure 9.12.

Discussion:

The freezing time is calculated as 38.1 minutes for the given conditions. The influence of increasing the convective heat transfer coefficient on the freezing time is very dramatic up to about 75 $W/m^2{}^\circ C$. A further increase in the convective heat transfer coefficient does not reduce the freezing time in any appreciable manner. The size of the object has a marked influence on the freezing time; note that the diameter term is squared in the equation. The freezing medium temperature reduces the freezing time. A more dramatic decrease is possible by using cryogenic freezing at temperatures lower than -100°C.

Worksheet Comments:

In this worksheet, we used Plank's equation to determine the freezing time.

	A	B
1	Given:	
2	Diameter, m	0.05
3	Initial Freezing Point, C	-1.2
4	Thermal conductivity, W/m C	1.2
5	Density, kg/m^3	1000
6	Enthalpy, kJ/kg	260
7	Tinf, C	-30
8	h, W/m^2 C	50
9	time, min	38.1
10		
11	Solution:	
12	h	time
13	5	263.8
14	25	63.2
15	75	29.8
16	200	19.3
17		
18	Tinf	time
19	-20	58.4
20	-30	38.1
21	-40	28.3
22	-100	11.1
23	-200	5.5
24		

Figure 9.8 A worksheet for data given in Example 9.5.

25	a	time
26	0.01	5.5
27	0.02	12.1
28	0.05	38.1
29	0.1	102.4

Figure 9.9 A worksheet for data given in Example 9.5.

To remove a legend from the chart, click on the legend then use the menu commands **Edit**, **Clear**, **All**.

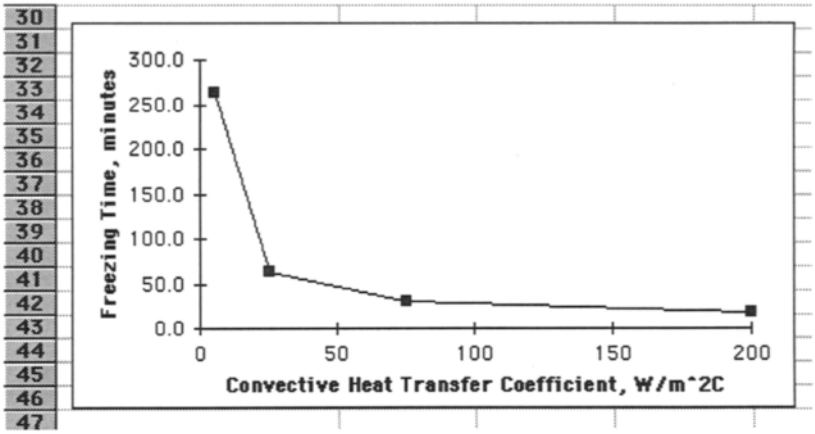
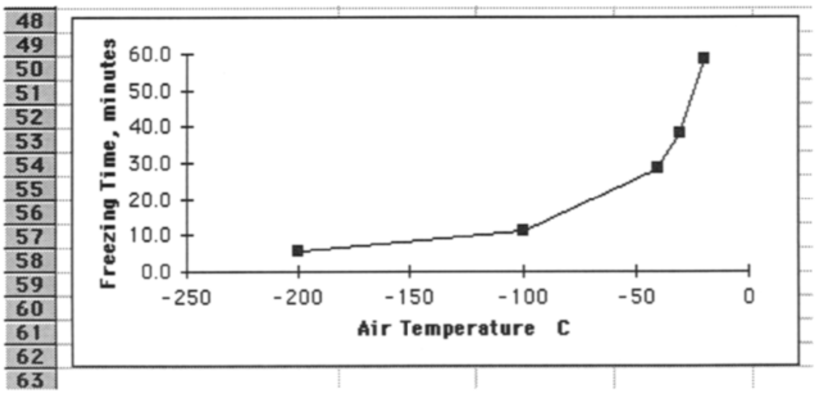


Figure 9.10 A plot of freezing time as a function of convective heat transfer coefficient.



