Chemical Engineer PE Practice Problems

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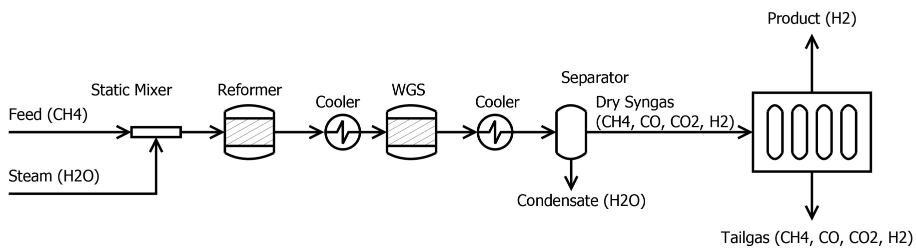
1 Problems

1.1 Problem 1



The diagram shows a simplified SMR (Steam Methane Reformer). The SMR has a feed of pure methane which is mixed with steam. The mixture undergoes two reversible reactions in the reformer and WGS reactor.

$$CH_4 + H_2O \longleftrightarrow 3H_2 + CO \tag{1}$$

$$CO + H_2O \longleftrightarrow 3H_2 + CO_2 \tag{2}$$

The resulting syngas is cooled and sent to a separtor which condenses out all unreacted water. The dry syngas stream has the following properties:

$CO_2/CO = 4$ **(on a molar basis)**

$CH_4 = 3$ **mol %**

This is sent to a PSA (pressure swing adsorper) which separates it into a product hydrogen stream and an offgas stream. The PSA recovers 85% of the incoming hydrogen to give a product hydrogen flow of 120 MMSCFH (million standard cubic feet per day).

The flow of CO_2 **in the offgas stream in MMSCFD is most nearly:**

A) 40

B) 30

C) 37

D) 56

1.2 Problem 2

An ASU has a nominal design production of 500,000 SCFH (standard cubic feet per hour @ 60 ºF, 1 atm) of gaseous oxygen and a design recovery rate of 96% of the oxygen in the feed stream (atmospheric air). Additionally the unit recoverys 65% of the the argon in the feed as a liquid argon side product.

Stream	**Pressure (atm abs)**	**Temperature (ºF)**	**Ar (mol %)**	**N_2 (mol%)**	**O_2 (mol%)**
Feed (Air)	1.0	67	0.93	78.11	20.96
Oxygen	24.5	63	0.40	0.00	99.60
Liquid Argon	1.1	-303	99.99	0.00	00.01

Current the unit is running at a turndown rate of 80% of the design capacity. Assume the recovery of each product remains unchanged at the turndown rate.

The flow of argon produced in tons/day (1 ton = 2000 lb) is most nearly:

