

Tikrit University

College of Petroleum Processes Engineering

**Department of Petroleum and Gas Refining
Engineering**

Gas Technology

Forth Class

Lectures 7

By

Jasim I. Humadi

Basic Calculations for Gaseous Fuel

Material and energy balances are very important in an gas industry.

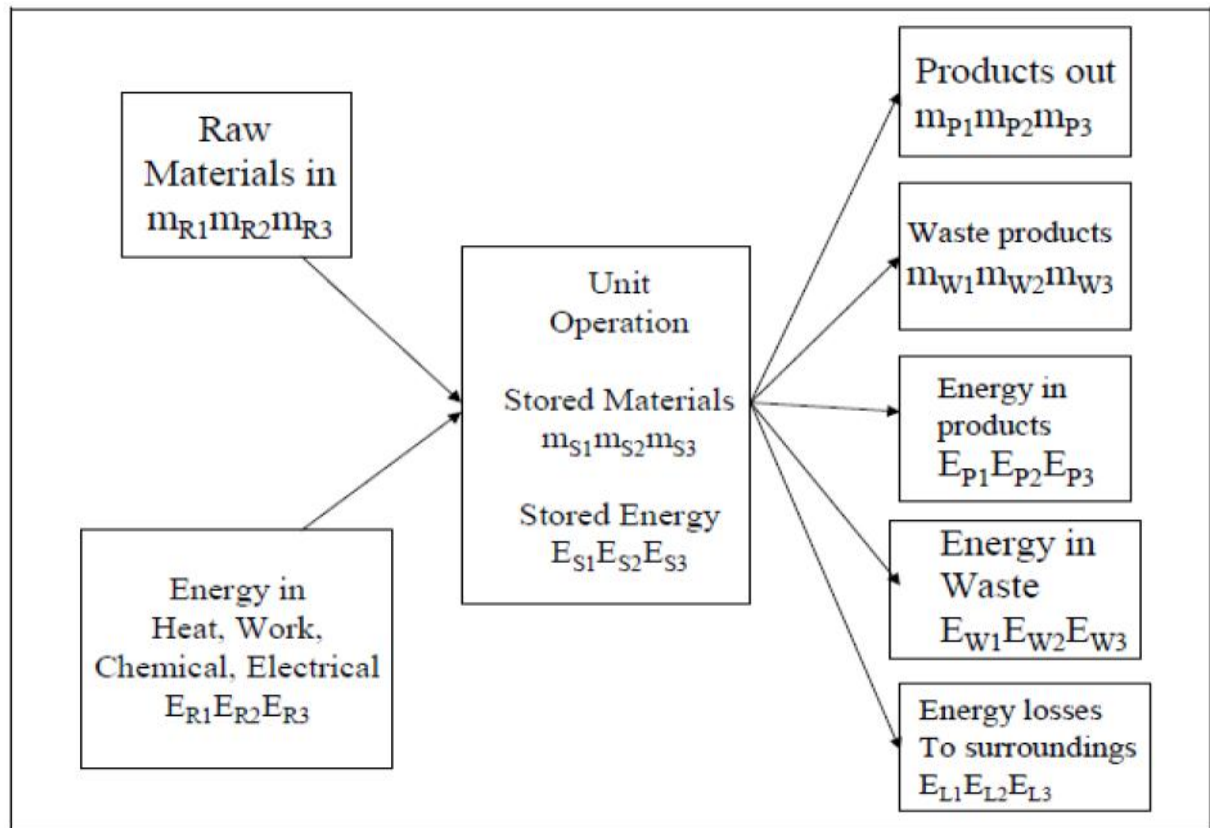
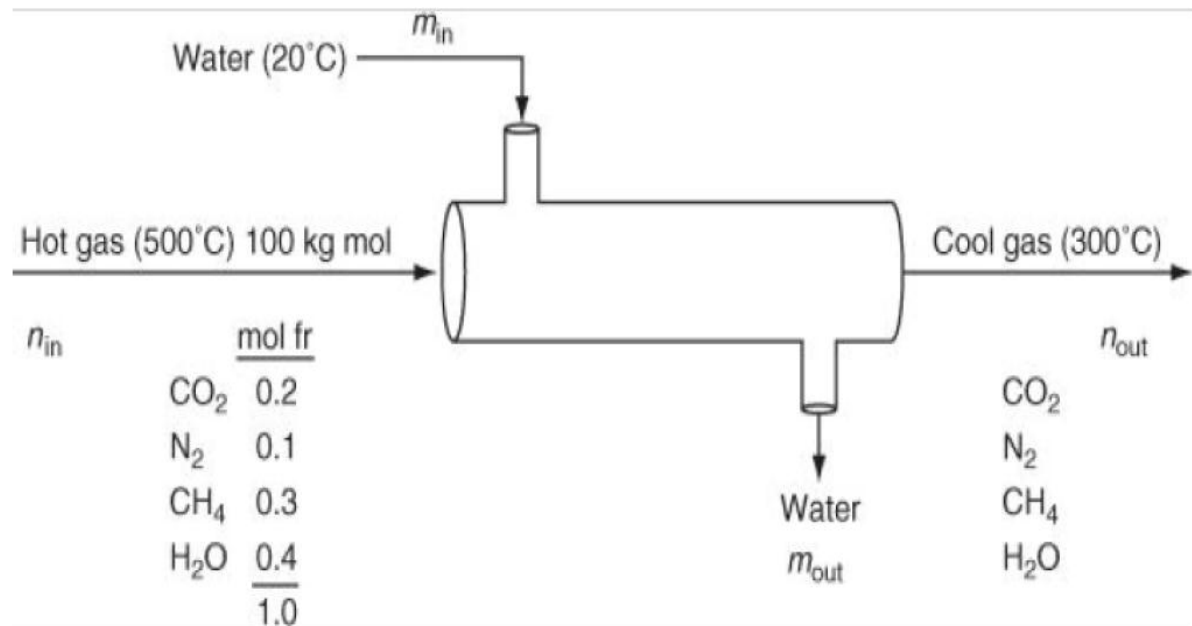


