

Problem 4.60

Do like we always do:

- 1) read
- 2) draw
- 3) label
- 4) reread
- 5) transform to math
- 6) write equations
- 7) solve

These steps were done in excel and appear below as a screen shot:

The screenshot shows an Excel spreadsheet with a process flow diagram and associated calculations. The diagram includes a reactor and a condenser. Stream 1 enters the reactor from the left, and stream 2 enters from the top. Stream 3 exits the reactor to the right. Stream 4 enters the condenser from the left, and stream 5 exits downwards. Stream 6 exits the condenser to the right, and stream 7 exits from the top. The condenser also has a cooling water inlet (stream 6) and outlet (stream 7). The reactor is labeled 'reactor' and the condenser is labeled 'cond'. The chemical reaction is given as $\text{CO} + 2\text{H}_2 \rightarrow \text{CH}_3\text{OH}$. The stream table (moles) is as follows:

Stream	Total	CO	H2	CH3OH	N2
1	100	32	64	0	4
2					
3					
4					
5					
6					
7					

The spreadsheet also contains the following equations and data:

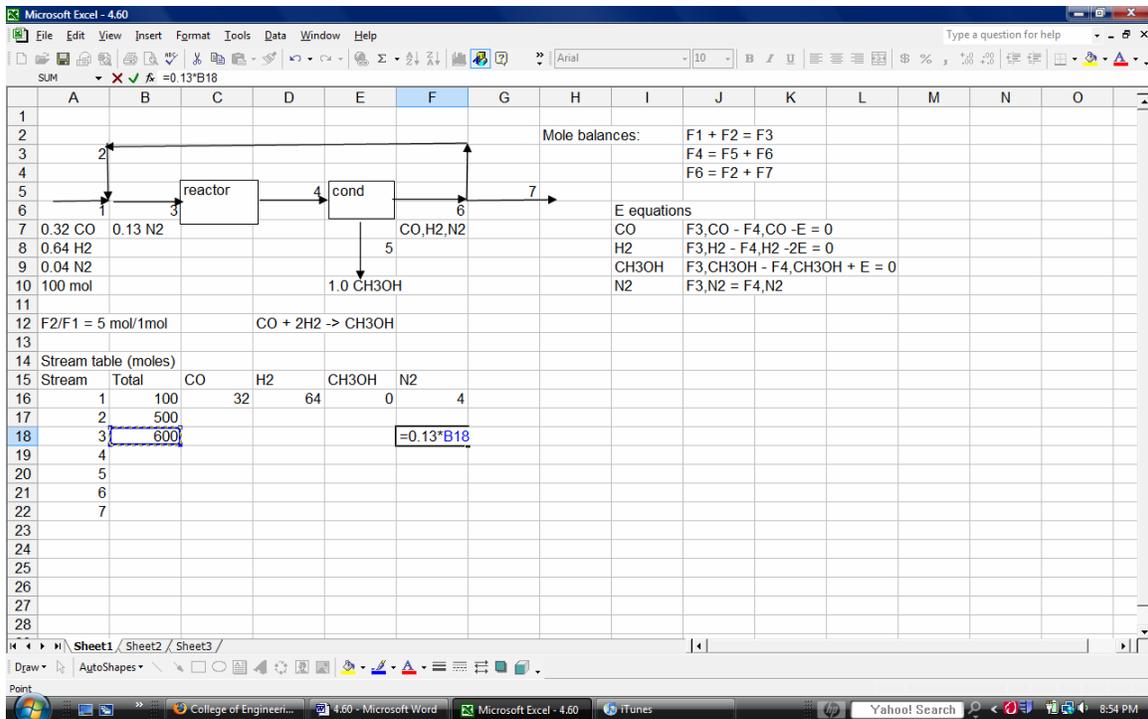
- Mole balances:
 - $F_1 + F_2 = F_3$
 - $F_4 = F_5 + F_6$
 - $F_6 = F_2 + F_7$
- E equations:
 - CO: $F_3, \text{CO} - F_4, \text{CO} - E = 0$
 - H2: $F_3, \text{H}_2 - F_4, \text{H}_2 - 2E = 0$
 - CH3OH: $F_3, \text{CH}_3\text{OH} - F_4, \text{CH}_3\text{OH} + E = 0$
 - N2: $F_3, \text{N}_2 = F_4, \text{N}_2$
- Reaction: $\text{CO} + 2\text{H}_2 \rightarrow \text{CH}_3\text{OH}$
- Subsidiary relationship: $F_2/F_1 = 5 \text{ mol}/1\text{mol}$