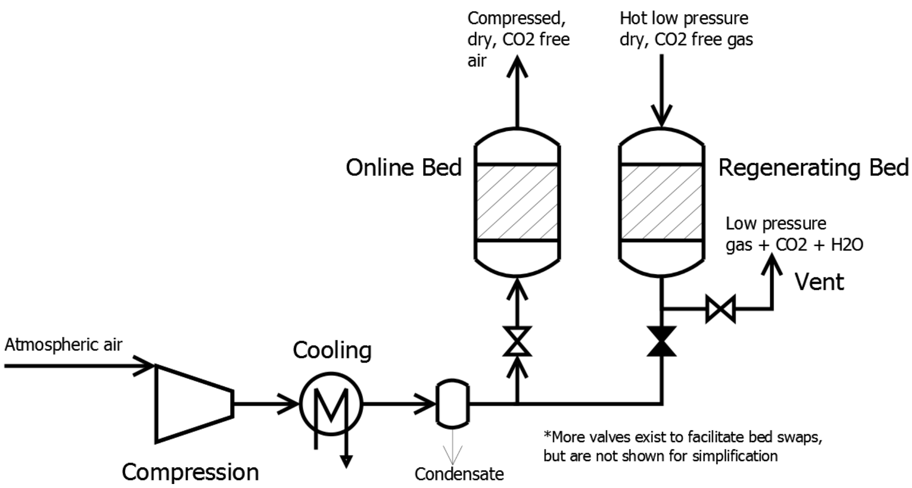
A) 25

B) 12

C) 375

D) 15

1.3 Problem 3



Additional Data	
Heat of adsorption of CO_2(g) + molsieve → CO_2(s) + molsieve	40 kJ/mol CO_2
Heat of adsorption of H_2O(g) + alumina → H_2O(s) + alumina	60 kJ/mol H_2O
Heat capacity of mole sieve	0.690 kJ/kg-ºC
Heat capacity of alumina	0.800 kJ/kg-ºC
Mass of mole sieve	4500 kg
Mass of alumina	4100 kg

Properties of air entering bed	
Pressure	5 bar-g
Temperature	18 ºC
N_2 (dry basis)	78 mol%
O_2 (dry basis)	21 mol%
Ar (dry basis)	1 mol%
relative humidity	100%
CO_2 (dry basis)	400 ppm vol
Molecular weight (dry)	28.97 g/mol
Flow	60,000 Nm^3/hr
Heat capacity (dry)	1014 J/kg-ºC

The diagram shows the front end purification section of an ASU (air separation unit). Atmospheric air has been compressed and cooled. It is then routed through a valve skid into an adsorption bed filled with a layer of alumina pellets and a layer of molecular sieve pellets. Water from the air adsorbs onto the alumina and CO_2 adsorbs onto the molecular sieve. The adsoption reactions are exothermic. When one bed becomes saturated CO_2 the valve skid routes air to the other bed while the first bed is regenerated with hot, low pressure gas. Assume that the bed has been online for some time so the solid materials in the bed have reached a steady state temperature. The air after the adsorption bed can be considered completely dry and CO_2 free.

The temperature of the air leaving the adsoprtion bed is most nearly:

A) 25.7 ºC

B) 22.0 ºC

C) 18.2 ºC

D) 40 ºC

1.4 Problem 4

The reforming section of an SMR reaches equilibrium at an outlet temperature of 1144 kelvin and a pressure of 30 bar abs. At these conditions the Keq Reforming = 703.2 bar^2 and Keq WGS = 0.9794. The feed is pure methane with a flow rate of 1760 SCFH. This is mixed with 5280 SCFH of steam. It can be assumed that the activity of each component is equal to its partial pressure.

$$\text{SMR} : CH_4 + H_2O \longleftrightarrow 3H_2 + CO$$

$$\text{WGS} : CO + H_2O \longleftrightarrow H_2 + CO_2$$

The equilibrium amount of CO_2 leaving the reforming section is most nearly:

A) 2,000 SCFH

B) 450 SCFH

C) 720 SCFH

D) 567 SCFH

1.5 Problem 5

The pretreatment unit of an SMR consists of a hydrotreater and a desulfurization bed. In the hydrotreater, organic sulphur containing mollecules such as methyl mercaptan are reacted with hydrogen over a catalyst to form hydrogen sulfide. In the desulfurization bed, the hydrogen sulfide in the feed is passed through a bed of calcium oxide. The hydrogen sulfide reacts with the bed to form calcium sulfide and water vapor. The gas leaving the bed is sulfur free.

$$CH_3SH + H_2 \rightarrow CH_4 + H_2S \quad (3)$$

$$H_2S + CaO \rightarrow CaS + H_2O_{(v)} \quad (4)$$

Feed Properties	
Temperature	800 ºF
Pressure	525 psig
Average Flow	1,500,000 SCFH (@ 60 ºF, 1 atm)
CH_4	85 mol%
C_2H_6	10 mol%
C_3H_8	5 mol%
Total sulfur content	0.4 gr / 100 SCF

If the desphurization bed has an initia charge of 10,000 lb of calcium oxide, the weight of the bed after 120 days of operation is most nearly?