9.11 A plot of freezing time as a function of the freezing medium temperature.

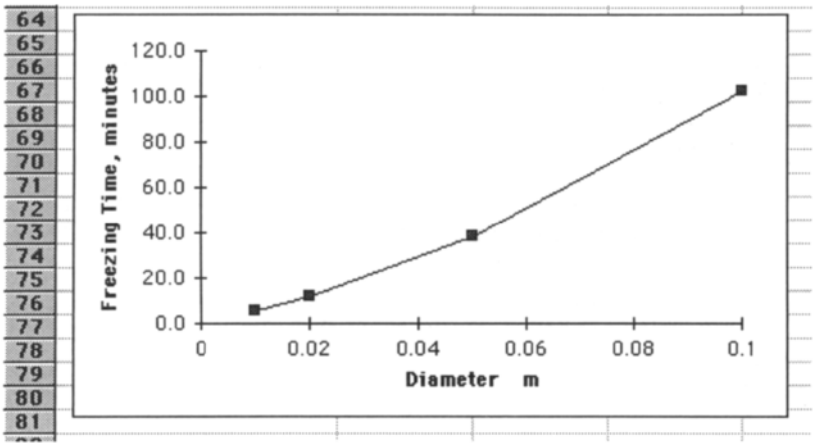


Figure 9.12 A plot of freezing time as a function of product diameter.

9.6 Loss of Quality in the Cold Chain

Quality attributes in foods during storage and distribution are largely influenced by the ambient temperature and time. If the temperature increases in some part of the chain for a certain length of time, more quality loss occurs, thus the remaining shelf life is decreased accordingly. In this example, we will determine the influence of changing the transport and distribution time on the quality of food.

Problem Statement:

Using data given by Jul(1984) and cited by Heldman and Singh (1993, p. 323) on the effect of temperature on shelf-life of frozen strawberries, determine the percent loss in quality at each stage of a typical storage and distribution.

Approach:

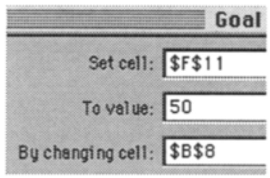
We will use the given data on frozen strawberries to develop a worksheet for calculating the percent loss in quality in each stage. We will use the results to create a pie chart and display the influence of changing the duration on the remaining quality. We will use the **Goal Seek** command to determine how many days the storage duration must be reduced at a given stage to obtain a desired level of remaining quality. Note that for the definition of quality we rely on the original study that developed the data for the frozen strawberries (Jul,1984)

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cells A1:F3, type the text labels and data values as shown in Fig. 9.13.
3. In cells A4:D11, type the text labels and data values as shown in Fig. 9.13.
4. In cell E4, type the following formula:

=1/D4

5. Using **AutoFill**, copy the contents of cell E4 into cells E5:E10.
6. In cell F4, type the following formula:
   =E4*B4*100
7. Using **AutoFill**, copy the contents of cell F4 into cells F5:F10.
8. In cell F11, type the following formula:
   =100-SUM(F4:F10)
9. Select cells A4:A10 and F4:F10. Click on the **ChartWizard** button and create a **pie** chart as shown in Figure 9.14.
10. If you change any time duration for a storage or distribution stage, the resulting change is displayed in the pie chart.
11. Let us use the **Goal Seek** command, to determine how much reduction in the retail storage is necessary, if we want to have a 50% as the final remaining quality instead of 38.9%.
12. Choose the menu commands **Tools**, **Goal Seek....** A dialog box will open.
13. Enter values in the dialog box as shown. Click **OK**.
14. The calculations will be carried out, and the resulting new storage time, 8.7 days, will be displayed in cell B8.



Discussion:

In this worksheet, we determined the loss in the quality of frozen strawberries as they move through different stages of storage and distribution. We set up the worksheet to determine the influence of time on the percent loss. This worksheet may be expanded to include the effect of temperature in addition to time. This would require using the given data to first determine a polynomial expression that includes both time and temperature.

Worksheet Comments:

In this worksheet, we used the function *SUM()* and we created a pie chart to determine the effect of changing storage time on the quality loss in frozen strawberries.

	A	B	C	D	E	F
1						
2	Stage	Time	Temperature	Acceptability	Loss per day	Loss
3		days	C	days	%/day	Percent
4	Producer	180	-22	660	0.001515	27.3
5	Transport	2	-14	220	0.004545	0.9
6	Wholesale	50	-23	710	0.001408	7.0
7	Transport	1	-12	140	0.007143	0.7
8	Retail	21	-11	110	0.009091	19.1
9	Transport	0.1	-3	18	0.055556	0.6
10	Home Freezer	10	-13	180	0.005556	5.6
11	Remaining Quality					38.9

Figure 9.13 A worksheet for data given in Example 9.6.

