Problem 4.72 Using Excel as a calculator.

A drug (D) is obtained in a three-stage extraction from the leaves of a tropical plant. About 1000 kg of leaf is required to produce 1 kg of the drug. The extraction solvent (S) is a mixture containing 16.5 wt% ethanol (E) and the balance water (W). The following process is carried out to extract the drug and recover the solvent.

1. 3300 kg of S and 620 kg of leaf are charged to a mixer and stirred for several hours, during which a portion of the drug contained in the leaf goes into solution. The contents of the mixer are then discharged through a filter. The liquid filtrate, which carries over roughly 1% of the leaf fed to the mixer, is pumped to a holding tank, and the solid cake (spent leaf and entrained liquid) is sent to a second mixer. The entrained liquid has the same composition as the filtrate and a mass equal to 15% of the mass of liquid charged to the mixer. The extracted drug has a negligible effect on t he total mass and volume of the spent leaf and the filtrate.

2. The second mixer is charged with the spent leaf from the first mixer and with the filtrate from the previous batch in the third mixer. The leaf is extracted for several more hours, and the contents of the mixer are then discharged to a second filter. The filtrate, which contains 1% of the leaf fed to the second mixer, is pumped to the same holding tank that received the filtrate from the first mixer, and the solid cake—spent leaf and entrained liquid—is sent to the third mixer. The entrained liquid is 15% of the mass of liquid charged to the mixer.

3. The third mixer is charged with the spent leaf from the second mixer and with 2720 kg of solvent S. The mixer contents are filtered; the filtrate, which contains 1% of the leaf fed to the third mixer, is recycled to the second mixer; and the solid cake is discarded. As before, the mass of the entrained liquid in the solid cake is 15% of the mass of the liquid charged to the mixer.

4. The contents of the filtrate holding tank are filtered to remove the carried-over spent leaf, and the wet cake is pressed to recover the entrained liquid. A negligible amount of liquid is lost in this step. The filtrate, which contains D, E, and W, is pumped to an extraction unit (another mixer).

5. In the extraction unit, the alcohol-water-drug solution is contacted with another solvent (F), which is almost but not completely immiscible with ethanol and water. Essentially all of the drug (D) is extracted into the second solvent, from which it is eventually separated by a process of no concern in this problem. Some ethanol but no water is also contained in the extract. The solution from which the drug has been extracted (the raffinate) contains 13.0 wt% E, 1.5% F, 85.5% W. It is fed to a steam stripper for recovery of the ethanol.

6. The feeds to the stripping column are the solution just described and steam. The two streams are fed in a ration such that the overhead product steam from the column contains 20.0 wt% E and 2.6% F, and the bottom product steam contains 1.3 wt% E and the balance W.

Draw and label a flowchart of the process, taking as a basis one batch of leaf processed. Then calculate

