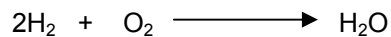
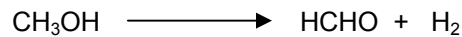


**Refer to Tables at the back of the textbook for physical and chemical properties (specific heats, latent heats etc.)**

- (Chapter 8, Prob. 8.36) Determine the specific enthalpy (kJ/mol) of *n*-hexane at 200°C and 2.0 atm relative to *n*-hexane at 20°C and 1 atm, assuming ideal gas behaviour for the vapour. Show clearly the process path you construct for this calculation and give the enthalpy changes for each step. State where you used the ideal gas assumption. What is the enthalpy of *n*-hexane liquid at 20°C and 1.0 atm relative to *n*-hexane at 200°C and 2.0 atm. Beginning with the value of specific enthalpy calculated in part (a) and still assuming ideal gas behaviour, determine the specific internal energy of the vapour at 200°C and 2.0 atm. Look at Tables B.1, B.2 for normal boiling point of *n*-hexane, latent heat of vapourization and specific heats.
- (Chapter 8, Prob. 8.68) Formaldehyde is produced from methanol in a catalytic oxidation reactor. The following reactions take place:

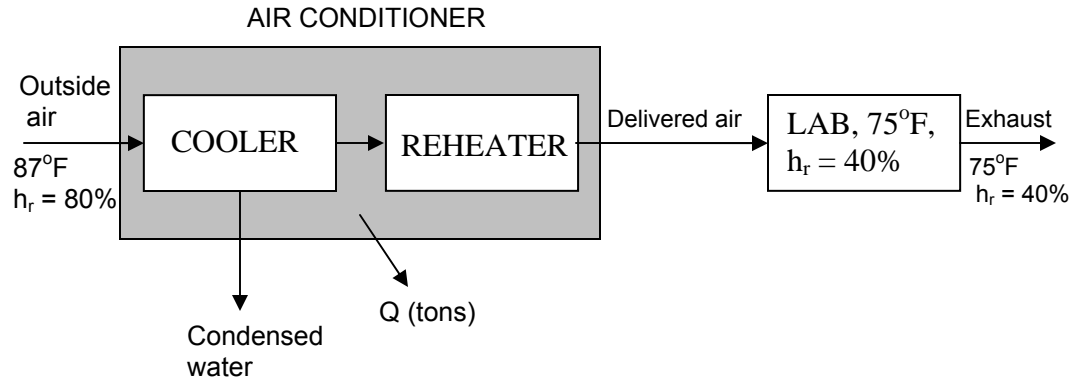


A stream of methanol is joined by a recycle stream, also methanol, and the combined stream is fed to a reactor. Also entering the reactor are air (to oxidize some of the hydrogen produced in the methanol conversion reaction) and steam (to control the reactor temperature). The product gas from the reactor contains 19.9 mole% formaldehyde, 8.34% methanol, 30.0% nitrogen, 0.830% oxygen, 5.0% hydrogen, and 35.6% water vapour and is at 600°C and 1 atm.

The following process is used to separate the formaldehyde from the unreacted methanol and noncondensable gases. The gases leaving the reactor are fed to a waste-heat boiler, in which they are cooled to 145°C, in the process generating steam at 3.1 bar from saturated liquid water (i.e., liquid water at its boiling point) at the same pressure. The gases are further cooled to 100°C in a heat exchanger, where they come into thermal contact with cooling water fed at 30°C. To reduce scaling on heat exchanger tubes, the temperature increase of the cooling water is limited to 15°C. The cooled gases are fed to an absorption column, where methanol and formaldehyde are absorbed in water. Pure water at 30°C is fed to the top of the column. The gas leaving the absorber is saturated with water vapour at 27°C and 1 atm and contains 200 parts of formaldehyde per million parts (by volume) of total gas. The aqueous solution leaving the bottom of the absorber at 88°C is fed to a distillation column that operates at 1 atm. The final product solution, which contains 37 wt% formaldehyde, 1% methanol, and the balance water, is removed from the reboiler at the bottom of the column, while pure methanol emerges as the overhead product and is condensed at 1 atm. A portion of the condensate is returned to the column at the top and the rest is recycled to the reactor. The reflux ratio, or ratio of methanol returned to the column to methanol recycled is 2.5:1.