Let's find F_2 using the subsidiary relationship given in the problem statement: $F_2/F_1 = 5$

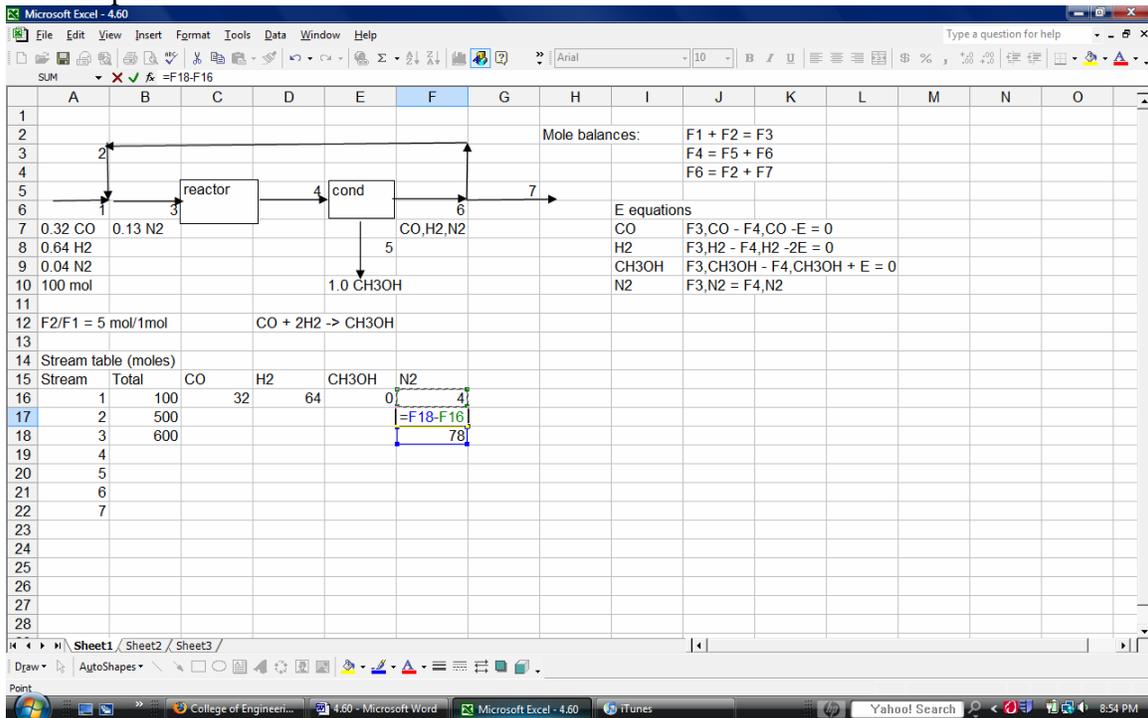
$F_2 = 500$ moles

Using our mass/mole balance equations, F_3 then is 600 moles

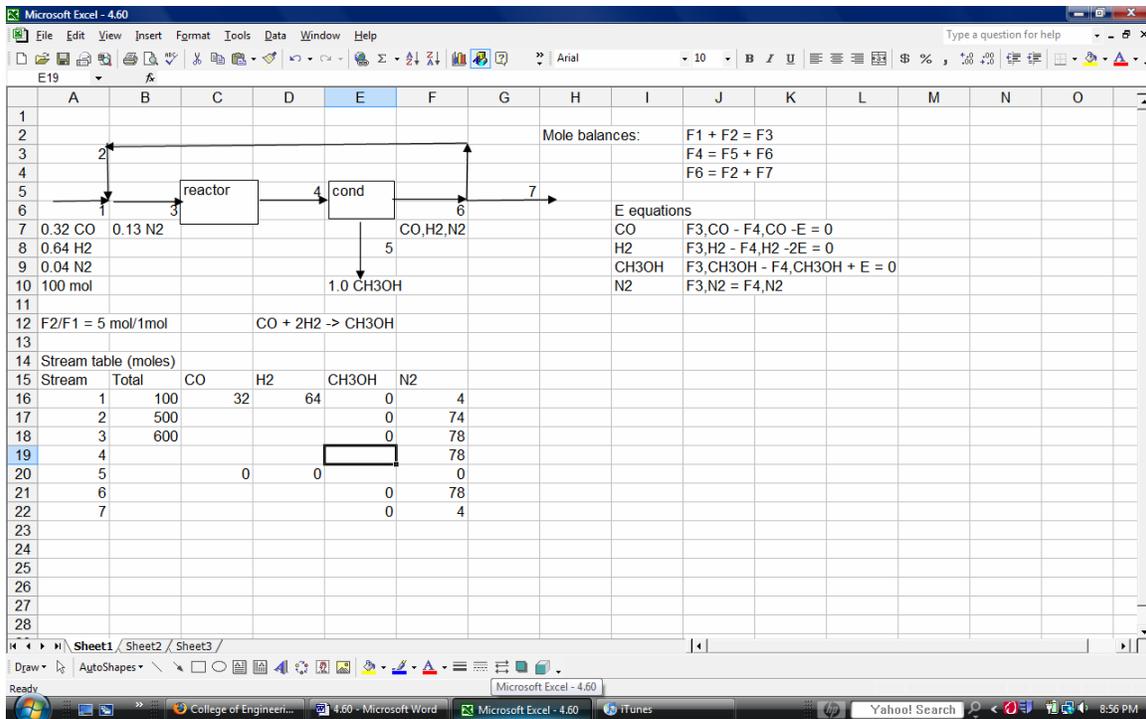
And we know F_3 is 0.13 N_2 so that is 78 moles of N_2 .



This then tells us that 74 moles of N₂ were in stream 2, using a nitrogen balance around the mix point.



We also fill in all the zeroes in the table and finish the nitrogen balances to get:



This is pretty much where we got bogged down in class on Monday. Let's pick up here and try writing some other things that we know are true (our goal is to get to a point where the number of equations equals the number of unknowns):

We know that for stream 3,

$$F_{3,\text{CO}} + F_{3,\text{H}_2} = 600 - 78 = 522 \text{ moles} \quad (\text{equation 1})$$

This is one equation with 2 unknowns. Now look at our E equations and rewrite those to see what we get:

$$F_{3,\text{CO}} - F_{4,\text{CO}} - E = 0 \quad (\text{equation 2})$$

$$F_{3,\text{H}_2} - F_{4,\text{H}_2} - 2E = 0 \quad (\text{equation 3})$$

At this point, we have three equations with the following 5 unknowns: $F_{3,\text{CO}}$, F_{3,H_2} , $F_{4,\text{CO}}$, F_{4,H_2} , E

Let's also add the balance around the mix point for CO and H2:

$$F_{3,\text{CO}} = 32 + F_{2,\text{CO}} \quad (\text{equation 4})$$

$$F_{3,\text{H}_2} = 64 + F_{2,\text{H}_2} \quad (\text{equation 5})$$

So, now we are at 5 equations with seven unknowns (the two new ones are $F_{2,\text{CO}}$ and F_{2,H_2}).

Hmmm...Are we going to end up going in circles here? Maybe. Let's be patient and keep going.