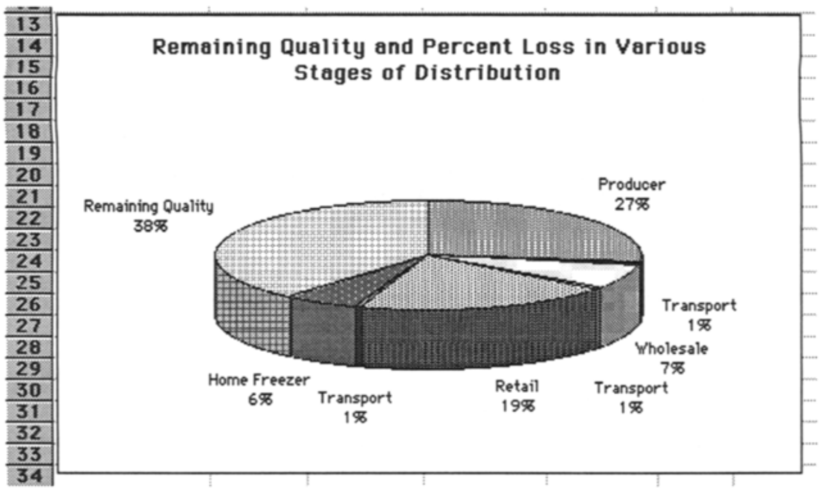


Figure 9.14 A pie chart showing quality loss at different stages of food distribution and storage.

Chapter TEN

Evaporation, Steam Properties, and Psychrometrics

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10.1 Solving Simultaneous Equations in Designing Multiple-Effect Evaporators

The design and analysis of multiple-effect evaporators involves conducting heat and energy balances around each effect. This type of analysis generates a number of simultaneous equations that must be solved to obtain information on flow rates of steam, vapors, product, and feed. In this example, we will solve a set of five simultaneous equations obtained for a four-effect evaporator.

Problem Statement:

The following expressions were obtained by conducting heat and mass balances on a four-effect evaporator:

$P = .52$
$V_1 + V_2 + V_3 + 2.3\ F = 5.9$
$S - V_1 - V_2 + .56\ F = .1$
$S - V_2 - 1.83 V_3 + .21 F = 0.21$
$2330S + 2200V_1 - 2389V_2 - 400F = 5023$
$190P + 2390V_1 - 2187V_2 - 2001V_3 + 340F = 998$.

Solve the simultaneous equations to obtain values for the product flow rate, P; steam flow rate, S; vapor flow rate from first effect, V_1; vapor flow rate from second effect, V_2; vapor flow rate from third effect, V_3; and the feed flow rate to the evaporator, F.

Approach

We will create a worksheet using the coefficients of the simultaneous equations. It is important that the simultaneous equations are written in the format shown below, using zeros as indicated.

$$
\begin{array}{l}
P + 0S + 0V_1 + 0V_2 + 0V_3 + 0F = 0.52 \\
0P + 0S + V_1 + V_2 + V_3 + 2.3F = 5.9 \\
0P + S - V_1 - V_2 + 0V_3 + 0.56F = 0.1 \\
0P + S + 0V_1 - V_2 - 1.83V_3 + 0.21F = 0.21 \\
0P + 2330S + 2200V_1 - 2389V_2 + 0V_3 - 400F = 5023 \\
190P + 0S + 2390V_1 - 2187V_2 - 2001V_3 + 340F = 998
\end{array}
$$

Using matrix algebra available in Excel, we will solve these equations.

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cells A1:F2, type the text labels as shown in Fig. 10.1.
3. In cells A3:F8, type the data values from the coefficients of the left-hand side of simultaneous equations.
4. In cells G3:G8, type the right-hand side coefficients of the simultaneous equations.
5. Select another array, A10:F15.
6. While keeping the array A10:F15 active, type the following in cell A10: **+MINVERSE(A3:F8)**
7. Press the **Command** and **Return** (**Ctrl+Shift+Return** in Windows) keys together.
8. An inverted matrix of coefficients will be created in cells A10:F15.
9. Select cells G10:G15 by dragging the cursor starting from cell G10 to G15.
10. While keeping the cells G10:G15 active, type the following into cell G10: **+MMULT(A10:F15,G3:G8)**
11. Press the **Command** and **Return** (**Ctrl+Shift+Return** in Windows) keys together.
12. The answers will be displayed in cells G10:G15.
13. You may organize the answers in cells D18:D23 as follows.