Figure 1: Mass and Energy Balance

Example 5: Figure below shows a hot gas stream at 500°C being cooled to 300°C by transferring heat to the liquid water that enters at 20°C and exits at 213°C . Assume that the heat exchanger is insulated. The cooling water does not mix with the gas. Calculate the value of the mass of the water?



Solution:

Basis: 100 kg mol of entering hot gas (1 min)

How can you calculate the value of m_{water} ?

Use the energy balance. The general energy balance

$$\Delta E = Q + W - \Delta(H + PE + KE)$$

can be greatly simplified by stating

$$\Delta E = 0 \text{ steady-state}$$

$Q = 0$ assume that the heat exchanger is insulated

$W = 0$ assumed (no information given)

$\Delta PE = 0$ assumed for all streams and inside the system

$\Delta KE = 0$ assumed for all streams and inside the system

Then $\Delta H = 0$

is the result, or in full:

$$[(n_{gas})(\hat{H}_{gas\ out}) + (m_{water})(\hat{H}_{water\ out})] - [(n_{gas})(\hat{H}_{gas\ in}) + (m_{water})(\hat{H}_{water\ in})] = 0$$

Rearrange to

$$n_{gas}\Delta\hat{H}_{gas} - m_{water}\Delta\hat{H}_{water} = 0$$

Component	$\Delta\hat{H}_i(\text{kJ/kg mol})$	$n_i(\text{kg mol})$	$\Delta H = n_i\Delta\hat{H}_i(\text{kJ})$
CO ₂	-9333	20	-186,660
N ₂	-6215	10	-62,150
CH ₄	-11,307	30	-339,210
H ₂ O	-7441	40	-297,640
Total		100	-885,660 = ΔH_{gas}