A) 9,500 lb

B) 48,000 lb

C) 16,000 lb

D) 13,000 lb

1.6 Problem 6

Fuel	
Pressure	70 psig
Temperature	70 ºF
Flow	85,000 SCFH (@ 60 ºF, 1 atm)
CH_4	35 mol%
C_2H_6	10 mol%
H_2	40 mol%
CO	15 mol%

Air	
Pressure	5 bar-g
Temperature	18 ºC
N_2	78 mol%
O_2	21 mol%
Ar	1 mol%

A fuel stream is combusted in a fired heater with atmospheric air. In order to achieve complete combustion, the fuel should be burnt with 10% excess air (10% more than the stoichiometric amount). The fluegas has an oxygen analyzer which measures the mole percent of O_2 in the fluegas on a dry basis.

The value that the analyzer should read is most nearly?

A) 1.7 %

B) 10 %

C) 2 %

D) 1.4 %

1.7 Problem 7

A counter current heat exchanger uses 5000 lb/hr of 300 psig saturated steam to heat a process stream from 100 ºF to 400 ºF. The process stream has a constant heat capacity of 17,000 Btu/hr-ºF. The heat exchanger has an overall heat transfer coefficient of 25 Btu/ft^2-hr-ºF in the region where steam is condensing and an overall heat transfer coefficient of 10 Btu/ft^2-hr-ºF in the region where condensate is cooling.

The required heat transfer surface area of the heat exchanger is most nearly?

A) 2600 ft^2

B) 1600 ft^2

C) 2300 ft^2

D) 1600 ft^2

1.8 Problem 8

Hydrochloric acid is being loaded from a storage tank onto a barge. Someone failed to obtain a permit to pump the acid, so it must be gravity fed from the tank to the barge. How long does it take to completely fill the barge?

1.9 Problem 9

An insulated vessel is pressurized with hydrogen. The source is a temperature of X and a pressure of Y. The vessel starts at a pressure of 1 atm and a temperature of X. What is the final temperature of the gas in the vessel?

1.10 Problem 10

A drilling mud with density X is being used to drill a well. Some of the fluid is lost to the formation, resulting in ... How much Y must be added?

1.11 Problem 11

A saying that partially reflects the dilligence required in engineering is:

A) "Doesn't know his/her ass from a hole in the ground"

B) "One oh shit is worth 20 ata boys"

C) "Busier than a cat trying to cleanup shit on a marble floor"

D) "He/she is a real fence post turtle"

1.12 Solution 11

The older generation of engineers and technicians have a virtually unlimited number of sayings. To translate:

A) "Doesn't know his/her ass from a hole in the ground" = Usually reserved for younger coworkers, this saying reflect the fact that the person in question doesn't yet have enough experience to be useful

B) "One oh shit is worth 20 ata boys" (correct answer) = The nature of engineering is that one screw up can cause more problems than 20 exceptional performances

C) "Busier than a cat trying to cleanup shit on a marble floor" = Just expresses the idea that someone is busy (and maybe flustered)

D) "He/she is a real fence post turtle" = A fence post turtle is a turtle found on top of a fence post. The turtle does not know how it got up there and it doesn't know how to get down. This is reserved for someone that was promoted to a position that they aren't really qualified for.

1.13 Problem 12

A 200 foot straight section of 8" schedule 80 carbon steel pipe is designed to carry 900 psig steam with 150 ºF of superheat. How much does the length of the pipe change when the pipe is at an ambient temperature of 65 ºF vs it is in operation?

A) 11 inches

B) 8 inches

C) 0.5 inches

D) 6 inches

1.14 Solution 12

First, the temperature of the steam is calculated. From a steam table, 900 psig saturated steam has a temperature of 534 ºF. With the superheat, the steam temperature is 684 ºF. Subtracting the initial temperture gives a total temperature increase of 619 ºF (343.9 ºC). In Perry's handbook the linear expansion coefficients of steel can be found. The formula for length is given as:

$$L = L_{ref}\left(1 + \alpha\left(T - T_{ref}\right) + \beta\left(T - T_{ref}\right)^2\right)$$

For the steel the constants are given as: $\alpha = 0.1118 \times 10^{-4}\ \text{º}C^{-1}$, $\beta = 0.0053 \times 10^{-6}\ \text{º}C^{-2}$. **Plugging these in as wll as the reference length of 200 feet gives:**

$$\triangle L = L_{ref}\left(\alpha\left(T - T_{ref}\right) + \beta\left(T - T_{ref}\right)^2\right) = 200ft\cdot\left(0.1118\times10^{-4}\ \text{º}C^{-1}\cdot 343.9\ \text{º}C + 0.0053\times10^{-6}\ \text{º}C^{-2}\left(343.9\ \text{º}C\right)^2\right) = 0.894$$

The answer is A. Note that depending on the source of thermal expansion data used, you may come up with a greater amount of expansion, but since A is the largest value, it is still the correct answer.