> When you select a range of cells, only the cell shown in the formula bar will accept information that you type in.

14. In cells B17, C18:C23, type the text labels as shown in Fig. 10.1.
15. In cell D18, type the following formula:
    =G10
16. Copy cell D18 into cells D19:D23 using the **AutoFill** command.
17. For cells D18:D23, reduce the significant digits to two using the **Decrease Decimal** button,
    , in the **Format** toolbar.

Discussion:

In this worksheet, we solved simultaneous equations using matrix algebra. The steam flow is calculated to be 1.91 kg/s for a feed rate of 1.24 kg/s.

Worksheet Comments:

In this worksheet, we used two functions *MINVERSE()* and *MMULT()* to determine the inverse of a matrix and product of two matrices, respectively. This example shows the capabilities of Excel in solving simultaneous equations.

	A	B	C	D	E	F	G
1	Given:						
2	P	S	Y1	Y2	Y3	F	
3	1	0	0	0	0	0	0.52
4	0	0	1	1	1	2.3	5.9
5	0	1	-1	-1	0	0.56	0.1
6	0	1	0	-1	-1.83	0.21	0.21
7	0	2330	2200	-2389	0	-400	5023
8	190	0	2390	-2187	-2001	340	998
9							
10	1	1.4959E-16	-5.236E-16	1.1687E-17	0	1.826E-19	0.52
11	0.07824133	0.11702233	-0.21011	0.51422243	0.00029866	-0.0004118	1.9073103
12	-0.00937	0.11767511	-0.3982398	0.01037929	0.00016646	4.9316E-05	1.53713097
13	0.07226785	0.17113506	-0.6269455	0.50941512	5.0442E-05	-0.0003804	0.96533373
14	0.00012004	0.00563263	0.26567338	-0.5426793	0.00011889	-6.318E-07	0.54243687
15	-0.0273991	0.306764	0.33022259	0.00994997	-0.000146	0.00014421	1.24134714
16							
17		Results:					
18			Product	0.52			
19			Steam	1.91			
20			Vapor1	1.54			
21			Vapor2	0.97			
22			Vapor3	0.54			
23			Feed	1.24			

Figure 10.1 A worksheet for data given in Example 10.1.

10.2 Properties of Saturated and Superheated Steam

Steam in used as a heating medium in many food processing operations such as distillation, evaporation, and heat exchangers. Steam may be in saturated or superheated state. In designing processing operations, there is a need to determine the properties of steam such as enthalpy of liquid and vapors. In the literature, the steam properties are available in tabulated form. Mathematical equations used to generate these tables can be programmed in a worksheet. In this example, we will create such a worksheet to calculate steam properties.

Problem Statement:

Create a worksheet for determining the enthalpies of saturated and superheated steam. Use the worksheet to determine the enthalpy of steam at 120°C.

Approach:

We will use empirical equations given by Martin (1961) to create a worksheet.

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cells A1:A48, type the text labels as shown in Fig. 10.2.
3. In cell B1, type 120.
4. In cells B2:B48, type the formulas or data values as shown in the following table

Cell Address	Formula or Data Value
B2	=B1*1.8+32
B3	7.46908269
B4	=-0.00750675994
B5	-0.0000000046203229
B6	-0.001215470111
B7	0
B8	=B2-705.398
B9	=(EXP(8.0728362+B8*(B3+B4*B8+B5*B8^3+B7*B8^4)/(1+B6*B8)/(B2+459.688)))*6.89473
B10	=B9
B11	=B10*0.1450383
B12	=B1
B13	=B12*1.8+32
B14	=(B13+459.688)/2.84378159
B15	=0.0862139787*B14
B16	=LN(B15)
B17	=-B16/0.048615207
B18	=0.73726439-0.0170952671*B17
B19	=0.1286073*B11
B20	=LN(B19)
B21	=B20/9.07243502
B22	=14.3582702+45.4653859*B21
B23	=(B15)^2/0.79836127
B24	=0.00372999654/B23
B25	=186210.0562*B24
B26	=EXP(B25+B20-B16+4.3342998)
B27	=B26-B19
B28	=B24*B27^2
B29	=B28^2
B30	=3464.3764/B15
B31	=-1.279514846*B30
B32	=B28*(B31+41.273)
B33	=B29*(B15+0.5*B30)
B34	=2*(B32+2*B33)
B35	=B28*(B30*B28-B31)
B36	=18.8131323+B22*B21