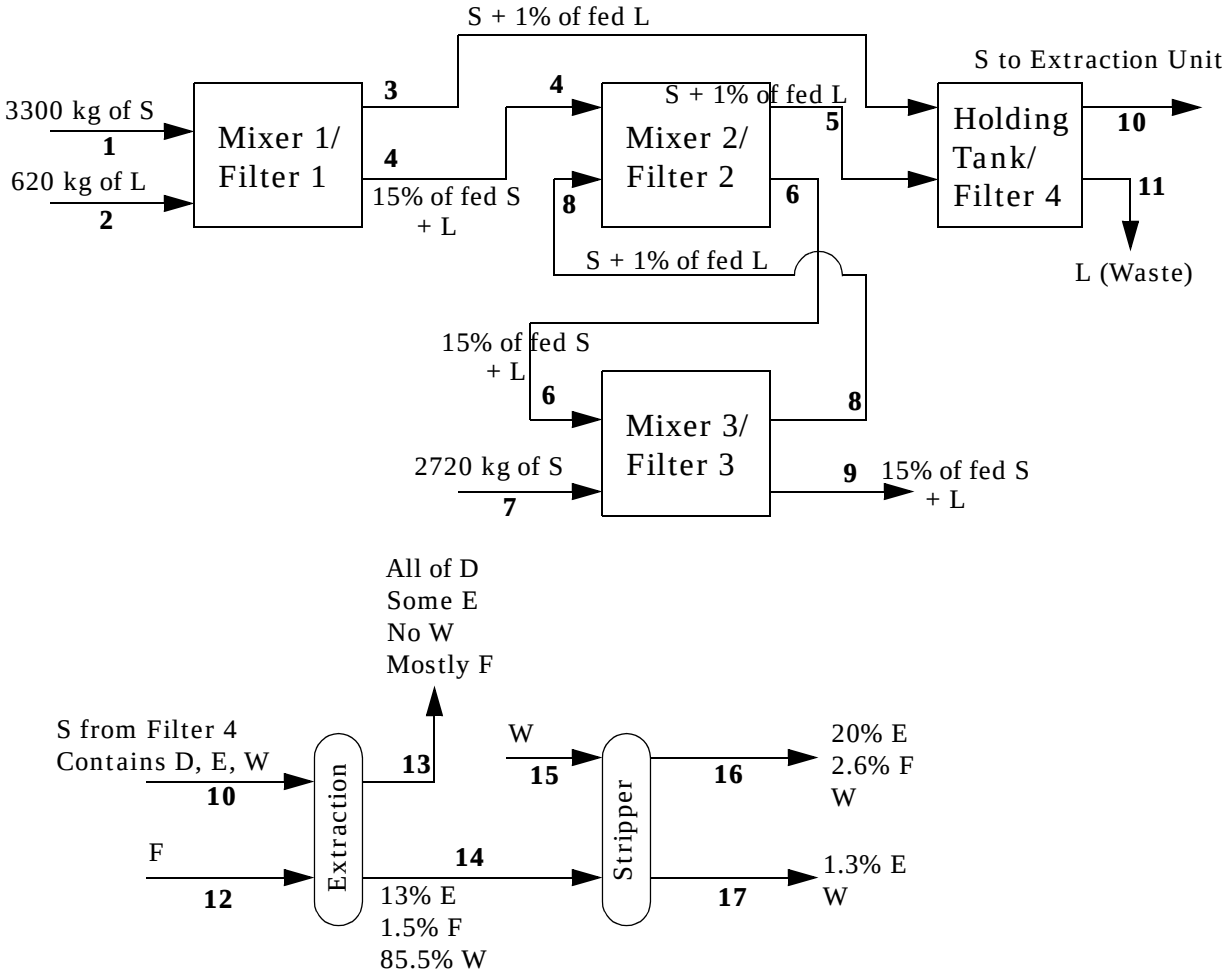
(a) The masses of the components of the filtrate holding tank.
(b) The masses of the components D and E of the extract stream from the extraction unit.
(c) The mass of steam fed to the stripper, and the masses of the stripper overhead and bottoms products

Solution:

Translation of this problem into a flowsheet and mass balances is the toughest part of the problem

First we draw the flowsheet and label the streams.

Flowsheet Drawing



From the flowsheet we can see that there is one recycle loop (Mixer 2 to Mixer 3 and back). The problem can also be separated into two problems: The Mixer/Filters, and the Extraction/Stripper.

For the first problem we perform a mass balance for S and L around each Mixer/Filter

Mixer 1

$$m_{3_L} = 0.01(m_{1_L} + m_{2_L})$$

$$m_{4_L} = (1 - 0.01)(m_{1_L} + m_{2_L})$$

$$m_{4_S} = 0.15(m_{1_S} + m_{2_S})$$

$$m_{3_S} = (1 - 0.15)(m_{1_S} + m_{2_S})$$

Mixer 2

$$m_{5_L} = 0.01(m_{4_L} + m_{8_L})$$

$$m_{6_L} = (1 - 0.01)(m_{4_L} + m_{8_L})$$

$$m_{6_S} = 0.15(m_{4_S} + m_{8_S})$$

$$m_{5_S} = (1 - 0.15)(m_{4_S} + m_{8_S})$$

Mixer 3

$$m_{8_L} = 0.01(m_{6_L} + m_{7_L})$$

$$m_{9_L} = (1 - 0.01)(m_{6_L} + m_{7_L})$$

$$m_{9_S} = 0.15(m_{6_S} + m_{7_S})$$

$$m_{8_S} = (1 - 0.15)(m_{6_S} + m_{7_S})$$

Holding Tank

$$m_{10_L} = 0$$

$$m_{11_L} = m_{3_L} + m_{5_L}$$

$$m_{11_S} = 0$$

$$m_{10_S} = m_{3_S} + m_{5_S}$$

In addition, we have three input streams specified.

$$m_{1_S} = 3300$$

$$m_{1_L} = 0$$

$$m_{2_S} = 0$$

$$m_{2_L} = 620$$

$$m_{7_S} = 2720$$

$$m_{7_L} = 0$$

Most of the formulas can be entered directly into Excel. However, we have to solve around the recycle loop. Solving simultaneously

$$m_{6_L} = (1 - 0.01)(m_{4_L} + m_{8_L})$$

and

$$m_{8_L} = 0.01(m_{6_L} + m_{7_L})$$

we get

$$m_{6_L} = \frac{0.99 m_{4_L}}{0.9901} + \frac{0.0099 m_{7_L}}{0.9901}$$

Solving simultaneously

$$m_{6_S} = 0.15(m_{4_S} + m_{8_S})$$

and

$$m_{8_S} = (1 - 0.15)(m_{6_S} + m_{7_S})$$

we get

$$m_{6_S} = \frac{0.15 m_{4_S}}{0.8725} + \frac{0.1275 m_{7_S}}{0.8725}$$

Entering the formulas.