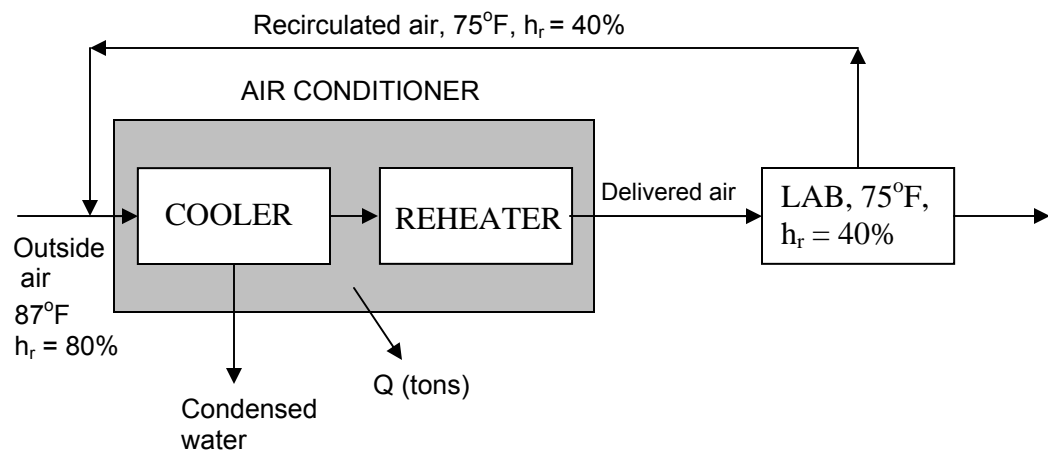
- Taking a basis of 100 mol of gas leaving the reactor, draw and completely a flow chart of this process. Then calculate the moles of fresh methanol feed, formaldehyde product solution, recycled methanol, and absorber off-gas, the kg of steam generated in the waste-heat reboiler, and the kg of cooling water fed to the heat exchanger between the waste-heat boiler and the absorber. Finally, calculate the heat (kJ) that must be removed in the distillation column overhead condenser, assuming the methanol enters as a saturated vapour at 1 atm and leaves as a saturated liquid at the same pressure.
- By what factor must all calculated quantities be multiplied to scale the flowchart to a production rate of  $3.6 \times 10^4$  metric tons per year of formaldehyde solution, assuming that the process is on-stream 350 days per calendar year?

3. (Chapter 8, Prob. 8.74) On an uncomfortable summer day, the air is at  $87^{\circ}\text{F}$  and 80% relative humidity. A laboratory air conditioner is to deliver  $1.00 \times 10^3 \text{ ft}^3/\text{min}$  of air at  $55^{\circ}\text{F}$  in order to maintain the interior air at an average temperature of  $75^{\circ}\text{F}$  and a relative humidity of 40%.
- a) If the vent switch on the air conditioner is turned to the "open" position, outside air enters the unit as shown below.



In the air conditioner, the air is cooled to a temperature low enough to condense the necessary amount of water and reheated to  $55^{\circ}\text{F}$ , at which point it has the same absolute humidity as the room air. Use the psychrometric chart to estimate the rate ( $\text{lb}_m/\text{min}$ ) at which water is condensed, the temperature to which the air must be cooled to condense water at this rate, and the net tons of cooling required ( $Q$ ), where 1 ton of cooling = - 12,000 Btu/h. [Note: The humid volume of the delivered air (at  $55^{\circ}\text{F}$ ), which is difficult to read from the psychrometric chart, is  $13.07 \text{ ft}^3/\text{lb}_m$  dry air, and the heat capacity of liquid water is  $1.0 \text{ Btu}/(\text{lb}_m \text{ }^{\circ}\text{F})$ .]

- b) If the vent switch is set to the "closed" position (as it normally would be), inside air would be recirculated through the air conditioner as shown in the following diagram.