B37	=B26+2*(B26*B25)
B38	=B37*B34/B27+B34-B35-B37
B39	-32.179105
B40	1.0088084
B41	-0.00011516996
B42	0.00000048553836
B43	-0.00000000073618778
B44	9.6350315E-13
B45	=(0.0302749643*(B34-B27+83.47150448*B15)/B19)*0.02832/0.45359
B46	=(B39+B40*B13+B41*B2^2+B42*B2^3+B43*B2^4+B44*B2^5)*2.3258
B47	=(835.417534-B17+B14+0.04355685*(B32+B23-B27+B38))*2.3258
B48	=B47-B46

Discussion:

For calculations involving saturated vapors:
Enter the desired temperature value in cell B1,
Type **=B9** in cell B10, and
=B1 in cell B12

For calculations involving superheated vapors:
Enter the desired pressure value in cell B10 and temperature value in cell B12. The results will be displayed in cells B45:B48.

This worksheet is useful for determining the enthalpies of saturated and superheated steam.

Worksheet Comments:

In this worksheet, we entered empirical expressions to calculate the steam properties.

	A	B
1	Temperature C?	120
2		248
3		7.46908269
4		-0.00750676
5		-4.62E-09
6		-1.22E-03
7		0
8		-457.398
9		198.558129
10	Pressure kPa?	198.558129
11		28.79853348
12	Temperature C?	120
13		248
14		248.8545543
15		21.45474124
16		3.065945658
17		-63.06556831
18		1.815387125
19		3.703701635
20		1.309332761
21		0.144319883
22		20.91982938
23		576.5634419
24		6.46936E-06
25		1.204659912
26		43.91899067

Figure 10.2 A worksheet for data given in Example 10.2.

	A	B
27		40.21528903
28		0.010462699
29		0.000109468
30		161.4736976
31		-206.6079934
32		-1.729850209
33		0.011186715
34		-3.414953557
35		2.179353383
36		21.83227963
37		149.7338856
38		-168.0431145
39		-3.22E+01
40		1.0088084
41		-1.15E-04
42		4.86E-07
43		-7.36E-10
44		9.64E-13
45	Yv	0.891717572
46	Hc	503.41
47	Hv or Hs	2705.613646
48	Hevap	2202.201327

Figure 10.3 Continuation of the worksheet for data given in Example 10.2.

10.3 Psychrometric Properties of Air

Knowledge of psychrometric properties of air is necessary in numerous food processing applications, such as in drying, storage, and water activity measurements. In the literature, mathematical equations have been reduced to charts, commonly called psychrometric charts. In this example, we will create a simple worksheet that will allow calculations of some of the common properties of air–water vapor mixtures.

Problem Statement:

Create a worksheet that uses the dry bulb and wet bulb temperatures to predict the following properties of air–water vapor mixtures, namely, vapor pressures at dry bulb and wet bulb temperatures, partial pressure, dew point temperature, humidity ratio, specific volume, and relative humidity.

Approach:

We will use the empirical expressions given by Martin (1961) and Steltz and Silvestri (1958), cited in Singh and Heldman(1993), to program this worksheet.