We know that all the CO and H2 in stream 4 goes to stream six so let's replace equations 2 and 3 by:

$$F_{3,\text{CO}} - F_{6,\text{CO}} - E = 0 \quad (\text{equation 2})$$

$$F_{3,\text{H}_2} - F_{6,\text{H}_2} - 2E = 0 \quad (\text{equation 3})$$

We can stall and also write that $F_{2,\text{CO}} + F_{2,\text{H}_2} = 500 - 74 = 426$ (equation 6)

We'll combine equations 2, 3, 4 and 5 above to get:

$$32 + F_{2,CO} - F_{6,CO} - E = 0 \quad (\text{equation 2'})$$

$$64 + F_{2,H_2} - F_{6,H_2} - 2E = 0 \quad (\text{equation 3'})$$

We can sum these two together and rearrange to get:

$$F_{2,CO} = F_{6,CO} + E - 32 \quad (\text{equation 2'})$$

$$F_{2,H_2} = F_{6,H_2} + 2E - 64 \quad (\text{equation 3'})$$

$$522 = F_{6,CO} + F_{6,H_2} + 3E$$

We seem to be at an impasse still.

There is twice as much H₂ as CO in stream 1. For every 1 mole of CO we use, we use 2 moles of H₂, so this ratio will stay 2:1 consistently as we move past the reaction. So, $F_{4,H_2}/F_{4,CO} = 2$ and $F_{2,H_2}/F_{2,CO} = 2$... Hey. A little logic in this case suggests that we can go back up to equation 6 to find:

$$F_{2,CO} + 2F_{2,CO} = 426 \rightarrow F_{2,CO} = 142 \text{ mole and } F_{2,H_2} = 284.$$

Let's place that in our table and start following that information around to fill in F₃ completely and see what else we know. The variables we know in the equations are now being turned to green as we know what they are:

Stream	Total	CO	H ₂	CH ₃ OH	N ₂
1	100	32	64	0	4
2	500	142	284	0	74
3	600	174	348	0	78
4				78	
5		0	0	0	0
6				0	78
7				0	4

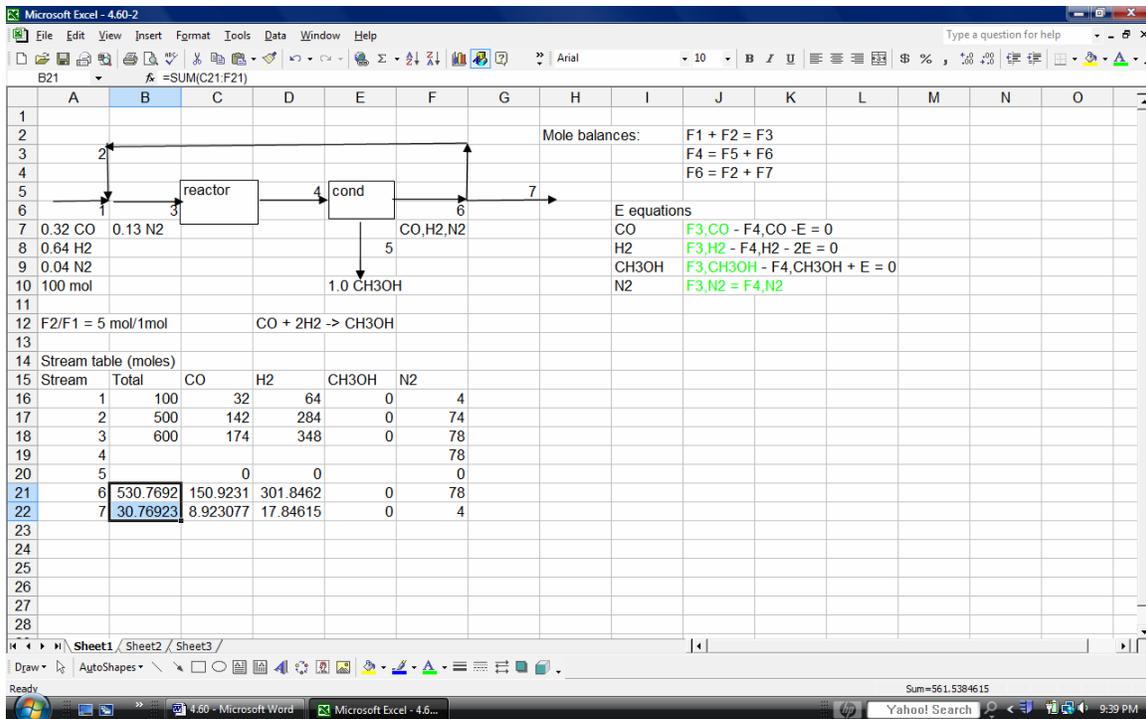
And we could continue with the logic that $F_{6,H_2}/F_{6,CO} = 2$