1.15 Problem 13

Syngas	
Pressure	40 bar-g
Temperature	1000 ºC
CO	30 mol%
H_2	70 mol%
Cl	105 ppm (by mass)

It is proposed to use a 316 stainless steel pipe for a section of the plant containing a syngas. What form of corrosion should be of greatest concern?

A) Dezincification

B) Metal dusting

C) Hydrogen embittlement

D) Chloride stress corrosion

1.16 Solution 13

Chapter 25 "Materials of Construction" in Perry's handbook is a good source of information regarding types of corrosion. From this chapter we can determine that AISI 316 is an austenitic stainless steel. Based on this, we know that dezincification is not a concern since this only aplies to brass alloys. Furthmore austenitic stainless steels are resistant to hydrogen embrittlement.

Metal dusting is not described in Perry's, but is a phenomena where a carbon containing feed decomposes to form a graphite layer on the wall of the pipe and then a migration of metal ions into that graphite occurs, causing the metal to break down into a metallic powder. Metal dusting might pose a problem in this system, but it is known to only happen in a certain temperature range, usually given as 400 ºC to 800 ºC. Outside of this range the chemical reactions that cause metal dusting are not favored. Since we are significantly above this temperature range, metal dusting should not be a problem.

Chloride could be an issue though. Perry's says that austenitic stainless steels are susceptible to it especially at high temperatures and pressures. They write that at these conditions a few ppms of chlorides can cause chloride stress corrosion. Therefore D) is the correct answer.

2 Solutions

2.1 Solution 1

Chemical reactions 1 and 2 can be rearranged to give reactions 3 and 4:

$$CH_4 + H_2O \longleftrightarrow 3H_2 + CO \tag{1}$$

$$CO + H_2O \longleftrightarrow 3H_2 + CO_2 \tag{2}$$

$$CH_4 + 2H_2O \longleftrightarrow 4H_2 + CO_2 \tag{3}$$

$$CH_4 + H_2O \longleftrightarrow 3H_2 + CO \tag{4}$$

Given these two equations, the CO_2,CO **and** H_2 **in the dry syngas stream are related to each other in the following way:**

$$H_2 = \text{Product Flow/PSA Recovery} = 4 \times CO_2 + 3 \times CO \tag{5}$$

Then substituting the given ratio: $CO_2/CO = 4$

$$\text{Product Flow/PSA Recovery} = 4 \times CO_2 + 3 \times CO_2/4 = 120\ \text{MMSCFD}/0.85 \tag{6}$$

Solving for the unknown gives an answer of $CO_2 = 29.72$ **MMSCFD. Since all the** CO_2**entering the PSA ends up in the tailgas, this is the final answer of B.**

2.2 Solution 2

First convert to moles of oxygen using the ideal gas law.

$$n_{O_2} = \frac{PV}{RT} = \frac{1\ \text{atm} \cdot \left(\frac{1.01\times10^5\,\text{Pa}}{\text{atm}}\right) \cdot 500,000\ \text{ft}^3/\text{hr} \cdot \left(\frac{0.02832\ \text{m}^3}{\text{ft}^3}\right)}{8.3145\frac{\text{Pa}\cdot\text{m}^3}{\text{mol}\cdot\text{K}}\left((60^{\text{o}}\text{F} - 32)\,\frac{5}{9} + 273.15\right)\text{K}} = 595790\frac{\text{mol}}{\text{hr}}$$

Next find design moles of air:

$$n_{Air} = \left(\frac{n_{O_2}}{recovery\ O_2}\right) \cdot \frac{1\ \text{mol air}}{0.2096\ \text{mol O}_2} = \frac{595790\frac{\text{mol}}{\text{hr}}}{0.96} \cdot \frac{1\ \text{mol air}}{0.2096\ \text{mol O}_2} = 2960948\frac{\text{mol}}{\text{hr}}$$