Programming the Worksheet:

1. Open a new worksheet expanded to full size.
2. In cells A1:E13, type the text labels and data values as shown in Fig. 10.4. It is important that all the coefficients as shown in cells D2:E13 are typed as shown with their complete significant digits.
3. In cells A14:A24, type the text labels as shown in Fig. 10.4.
4. In cell B14, type the following formula:
   =(B2*1.8+32)-705.398
5. In cell B15, type the following formula:
   =(B3*1.8+32)-705.398
6. In cell B16, type the following formula:

=6.895*EXP(8.0728362+(B14*(D2+E2*B14+D3*B14^3)/((1+E3*B14)*((B2*1.8+32)+459.688))))

7. In cell B17, type the following formula:
   =6.895*EXP(8.0728362+(B15*(D2+E2*B15+D3*B15^3)/((1+E3*B15)*((B3*1.8+32)+459.688))))
8. In cell B18, type the following formula:
   =B17-((101.325-B17)*(B2-B3)/(1555.56-(0.722*B3)))
9. In cell B19, type the following formula:
   =B18/6.895
10. In cell B20, type the following formula:
   =LN(10*B19)
11. In cell B21, type the following formula:
   =((E5+E6*B20+E7*B20^2+E8*B20^3+E9*B20^4+E10*B20^5+E11*B20^6+E12*B20^7+E13*B20^8)-32)/1.8
12. In cell B22, type the following formula:
   =0.622*B18/(101.325-B18)
13. In cell B23, type the following formula:
   =(0.082*B2+22.4)*(1/29+0.023/18)
14. In cell B24, type the following formula:
   =B18/B16*100

Discussion:

This worksheet may be used when dry and wet bulb temperatures are known. However, using the **Goal Seek** command, it is possible to determine the dry or wet bulb temperature for a desired value of the other properties such as dew point, relative humidity and humidity ratio. For example, let us say that you want to determine the dry bulb temperature that will provide a relative humidity of 75% while keeping the wet bulb temperature same as 25°C. The following steps will be required:

- In cell B3, type **25**.
- Select cell B24.
  - Choose the menu commands **Tools, Goal Seek....**

- A dialog box will open.
- In the edit box **Set cell:**, type **$B$24**
- In the edit box, **To value:**, type **75**
- In the edit box, **By changing cell:**, type **$B$2**
- Click **OK.**

The result will be displayed in cell B2 as 28.6°C.

Worksheet Comments:

In this worksheet, we used empirical expressions to determine the psychrometric properties. It should be noted that this worksheet is valid for a limited range of temperatures, therefore, for more comprehensive calculations, more advanced expressions may be necessary.

	A	B	C	D	E
1	Given:				
2	Dry Bulb Temperature (C)	35		7.46908269	-0.00750675994
3	Wet Bulb Temperature (C)	25		-4.6203229E-09	-0.0012154701
4					
5					35.15789
6					24.592588
7					2.1182069
8					-0.3414474
9					0.15741642
10					-0.031329585
11					0.003865828
12					-0.000249018
13	Solution:				0.0000068401559
14	x1	-610.4			
15	x2	-628.4			
16	vapor pressure (at dbt)	5.622			
17	vapor pressure (at wbt)	3.167			
18	pw (kPa)	2.529			
19	pw (psia)	0.367			
20	pw intermediate	1.299			
21	Dew Point Temperature	21.27			
22	Humidity Ratio (kg water/kg dry air)	0.016			
23	Specific Volume (m^3/kg dry air	0.904			
24	Relative Humidity (%)	44.98			

Figure 10.4. A worksheet for data given in Example 10.3.

10.4 Describing the Process of Adiabatic Saturation of Air Using Psychrometrics

When heated air is conveyed through a bed of moist food material, the moist food undergoes drying while the air gains moisture. This increase in moisture content of air is described as an adiabatic saturation process. On a psychrometric chart, the process is shown as a constant enthalpy line towards extending towards saturation. The enthalpy and the wet bulb temperature lines coincide on the psychrometric chart. We will create a worksheet using psychrometric properties and calculate the amount of moisture that is removed up by air as it moves through a thick bed of food material.

Problem Statement:

Air at 55°C dry bulb temperature and 25°C wet bulb temperature is conveyed through a thick bed of moist peanuts. Under steady-state conditions, assuming that the air exits the bed under saturated conditions, how much moisture is picked up by the air per kg of dry air? Also, determine the amount of water removed by air if it exits with a dry bulb temperature of 50, 45, 40, 35, 30, and 25°C.

Approach:

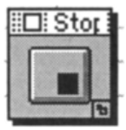
We will use the psychrometric worksheet developed in Example 10.3 to determine the amount of water removed by the air. Instead of repeating calculations manually, we will record a macro and use it to calculate the humidity ratio for each of the exit air temperatures. For more explanation of the adiabatic saturation process, refer to Singh and Heldman (1993).