The finished spreadsheet for the first part looks like:

Composition of Solvent			kg of D extracted per kg of L								
E	*0.165*		*0.001*								
W	*0.835*										
Species	**Strm 1**	**Strm 2**	**Strm 3**	**Strm 4**	**Strm 5**	**Strm 6**	**Strm 7**	**Strm 8**	**Strm 9**	**Strm 10**	**Strm 11**
S	*3300*	*0*	2805	495	2734.6	482.58	*2720*	2722	480.4	5539.6	*0*
L	*0*	*620*	6.2	619.38	6.2557	619.32	*0*	6.193	613.1	*0*	12.456
Total	3300	620	2811.2	1114.4	2740.9	1101.9	2720	2728	1094	5539.6	12.456
S in Tank	**5539.6**										
L in Tank	**12.456**										

Nomenclature: In a spreadsheet, the cells containing entries that can be changed are in *italics*, the intermediate calculated quantities are in plain text, and the answers are in **bold text**.

If you are running this tutorial in *FrameMaker* and you have *Microsoft Excel* available, you can double-click the spreadsheets above and below and they will operate just like in *Excel*.

The formulas that are entered into the cells are:

Compositio		kg of D extracted p
E	*0.165*	*=1/1000*
W	*=1-B2*	

Species	**Strm 1**	**Strm 2**	**Strm 3**	**Strm 4**	**Strm 5**
S	*3300*	*0*	=(1-0.15)*(B6+C6)	=0.15*(B6+C6)	=(1-0.15)*(E6+I6)
L	*0*	*620*	=0.01*(B7+C7)	=(1-0.001)*(B7+C7)	=0.01*(E7+I7)
Total	=SUM(B6:B7)	=SUM(C6:C7)	=SUM(D6:D7)	=SUM(E6:E7)	=SUM(F6:F7)

S in Tank	**=K6+L6**
L in Tank	**=K7+L7**

and

Strm 6	Strm 7	Strm 8	Strm 9	Strm 10	Strm 11
=0.15/0.8725*E6+0.1275/0.8725*H6	*2720*	=(1-0.15)*(G6+H6)	=0.15*(G6+H6)	=D6+F6	*0*
=0.99/0.9901*E7+0.0099/0.9901*H7	*0*	=0.01*(G7+H7)	=(1-0.01)*(G7+H7)	*0*	=D7+F7
=SUM(G6:G7)	=SUM(H6:H7)	=SUM(I6:I7)	=SUM(J6:J7)	=SUM(K6:K7)	=SUM(L6:L7)

There are a number of techniques for entering formulas that speed entry immensely. You should (almost) never enter a cell reference by hand. For example, in cell K6 the formula reads "=D6+F6". You enter this formula by clicking on cell K6, typing "=", clicking on cell D6, typing "+", clicking on cell F6, and finally pressing the Enter key.

The next is autogeneration of a series. To label the streams as "Strm 1" through "Strm 11": Click on cell B5 and enter "Strm 1". You should see a small black handle in the bottom right corner. Click and drag the little black handle to the right and *Excel* will automatically autofill the labels to "Strm 11".

The third is similar. Click on cell B8. Type "=sum(". Click and drag from cell B6 to cell B7. Type ")" and press Enter. Again click and drag the little black handle to the right and Excel will automatically calculate the total mass flow in each stream

To solve the extractor and the stripper we first calculate the feed (Stream 10) from the solvent composition and an overall mass balance