From the values in the saturated portion of the steam tables

$T(^{\circ}\text{C})$	$\hat{H}(\text{kJ/kg})$
20	35.7
213	911.4

$\Delta\hat{H} = 875.7 \text{ kJ/kg}$

$$m_{water} = \frac{-\Delta H_{gas}}{\Delta\hat{H}_{water}} = \frac{-(-885,660) \text{ kJ}}{875.7 \text{ kJ/kg}} = 1011 \text{ kg}$$

$$m_{water} 1,011 \text{ kg/min} \quad (\text{the basis was 1 min})$$

Combustion Systems for Gaseous Fuel

Combustion is the reaction of a substance with oxygen with the associated release of energy and generation of product gases such as H₂O, CO₂, CO, and SO₂. Most combustion processes use air as the

source of oxygen. For our purposes you can assume that air contains 79% N₂ and 21% O₂.

1- Flue or stack gas: All the gases resulting from combustion process including the water vapor, sometimes known as a wet basis .

2- Orsat analysis or dry basis: All the gases resulting from combustion process not including the water vapor.

3- Complete combustion: the complete reaction of the hydrocarbon fuel producing CO₂, SO₂, and H₂O .

4- Partial combustion: the combustion of the fuel producing at least some CO. Because CO itself can react with oxygen, the production of CO in a combustion process does not produce as much energy as it would if only CO₂ were produced

5- Theoretical air (or theoretical oxygen): The minimum amount of air (or oxygen) required to be brought into the process for complete combustion. Sometimes this quantity is called the required air (or oxygen).

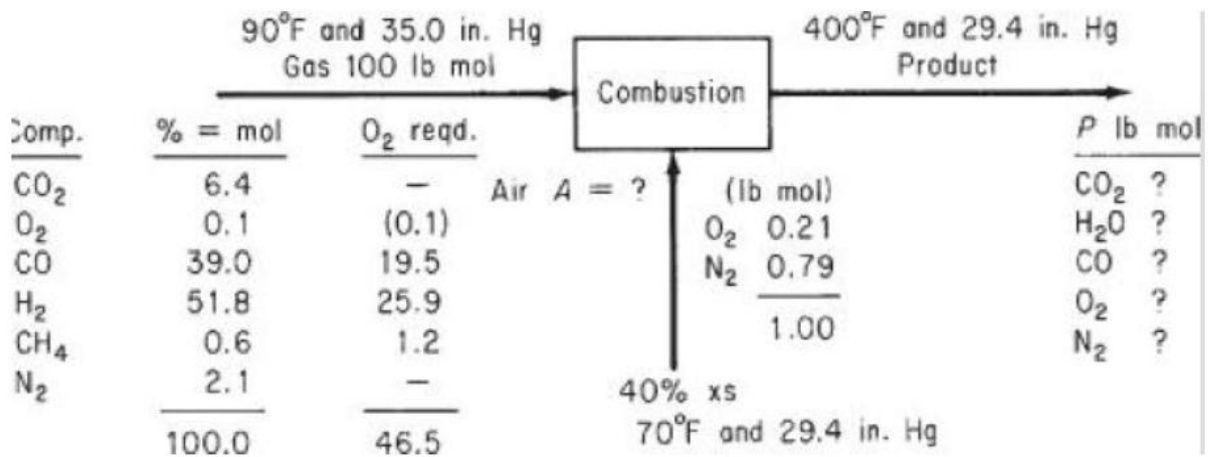
6- Excess air (or excess oxygen) : excess air (or oxygen) would be the amount of air (or oxygen) in excess of that required for complete combustion as defined in (5).