Now find the turndown moles of air:

$$n_{Air,turndown} = n_{Air} \cdot 0.80 = 2368759\frac{\text{mol}}{\text{hr}}$$

Now find the argon recovered from the air:

$$n_{Ar} = n_{Air,turndown} \cdot \frac{0.0093\ \text{mol Ar}}{1\ \text{mol Air}} \cdot \frac{0.65\ \text{mol Ar recovered}}{1\ \text{mol Ar}} = 14319\frac{\text{mol}}{\text{hr}}$$

Finally use the convert to the appropriate units:

$$m_{Ar} = n_{Ar} \cdot \mathscr{M} = 14319\frac{\text{mol}}{\text{hr}} \cdot \frac{0.03995\ \text{kg}}{1\ \text{mol Ar}} \cdot \frac{2.205\ \text{lb}}{\text{kg}} \cdot \frac{1\ \text{ton}}{2000\ \text{lb}} \cdot \frac{24\ \text{hr}}{1\ \text{day}} = 15.14\frac{\text{ton}}{\text{day}}$$

The answer is D.

2.3 Solution 3

Using a steam table, we find the saturation pressure of steam at 18ºC = 0.0206 bar-a. Using Dalton's law of partial pressure, we can determine the approximate mole fraction of water in the inlet air (corresponding to 100% saturation):

$$y_{H_2O} = \frac{P^{sat}_{H_2O}}{P} = \frac{0.0206}{1.01+5} = 0.003428$$

Then since we are told that the air after the bed is dry and CO_2 free, we can find the enthalpy released for the completely adsorption both of these.

$$\Delta H_{total} = y_{H_2O}\Delta H_{H_2O\ ads} + y_{CO_2}\Delta H_{CO_2\ ads} =$$

$$0.003428\frac{mol\ H_2O}{mol\ air}\cdot 60,000\frac{J}{mol\ H_2O} + 400\frac{mol\ CO_2}{1\times 10^6 mol\ air}\cdot 40,000\frac{J}{mol\ CO_2} = 221.7\frac{J}{mol\ air}$$

Finally we assume that since the bed has already reached a pseudo steady temperature profile, all the heat generated by the adsorption will be carried away in the dry air leaving the bed. (The mass and heat capacity of the bed is merely a distractor). Note that we should correct for the fact that the molar flow of dry air is slightly less than the molar flow of wet air.

$$\Delta H_{total} = (T_{out} - T_{in})\frac{(1-0.0206-0.000400)\,mol\ dry\ air}{mol\ air}Cp_{dry\ air} \rightarrow T_{out} =$$

$$T_{in} + \frac{\Delta H_{total}}{0.9794\cdot 1014\frac{J}{kg^{\circ}\mathrm{C}}\cdot 0.02897\frac{kg}{mol}} = 25.71^{\circ}C$$

The answer is A.

2.4 Solution 4

Equilibrium equations can be written for both the SMR reaction and the WGS reaction:

$$K_{eq,SMR} = \frac{\left(\frac{F_{H_2}}{F_{total}}P\right)^3 \left(\frac{F_{CO}}{F_{total}}P\right)}{\left(\frac{F_{CH_4}}{F_{total}}P\right)\left(\frac{F_{H_2O}}{F_{total}}P\right)} \rightarrow \frac{K_{eq,SMR}}{P^2} = \frac{F_{H_2}^3 F_{CO}}{F_{CH_4}F_{H_2O}} \cdot \left(\frac{1}{F_{H_2}+F_{CO}+F_{CO_2}+F_{H_2O}+F_{CH_4}}\right)^2$$

$$K_{eq,WGS} = \frac{\left(\frac{F_{H_2}}{F_{total}}P\right)\left(\frac{F_{CO_2}}{F_{total}}P\right)}{\left(\frac{F_{CO}}{F_{total}}P\right)\left(\frac{F_{H_2O}}{F_{total}}P\right)} \rightarrow K_{eq,WGS} = \frac{F_{H_2}F_{CO_2}}{F_{CO}F_{H_2O}}$$