$$m_{10_D} = \frac{1}{1000} m_{2_L}$$

$$m_{10_E} = 0.165 m_{10}$$

$$m_{10_W} = (1 - 0.165) m_{10}$$

We then perform a mass balance around the extractor

$$m_{13_D} + m_{14_D} = m_{10_D}$$

$$m_{13_E} + m_{14_E} = m_{10_E}$$

$$m_{13_F} + m_{14_F} = m_{12_F}$$

$$m_{13_W} + m_{14_W} = m_{10_W}$$

We combine these with the specified mass fractions in Stream 14

$$x_{14_D} = \frac{m_{14_D}}{m_{14}} = 0$$

$$x_{14_E} = \frac{m_{14_E}}{m_{14}} = 0.13$$

$$x_{14_F} = \frac{m_{14_F}}{m_{14}} = 0.015$$

$$x_{14_W} = \frac{m_{14_W}}{m_{14}} = 0.855$$

$$m_{14} = m_{14_D} + m_{14_E} + m_{14_F} + m_{14_W}$$

And the specified split fractions in Stream 13

$$\frac{m_{13_D}}{m_{10_D} + m_{12_D}} = 1$$

$$\frac{m_{13_F}}{m_{10_F} + m_{12_F}} = 0$$

$$\frac{m_{13_W}}{m_{10_W} + m_{12_W}} = 0$$

Solving simultaneously

$$m_{14_W} = m_{10_W}$$

$$m_{14_F} = \frac{1.5}{85.5} m_{14_W}$$

$$m_{14_E} = \frac{0.084321309}{0.55457476} m_{10_W}$$

$$m_{14_D} = 0$$

and

$$m_{13_D} = m_{10_D}$$

$$m_{13_E} = m_{10_E} - m_{14_E}$$

There is not enough information to determine the amount of F in Stream 12 or 13. I arbitrarily chose $m_{12_F} = 5000 \text{ kg}$.

The easiest way to get at the stripper is to combine a mass balance on F with the composition of Stream 16

$$m_{16_F} = m_{14_F}$$

$$m_{16} = \frac{m_{16_F}}{0.026} = \frac{m_{14_F}}{0.026}$$

$$m_{16_W} = (1 - 0.2 - 0.026) m_{16}$$

Then do a mass balance on E

$$m_{17_E} = m_{14_E} - m_{16_E} = m_{14_E} - 0.2m_{16}$$

$$m_{17} = \frac{m_{17_E}}{0.013}$$

And finally a balance on W

$$m_{15} = m_{15_W} = m_{16_W} + m_{17_W} - m_{14_W} = m_{16_W} + (1 - 0.013)m_{17} - m_{14_W}$$

The finished second part of the spreadsheet looks like

Species	Strm 10	Strm 12	Strm 13	Strm 14	Strm 15	Strm 16	Strm 17
D	0.62	*0*	**0.62**	*0*	*0*	*0*	*0*
E	914.04	*0*	**210.73**	703.3	*0*	624.23	79.07
W	4625.6	*0*	*0*	4625.6	**3793.4**	2415.8	6003.2
F	*0*	*5000*	4918.8	81.15	*0*	81.15	*0*
Total	5540.2	5000	5130.2	5410	**3793.4**	**3121.2**	**6082.3**

As before, in the above spreadsheet, the cells containing entries that can be changed are in *italics*, the intermediate calculated quantities are in plain text, and the answers are in **bold text**.

The formulas that are entered are:

Species	Strm 10	Strm 12	Strm 13	Strm 14
D	=D2*C7	*0*	**=B15**	*0*
E	=B2*K8	*0*	**=B16-E16**	=0.084321309/0.55457476*E17
W	=B3*K8	*0*	*0*	=B17
F	*0*	*5000*	=C18-E18	=1.5/85.5*E17
Total	=SUM(B15:B18)	=SUM(C15:C18)	=SUM(D15:D18)	=SUM(E15:E18)

and

Strm 15	Strm 16	Strm 17
0	*0*	*0*
0	=0.2*G19	=E16-G16
=G17+H17-E17	=(1-0.2-0.026)*G19	=H19-H16
0	=E18	*0*
=SUM(F15:F18)	**=G18/0.026**	**=H16/0.013**

The same shortcuts for formula entry work here.

The complete spreadsheet

Composition of Solvent			kg of D extracted per kg of L								
E	*0.165*		*0.001*								
W	*0.835*										
Species	**Strm 1**	**Strm 2**	**Strm 3**	**Strm 4**	**Strm 5**	**Strm 6**	**Strm 7**	**Strm 8**	**Strm 9**	**Strm 10**	**Strm 11**
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L	*0*	*620*	6.2	619.38	6.2557	619.32	*0*	6.193	613.1	*0*	12.456
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S in Tank	**5539.6**										
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Species	**Strm 10**	**Strm 12**	**Strm 13**	**Strm 14**	**Strm 15**	**Strm 16**	**Strm 17**				
D	0.62	*0*	**0.62**	*0*	*0*	*0*	*0*				
E	914.04	*0*	**210.73**	703.3	*0*	624.23	79.07				
W	4625.6	*0*	*0*	4625.6	**3793.4**	2415.8	6003.2				
F	*0*	*5000*	4918.8	81.15	*0*	81.15	*0*				
Total	5540.2	5000	5130.2	5410	**3793.4**	**3121.2**	**6082.3**				