$$\% \text{ excess air} = 100 \frac{\text{excess air}}{\text{required air}} = 100 \frac{\text{excess O}_2/0.21}{\text{required O}_2/0.21} = 100 \frac{\text{excess O}_2}{\text{required O}_2}$$

$$\% \text{ excess air} = 100 \frac{\text{O}_2 \text{ entering process} - \text{O}_2 \text{ required}}{\text{O}_2 \text{ required}}$$

$$\% \text{ excess air} = 100 \frac{\text{excess O}_2}{\text{O}_2 \text{ entering} - \text{excess O}_2}$$

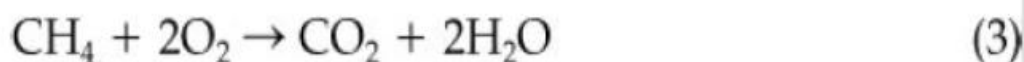
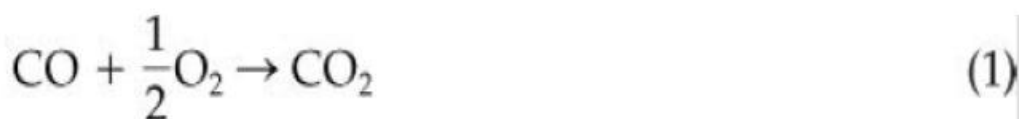
Example 6: To evaluate the use of renewable resources, an experiment was carried out with rice hulls. After pyrolysis, the product gas analyzed 6.4% CO₂, 0.1% O₂, 39% CO, 51.8% H₂, 0.6% CH₄, and 2.1% N₂. It entered a combustion chamber at 90°F and a pressure of 35.0 in. Hg and was burned with 40% excess air (dry) at 70°F and an atmospheric pressure of 29.4 in. Hg; 10% of the CO remains. How many cubic feet of air were supplied per cubic foot of entering gas? How many cubic feet of product gas were produced per cubic foot of entering gas if the exit gas was at 29.4 in. Hg and 400°F?



Solution:

Basis: 100 lb mol of pyrolysis gas

The entering air can be calculated from the specified 40% excess air; the reactions for complete combustion are



The excess oxygen is

$$\text{Excess O}_2: 0.4(46.3) = 18.6$$

$$\text{Total O}_2: 46.5 + 18.6 = 65.1$$

$$\text{N}_2 \text{ in is } 65.1 \left(\frac{79}{21} \right) = 244.9$$

Total moles of air in are $244.9 + 65.1 = 310.0$ lb mol.

Finally, use the specification for CO to assign $n_{\text{CO}} = 0.10(39.0) = 3.9$

Make the element balances in moles to calculate the unknown quantities

	In	=	Out
N	$(2)(2.1) + (2)(244.9)$	=	$2n_{\text{N}_2}$
C	$6.4 + 39.0 + 0.6$	=	$n_{\text{CO}_2} + 3.9$
H	$(2)(51.8) + (0.6)(2)$	=	$2n_{\text{H}_2\text{O}}$
O	$(2)(6.4) + (2)(0.1) + 39 + (2)(65.1)$	=	$2n_{\text{O}_2} + 2n_{\text{CO}_2} + n_{\text{H}_2\text{O}} + n_{\text{CO}}$

The solutions of these equations are

$$n_{\text{N}_2} = 247$$

$$n_{\text{CO}_2} = 42.1$$

$$n_{\text{H}_2\text{O}} = 53.0$$

$$n_{\text{O}_2} = 20.55$$

The total moles exiting calculated from the implicit equation sum to 366.6 mol.