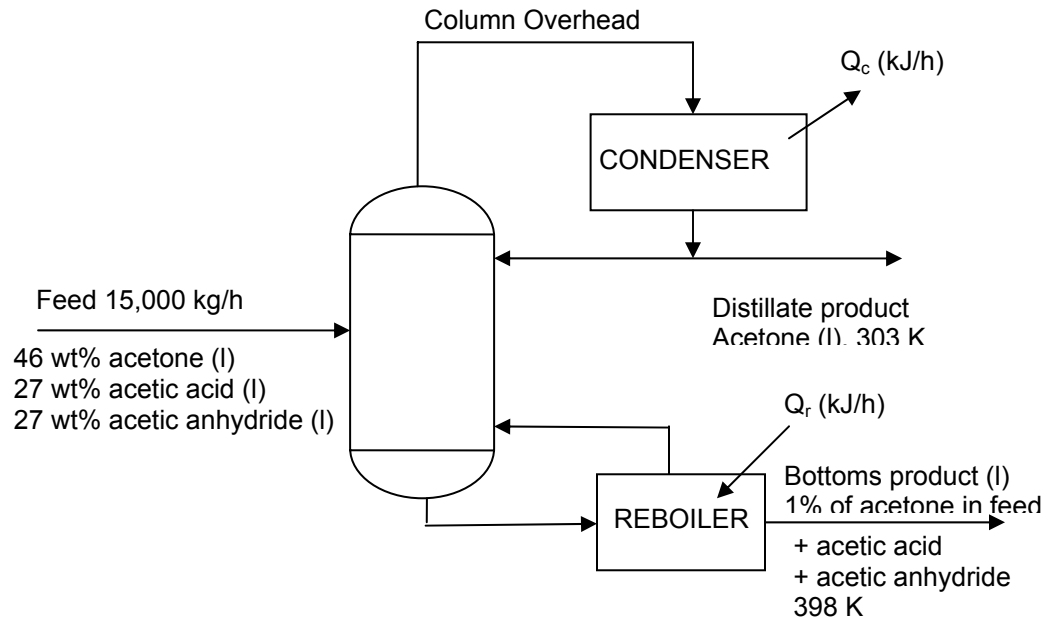


The recycle ratio ( $\text{ft}^3$  recirculated/ $\text{ft}^3$  exhausted) is 6:1. Calculate the condensation rate and the overall cooling requirement in tons if conditioned air is delivered at the same rate, temperature and relative humidity as in part (a). What percentage of the cooling load on the air conditioner is saved by recirculating air? Explain in your own words why the cooling rate is lower when room air is recirculated instead of bringing all the air from the outside.

4. (Chapter 8, Prob. 8.57) A mixture that contains 46 wt% acetone ( $\text{CH}_3\text{COCH}_3$ ), 27% acetic acid ( $\text{CH}_3\text{COOH}$ ), and the balance acetic anhydride [ $(\text{CH}_3\text{CO})_2\text{O}$ ] is distilled at  $P = 1$  atm. The feed enters the distillation column at  $T = 348$  K at a rate of 15,000 kg/h. The distillate (overhead product) is essentially pure acetone, and the bottom product contains 1% of the acetone in the feed.

The vapour effluent from the top of the column enters a condenser at 329 K and emerges as a liquid at 303 K. Half of the condensate is withdrawn as the overhead product, and the remainder is returned (or refluxed) to the column. The liquid leaving the bottom of the column goes into a steam heated reboiler, in which it is partially vapourized. The vapour leaving the reboiler is returned to the column at a temperature of 398 K, and the residual liquid, also at 398 K, constitutes the bottom product. A flowchart of the process and the thermodynamic data for the process materials follow.

- Calculate the molar flow rates and compositions of the product streams.
- Calculate the condenser cooling requirement,  $Q_c$  (kJ/h).
- Use an overall energy balance to determine the reboiler heating requirement,  $Q_r$  (kJ/h).
- If the reboiler heat is provided by the condensation of saturated steam at 10 bar gauge, at which rate must steam be fed?



**Thermodynamic data** (All temperatures are in Kelvin)

Acetone:  $C_{pl} = 2.30$  kJ/(kg.K)  
 $C_{pv}$  [kJ/(kg.K)] =  $0.459 + 3.15 \times 10^{-3} T - 0.790 \times 10^{-6} T^2$   
 $\Delta H_v = 520.6$  kJ/kg

Acetic acid:  $C_{pl} = 2.18$  kJ/(kg.K)  
 $C_{pv}$  [kJ/(kg.K)] =  $0.688 + 1.87 \times 10^{-3} T - 0.411 \times 10^{-6} T^2$   
 $\Delta H_v$  (391 K) = 406.5 kJ/kg.

Acetic anhydride:  $C_{pl}$  = Estimate it using Kopp's rule  
 $C_{pv}$  [kJ/(kg.K)] =  $0.751 + 1.34 \times 10^{-3} T - 0.046 \times 10^{-6} T^2$

$\Delta H_v$  (normal boiling point is 413 K) = Estimate it using Trouton's rule.

Atomic heat capacities for Kopp's rule (J/(g atom. °C) C: 12, H: 18, O: 25