Programming the Spreadsheet:

1. Open a new worksheet expanded to full screen.

2. Open the worksheet in Example 10.3, and copy cells A1:E24 into the current worksheet, Sheet1.
3. Click on the Sheet2 tab to open a new worksheet.
4. In cells A1:A7, create a series from 55 to 25, decreasing by 5, using the **AutoFill** command.
5. Click on cell A1. Choose the menu commands **Tools, Record Macro, Use Relative References**. A toggle mark will appear next to the **Use Relative References**. This is necessary so that later we can operate the macro using any desired cell as input value for dry bulb temperature.

6. Choose the menu commands **Tools, Record Macro, Record New Macro....** A dialog box will open. **In Macro Name:**, type:
   AdiabaticSaturation
   Click **OK**.
7. Click on cell A1, copy the cell (using the menu commands **Edit, Copy** or **Command+C** (**Ctrl+C** in Windows) keys.
8. Click on **Sheet1** tab.
9. Click on cell B2, choose the menu commands **Edit, Paste Special....** A dialog box will open. Select the **Values** button. Click **OK**.
10. Click on cell B3, type **25**. Press **Enter**.
11. Click on cell B22, copy the cell by choosing **Edit, Copy** or **Command+C** (**Ctrl+C** in Windows) keys.
12. Select **Sheet2**.
13. Click on cell B1, choose the menu commands **Edit, Paste Special....** A dialog box will open. Select the **Values** button. Click **OK**.
14. Click on the **Macro Stop** floating button.



15. To run the macro for other temperatures. Click on cell A2. Choose the menu commands **Tools, Macro....** A dialog box will open. Double-click on **AdiabaticSaturation**. The macro will run and the calculated value of Humidity Ratio will be pasted in cell B2.
16. Repeat step 15 for cells A3 through A7.
17. In cell C1, type the text label as shown in Fig. 10.5.
18. In cell C2, type the following formula:

=B2-$B$1

19. Copy the contents of cell C2 into cells C3:C7.
20. The results will be displayed in cells C2:C7.

Discussion:

In this worksheet, we determined the amount of water removed under steady state conditions during the adiabatic saturation process. The maximum water removal will be when the air is fully saturated, or the dry bulb temperature is same as wet bulb temperature of 25°C.

Spreadsheet Comments:

We used a macro to carry out the repetitive calculations to determine humidity ratios at different dry bulb temperatures.

	A	B	C	D
1	55	0.00777966	kg water/kg dry air	
2	50	0.00979494	0.0020	
3	45	0.01182316	0.0040	
4	40	0.01386444	0.0061	
5	35	0.01591892	0.0081	
6	30	0.01798672	0.0102	
7	25	0.02006796	0.0123	

Sheet1 Sheet2 Sheet3 Sheet4 Sheet5

Figure 10.5 A worksheet containing the results after running the macro.

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Appendix:

Using Short-Cut Keys in Excel

Selected Short-Cut keys in *Excel for Macintosh* :

Press	To
Command+U	edit active cell
Esc key	cancel action
Shift+F3	display **Function Wizard**
Command+Shift+T	insert autosum formula
Command+hyphen	enter date in cell or formula bar
Command+semicolon	enter time in cell or formula bar
Command+D	fill down
Command +R	fill right
Control+Option+Enter	insert carriage return or line break
Control+Option+Tab	insert tab
Control+Shift+ "	copy values from cell above the active cell
Control+'	copy formula from cell above the active cell
Control+`	alternate between displaying values or formulas
Control+Enter	fill a selection of cells with current entry
Command+T	change cell reference type from absolute to relative to mixed
F12	use **Save as** command
Command+P	print
Command+S	save
Command+Q	quit Excel

Press	To
Command+X	cut
Command+C	copy
Command+V	paste
Command+F	display **Find** dialog
Command+H	display **Replace** dialog
Shift+F4	find next
Command+Shift+F4	find previous
Control+G	go to
Command+K	delete selected cells
Command+I	display **Insert** dialog
Shift+F11	insert a new worksheet
F11	insert new chart sheet
Command+F3	display **Define Name** dialog
Command+1	display **Format Cells** dialog
Control+9	hide rows
Control+Shift+(	unhide rows
Control+0	hide columns
Control+Shift+)	unhide columns
F7	check spellings
Command+F6	switch to next window
Command+Shift+F6	switch to previous window
Shift+F1	access **Help Contents** screen
Control+7	show or hide standard toolbar
Return	move down through selected cells
Shift+Return	move up through selection
Tab	move right through selection
Shift+Tab	move left through selection