you can convert the pound moles of air and products that were calculated on the basis of 100 lb mol of pyrolysis gas to the volumes of gases at the states requested using the ideal gas law

$$T_{\text{gas}} = 90 + 460 = 550^\circ\text{R} \rightarrow 306 \text{ K}$$

$$T_{\text{air}} = 70 + 460 = 530^\circ\text{R} \rightarrow 294 \text{ K}$$

$$T_{\text{product}} = 400 + 460 = 860^\circ\text{R} \rightarrow 478 \text{ K}$$

$$\text{ft}^3 \text{ of gas: } \frac{100 \text{ lb mol entering gas}}{1 \text{ lb mol}} \left| \frac{359 \text{ ft}^3 \text{ at S.C.}}{1 \text{ lb mol}} \right| \frac{550^\circ\text{R}}{492^\circ\text{R}} \left| \frac{29.92 \text{ in. Hg}}{35.0 \text{ in. Hg}} \right| = 343 \times 10^2$$

$$\text{ft}^3 \text{ of air: } \frac{310 \text{ lb mol air}}{1 \text{ lb mol}} \left| \frac{359 \text{ ft}^3 \text{ at S.C.}}{1 \text{ lb mol}} \right| \frac{530^\circ\text{R}}{492^\circ\text{R}} \left| \frac{29.92 \text{ in. Hg}}{29.4 \text{ in. Hg}} \right| = 1220 \times 10^2$$

$$\text{ft}^3 \text{ of product: } \frac{366.6 \text{ lb mol } P}{1 \text{ lb mol}} \left| \frac{359 \text{ ft}^3 \text{ at S.C.}}{1 \text{ lb mol}} \right| \frac{860^\circ\text{R}}{429^\circ\text{R}} \left| \frac{29.92 \text{ in. Hg}}{35.0 \text{ in. Hg}} \right| = 2331 \times 10^2$$

The answers to the questions are

$$\frac{1220 \times 10^2}{343 \times 10^2} = 3.56 \frac{\text{ft}^3 \text{ air at } 530^\circ\text{R} \text{ and } 29.4 \text{ in. Hg}}{\text{ft}^3 \text{ gas at } 550^\circ\text{R} \text{ and } 35.0 \text{ in. Hg}}$$

$$\frac{2255 \times 10^2}{343 \times 10^2} = 6.57 \frac{\text{ft}^3 \text{ product at } 860^\circ\text{R} \text{ and } 29.4 \text{ in. Hg}}{\text{ft}^3 \text{ gas at } 550^\circ\text{R} \text{ and } 35.0 \text{ in. Hg}}$$

Heat of Combustion Reaction

it is defined as the energy liberated from a chemical reaction when products are brought back to the initial temperature of the reactants

If the water formed exists in the vapor state, the heat of combustion is termed lower heating value. If the water in the product state exists as a liquid, the heat of combustion is termed higher heating value of the fuel. This implies that the product mixture gave up its additional latent heat in going from a vapor to a liquid state

$$LHV = \sum_{i=1}^{\nu} x_i LHV_i$$

$$HHV = \frac{\sum_{i=1}^{\nu} x_i HHV_i}{Z_m}$$

Where Z_m is the compressibility factor

Wobbe index

Wobbe index (W) is an important criterion of inter-changeability of gases in the industrial applications (engines, boilers, burners, etc). Gas composition variation does not involve any notable change of air factor and of flame speed when Wobbe index remains almost constant. Wobbe index can be calculated starting from the high heating value (HHV) and specific gas density (d) by

$$W = \frac{HHV}{\sqrt{d}}$$

This parameter is usually used to characterize gas quality

Utilization of Natural Gas

Natural gas is one of the major fossil energy sources. When one standard cubic feet of natural gas is combusted, it generates 700 Btu to 1,600 Btu of heat, depending upon gas composition.

Example 7: Natural gas from the Schleicher County, Texas, Straw Reef has a heating value of 1,598 Btu/scf. If this gas is combusted to generate power of 1,000 kW, what is the required gas flow rate in Mscf/day? Assume that the overall efficiency is 50 percent (1 kW= 1,903 Btu/h).

Solution:

Output power of the generator

$$1000 \text{ kW} = 1.903 \times 10^6 \text{ Btu/h} = 4.57 \times 10^7$$

$$\frac{4.57 \times 10^7 \text{ Btu/day}}{1,598 \text{ Btu/scf} \times (0.5)} = 57.2 \text{ Mscf/day}$$