The amount of each component at equilibrium can be written as the feed amount of each component (which is 0 except for the methane and steam) and the extent of both reactions.

$$F_{H_2} = 3 \cdot E_{SMR} + E_{WGS}$$

$$F_{CO_2} = E_{WGS}$$

$$F_{CO} = E_{SMR} - E_{WGS}$$

$$F_{H_2O} = F_{H_2O,feed} - E_{SMR} - E_{WGS}$$

$$F_{CH_4} = F_{CH_4,feed} - E_{SMR}$$

If these are substituted into the above equations:

$$\frac{K_{eq,SMR}}{P^2} = \frac{(3 \cdot E_{SMR} + E_{WGS})^3 (E_{SMR} - E_{WGS})}{(F_{CH_4,feed} - E_{SMR})(F_{H_2O,feed} - E_{SMR} - E_{WGS})} \cdot \left(\frac{1}{F_{H_2O,feed} + F_{CH_4,feed} + 2 \cdot E_{SMR}}\right)^2$$

$$K_{eq,WGS} = \frac{(3 \cdot E_{SMR} + E_{WGS})(E_{WGS})}{(E_{SMR} - E_{WGS})(F_{H_2O,feed} - E_{SMR} - E_{WGS})}$$

It would be possible to solve these two equations for E_{WGS} and E_{SMR}. However, this is complicated. An easier method is to substitute in different answers to see if the satisfy both equations. Lets start with b) $F_{CO_2} = 450\ SCFH$.

$$E_{WGS} = F_{CO_2} = 450\ SCFH$$

$$K_{eq,WGS} = 0.9794 = \frac{(3 \cdot E_{SMR} + 450\ SCFH)(450\ SCFH)}{(E_{SMR} - 450\ SCFH)(5280\ SCFH - E_{SMR} - 450\ SCFH)}$$

This equation can be solved by rearranging and using the quadratic formula. This yields two solutions, $E_{SMR} = 3145$ or $E_{SMR} = 756.9$. Only the 2nd solution is physically possible (we can't have negative moles of methane and water in the product). We can then plug both extents of reaction into the 2nd equilibrium equation:

$$\frac{703.2\ bar^2}{(30\ bar)^2} = \frac{(3 \cdot 756.9 + 450)^3 (756.9 - 450)}{(1760 - 756.9)(5280 - 756.9 - 450)} \cdot \left(\frac{1}{1760 + 5280 + 2 \cdot 756.9}\right)^2$$

$$0.7813 \neq 0.02068$$

It is clear that answer b) is not a solution. Answer a) can be ruled out because $2,000 > 1760$ **which would mean that more carobon was leaving the SMR than entering. If we try to solve the WGS equilibrium equation with answer c) we get no real number results which means that this is not a solution. This leaves only d). We can check this answer:**

$$E_{WGS} = F_{CO_2} = 567\ SCFH$$

$$K_{eq,WGS} = 0.9794 = \frac{(3 \cdot E_{SMR} + 567\ SCFH)(567\ SCFH)}{(E_{SMR} - 567\ SCFH)(5280\ SCFH - E_{SMR} - 567\ SCFH)}$$

This yields two solutions, $E_{SMR} = 2143$ **or** $E_{SMR} = 1400$**. Only the 2nd solution is physically possible. Plugging into the 2nd equation:**

$$\frac{1046\ bar^2}{(30\ bar)^2} = \frac{(3 \cdot 1400 + 567)^3 (1400 - 567)}{(1760 - 1400)(5280 - 1400 - 567)} \cdot \left(\frac{1}{1760 + 5280 + 2 \cdot 1400}\right)^2$$

$$0.7813 \approx 0.7814$$

Both equations are solved, so d) is the correct answer.