$$522 = F_{6,CO} + 2F_{6,CO} + 3E$$

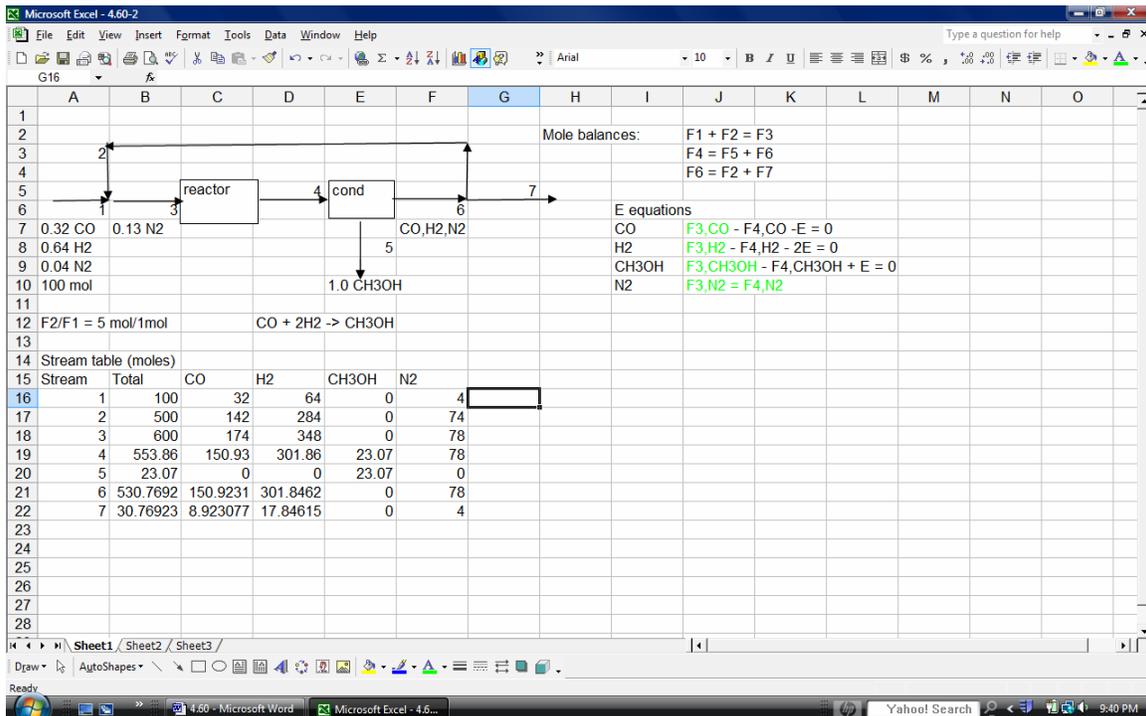
$$174 = F_{6,CO} + E$$

Here is one equation with two unknowns... So close!

Hey! Wait a minute. Go back and look at the nitrogen information around streams 2, 6, and 7... We know that $78/4 = F_2/F_7$. And since this is a split point where compositions remain constant, we can then find F₇ of CO and H₂ are 8.92 and 17.85 moles, respectively. And then we fill in F₆ to get the following table:



And now that we know F_6, CO , we find $E = 23.07$ and we can then find the rest of the information:



Let's say we are a little doubtful that everything worked out. We can do an external check to see if the number of carbon atoms in is equal to the number of carbon atoms out using streams 1, 5 and 7 (much like we were contemplating last Monday):
 C balance: $32(1)$ should equal $23.07(1) + 8.92(1)$... Answer is...yes.
 O balance: $32(1)$ should equal $23.07(1) + 8.92(1)$...yes.

H balance: $64(2)$ should equal $23.07(4) + 17.85(2)$...answer is?...yes!
We have external confirmation that our numbers all worked out. Whew!