Press	To
Shift+Arrow key	extend selection by one cell
Command+Up Arrow or **Command+Down Arrow**	move up or down to edge of current data region
Command+Left Arrow or **Command+Right Arrow**	move left or right to edge of current data region
Shift+Home	extend selection to beginning of row
Command+Home	move to beginning of worksheet
Command+Shift+Home	extend selection to beginning of worksheet
Command+End	move to last cell in worksheet
Command+Shift+End	extend selection to last cell in worksheet
Command+Spacebar	select entire column
Shift+Spacebar	select entire row
Command+A	select entire worksheet
Page Down	move down one screen
Page Up	move up one screen
Option+Page Down	move right one screen
Option+Page Up	move left one screen
Command+Page Down	move to next sheet in workbook
Command+Page Up	move to previous sheet in workbook
Control+Shift+*	select rectangular range of cells around the active cell, the range selected is bounded by blank rows and columns
Command+[	select only cells directly referred to by formulas in selection
Command+Shift+{	select all cells directly or indirectly referred to by formulas in selection

Press	To
Command+F4	close window
Command+]	select only cells with formulas that refer directly to the active cell
Command+Shift+}	select all cells within formulas that directly or indirectly refer to active cell
Control+Shift+~	use general number format
Control+Shift+$	use currency format with two decimal places
Control+Shift+%	use percentage format with no decimal places
Control+Shift+^	use exponential number format with two decimal places
Control+Shift+#	use date format with day, month and year
Control+Shift+!	use two decimal place format with commas
Command+F10	minimize or maximize window
Command+M	move to next window
Command+Shift+M	move to previous window

Selected Short-Cut keys for *Excel in Windows*:

Press	To
F10	activate menu bar
Shift+F10	display Shortcut menu
Alt+Space	display application control menu
Ctrl+F5	restore menu
Ctrl+F7	move menu
Ctrl+F8	size menu
Ctrl+F9	minimize menu
Ctrl+F10	maximize menu
Ctrl+W	close menu
Alt+F	display file menu
Ctrl+N	new file
Ctrl+O	open file
Ctrl+W	close file
Ctrl+S	save file
F12	save as file
Alt+F4	exit file
Alt+E	display **Edit** menu
Ctrl+Z	undo
Ctrl+D	fill down
Ctrl+R	fill right
Ctrl+F	find
Ctrl+H	replace
F5	**Go to**
Alt+V	display **View** menu
Ctrl+7	toggle standard toolbar
Alt+i	display **Insert** menu
Ctrl+Shift+=	insert cells
Alt+Shift+F1	insert worksheet
Shift+F3	insert function
Ctrl+F3	define **Name**
F3	paste **Name**
Ctrl+Shift+F3	create **Name**
Ctrl+1	format cells

Press	To
Ctrl+Shift+~	apply general number format
Ctrl+Shift+4	apply currency Style
Ctrl+Shift+5	apply percent Style
Ctrl+Shift+1	apply common style
Ctrl+Shift+6	apply exponential format
Ctrl+Shift+3	apply date format
Ctrl+Shift+2	apply time format
Ctrl+B	toggle bold
Ctrl+I	toggle italic
Ctrl+U	toggle underline
Ctrl+Shift+7	apply outline border
Ctrl+Shift+-	remove all borders
Ctrl+9	hide rows
Ctrl+Shift+9	unhide rows
Ctrl+0	hide columns
Ctrl+Shift+0	unhide columns
Alt+'	format style
Alt+T	display **Tools** menu
F7	check spelling
Ctrl+6	toggle object display
Ctrl+`	toggle formula display
Ctrl+8	toggle outline symbol display
Ctrl+F2	display **Info** window
Alt+D	display **Data** menu
Alt+W	display **Window** menu
Ctrl+F6	display next workbook
Ctrl+Shift+F6	display previous workbook
Alt+H	display **Help** menu
F1	Microsoft Excel **Help** topics

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