2.5 Solution 5

The sulfur content is measured in grains / 100 SCF. 1 grain $\equiv 6.48 \times 10^{-5}$**kg. The total sulfur entering the bed is:** $1.5 \times 10^6\ SCF/hr \cdot \frac{6.48 \times 10^{-5} kg}{100\ SCF} \cdot \frac{24\ hr}{day} \cdot 120\ day = 2800\ kg$**. Each atom of sulfur displaces an atom of oxygen in the bed. Therefore the total increase in weight is:**

$$2800\ kg\ S \cdot \frac{mol\ S}{32.07\ kg\ S} \cdot \left(1\ mol\ S \cdot \frac{32.07\ kg}{mol\ S} - 1\ mol\ O \cdot \frac{16.00\ kg}{mol\ O}\right) = 1403\ kg$$

Adding this to the original weight of the bed gives: $10,000\ lb + 1403\ kg \cdot \frac{2.02\ lb}{kg} = 13,093\ lb$**. The answer is D.**

2.6 Solution 6

First find the reactions for complete combustion of the various components of the fuel.

$$1 \cdot CH_4 + 2 \cdot O_2 \rightarrow 2 \cdot H_2O + 1 \cdot CO_2$$

$$1 \cdot C_2H_6 + 3.5 \cdot O_2 \rightarrow 3 \cdot H_2O + 2 \cdot CO_2$$

$$1 \cdot H_2 + 0.5 \cdot O_2 \rightarrow 1 \cdot H_2O$$

$$1 \cdot CO + 0.5 \cdot O_2 \rightarrow 1 \cdot CO_2$$

Next multiply each of these equations by the mole percentage in the feed to get an overall combustion equation:

$$1 \cdot FEED = 0.35 \cdot CH_4 + 0.1 \cdot C_2H_6 + 0.4 \cdot H_2 + 0.15 \cdot CO + (0.35 \times 2 + 0.1 \times 3.5 + 0.4 \times 0.5 + 0.15 \times 0.5) \cdot O_2 \rightarrow$$

$$(0.35 \times 2 + 0.1 \times 3 + 0.4 \times 1 + 0.15 \times 0) \cdot H_2O + (0.35 \times 1 + 0.1 \times 2 + 0.4 \times 0 + 0.15 \times 1) \cdot CO_2 \Rightarrow$$

$$1 \cdot FEED + (1.325) \cdot O_2 \rightarrow 1.4 \cdot H_2O + 0.7 \cdot CO_2$$

The air flow to achieve complete combustion is the oxygen flow divided by the amount of oxygen in the air. However we need 10% excess air (which equates to having 10% more oxygen than stoichiometrically necessary). This gives the following (INERTS are N2 and Ar):

$$1 \cdot FEED + \left(1 + \frac{10}{100}\right)\left(\frac{1.325}{0.21}\right) \cdot AIR \rightarrow$$

$$1.4 \cdot H_2O + 0.7 \cdot CO_2 + \left(1 + \frac{10}{100}\right)\left(\frac{1.325}{0.21}\right) \cdot (1 - 0.21) \cdot INERTS + \left(\frac{10}{100}\right) \cdot 1.325 \cdot O_2$$

Since the analyzer operates on a dry basis we will remove the water which gives that the products are: $0.7 \cdot CO_2 + 6.940 \cdot INERTS + 0.1325 \cdot O_2$**. So the mole fraction of oxygen is:** $\frac{0.1325}{0.1325+0.7+6.940} = 0.01705 = 1.705\ mol\%\ O_2$**. The answer is A.**

2.7 Solution 7

Because no pressure drops are given, we will assume they are negligable. The required duty to heat the process stream is found.

$$Q_{process} = m \cdot Cp \cdot \Delta T = 17,000\, Btu/hr - {}^{\underline{o}}F \times (400^{\underline{o}}F - 100^{\underline{o}}F) = 5.1 \times 10^6 Btu/hr$$

The duty from condensing the steam can be found by looking up the latent heat of the steam on a steam table.

$$Q_{steam} = m \cdot L = 5,000\, lb/hr \times 805.1\, Btu/lb = 4.026 \times 10^6 Btu/hr$$

The temperature of the steam is 421.8 ºF from the steam table. The heat capacity of liquid water is approximately 1 Btu/lb. An energy balance on the system gives:

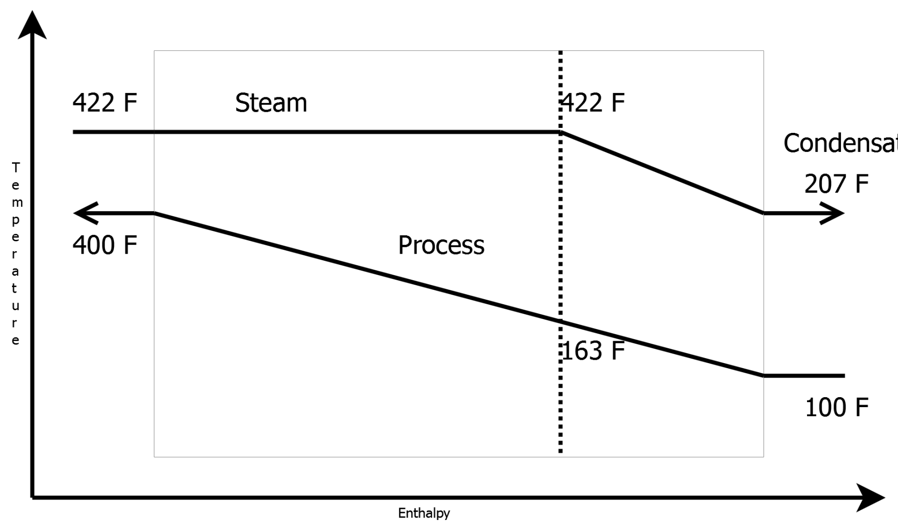
$$Q_{process} - Q_{steam} = m \cdot Cp \cdot \Delta T_{water} \rightarrow$$

$$\Delta T_{water} = \left(5.1 \times 10^6 Btu/hr - 4.026 \times 10^6 Btu/hr\right) / \left(5000\, lb/hr \times 1\, Btu/lb\right) = 214.8^{\underline{o}}F$$

This means the outlet steam has condensed and reached a temperature of 421.8 ºF - 214.8 ºF = 207 ºF. The intermediate temperature of the process stream can also be found:

$$T_{intermediate} = 400^{\underline{o}}F - \frac{4.026 \times 10^6 Btu/hr}{17,000\, Btu/hr - {}^{\underline{o}}F} = 163.2\ {}^{\underline{o}}F$$

The heat exchanger is composed of two regions as shown:



In each region we can find the log mean temperature difference.

$$\Delta T_{lm,steam} = \frac{(421.8\ {}^{\underline{o}}F - 163.2\ {}^{\underline{o}}F) - (421.8\ {}^{\underline{o}}F - 400\ {}^{\underline{o}}F)}{ln\left(\frac{421.8\ {}^{\underline{o}}F - 163.2\ {}^{\underline{o}}F}{421.8\ {}^{\underline{o}}F - 400\ {}^{\underline{o}}F}\right)} = 95.65\ {}^{\underline{o}}F$$

$$\Delta T_{lm,condensate} = \frac{(421.8\ {}^{\underline{o}}F - 163.2\ {}^{\underline{o}}F) - (207\ {}^{\underline{o}}F - 100\ {}^{\underline{o}}F)}{ln\left(\frac{421.8\ {}^{\underline{o}}F - 163.2\ {}^{\underline{o}}F}{207\ {}^{\underline{o}}F - 100\ {}^{\underline{o}}F}\right)} = 173.2\ {}^{\underline{o}}F$$

Then we can find the area of each region.

$$UA\Delta T_{lm,steam} = Q \rightarrow$$

$$A_{steam} = \frac{4.026 \times 10^6 Btu/hr}{95.65\ ^{o}F \cdot (25\ Btu/ft^2 - hr -\ ^{o}F)} = 1684\ ft^2$$

$$A_{condensate} = \frac{\left(5.1 \times 10^6 Btu/hr - 4.026 \times 10^6 Btu/hr\right)}{173.2\ ^{o}F \cdot (10\ Btu/ft^2 - hr -\ ^{o}F)} = 620.1\ ft^2$$

The total area of the exchanger is found by adding these areas together: $A_{total} = 2304\, ft^2$**. The answer is C.**

