Instrument Procedure: Stoichiometric Ratio Method

Description

Assuming the biomass is moisture and ash free, and the products after gasification process contains no tars, remaining carbons as well as other minor compounds; the gasification reaction can be expressed by the equation 7.

$$CH_mO_p + h \cdot H_2O + x \cdot (O_2 + 3.76\ N_2) \Rightarrow aCO + bCO_2 + cH_2 + dCH_4 + eH_2O + fN_2 + gO_2 \quad (7)$$

The following equations can be deduced:

$$\Sigma X_{mc} = X_{CO} + X_{CO2} + X_{CH4} \quad (8)$$

$$a = X_{CO} / \Sigma X_{mc} \quad (9)$$

$$b = X_{CO2} / \Sigma X_{mc} \quad (10)$$

$$c = X_{H2} / \Sigma X_{mc} \quad (11)$$

$$d = X_{CH4} / \Sigma X_{mc} \quad (12)$$

$$f = X_{N2} / \Sigma X_{mc} \quad (13)$$

$$g = X_{O2} / \Sigma X_{mc} \quad (14)$$

$$X_{CO} = a / (a + b + c + d + f + g) \quad (15)$$

$$X_{CO2} = b / (a + b + c + d + f + g) \quad (16)$$

$$X_{H2} = c / (a + b + c + d + f + g) \quad (17)$$

$$X_{CH4} = d / (a + b + c + d + f + g) \quad (18)$$

$$X_{O2} = g / (a + b + c + d + f + g) \quad (19)$$

Where X is the mole fraction for each gas, Σ Xmc is the sum of mole fraction of measured carbon containing compounds. Since the results of gas percentage from the GC are based upon the gas volume, this percentage also refers to the mole fraction for each gas component at the same temperature and pressure. For example, if the GC results show that the concentration for carbon monoxide is 25%, it means $X_{CO} = 25\%$. Thus, with the GC results, a, b, c, d, g and f can be calculated. Based on those experimental results, the syn-gas volume produced from 1 kg of biomass and the thermal efficiency can thus be calculated.

Procedure

The following demonstrates the procedures to calculate the syn-gas volume through the stoichiometric ratio method:

1. On the basis of GC results from gasification, Σ Xmc = CO% + CO2% + CH4%.
2. Calculate the coefficient a = CO% / (CO% + CO2% + CH4%). Similarly, b = CO2% / (CO% + CO2% + CH4%), c = H2% / (CO% + CO2% + CH4%), d = CH4% / (CO% + CO2% + CH4%), f = N2% / (CO% + CO2% + CH4%), g = O2% / (CO% + CO2% + CH4%).
3. Based on the reaction (7) and the syn-gas composition, 1 mole of biomass (CHmOp) can produce (28a + 44b + 2c + 16d + 28f + 32g) mole of syn-gas.
4. Because the molecular weight of CHmOp is (12 + m + 16p) kg/mol, the mass of 1 mole of biomass (CHmOp) is (12 + m + 16p) kg. Therefore, 1 kg of CHmOp equals to 1 / (12 + m + 16p) mole.
5. The mass of syn-gas produced from 1 kg of biomass (CHmOp) gasification can be calculated:

$$M_{syn\text{-}gas} = (28a + 44b + 2c + 16d + 28f + 32g) / (12 + m + 16p) \text{ kg.}$$

6. Same as in the equivalence ratio method, the density of syn-gas can be calculated through the equation:

$$\rho_{syn\text{-}gas} = \rho(H_2) \times H_2\% + \rho(O_2) \times O_2\% + \rho(N_2) \times N_2\% + \rho(CH_4) \times CH_4\% + \rho(CO) \times CO\% + \rho(CO_2) \times CO_2\% + \rho(H_2O) \times H_2O\ \%$$

7. Once the density of syn-gas is determined, the volume of syn-gas generated from 1 kg of biomass can be calculated:

$$V^o_{syn\text{-}gas} = M_{syn\text{-}gas} / \rho_{syn\text{-}gas}$$

8. $V^o_{syn\text{-}gas}$ represents the amount of syn-gas produced from 1 kg of biomass gasification in theory. The actual amount of syn-gas $V_{syn\text{-}gas}$, however, needs to be adjusted by introducing a constant A:

$$V_{syn\text{-}gas} = A \cdot V^o_{syn\text{-}gas}$$

9. When gasifying different types of biomass, different pressures were applied. Different pressures used in the same gasification system were directly related to the gas flow rate, hence affecting the amount of syn-gas produced from 1 kg of biomass. Thus, constant A is determined by constant A^o and the pressure ratio.

$$A = A^o \times P_{biomass} / P_{woodchips}$$

10. Set the woodchip gasification as the baseline, P_{wood} is the pressure used for woodchip gasification while $P_{biomass}$ is the pressure used for any other type of biomass. In this case, it refers to the pressure used for the mixture gasification (P_{mix}) and Arundo donax gasification (P_{Arundo}). A^o is the correction factor based on the volume of syn-gas calculated from the equivalence ratio method ($V_{ERsyn\text{-}gas}$). Assuming $V_{ERsyn\text{-}gas}$ is the actual amount of syn-gas produced from 1 kg of woodchips, and $V^o_{syn\text{-}gas}$ is the volume of woodchip syn-gas calculated from the stoichiometric ratio method. Therefore, the correction factor A^o is determined by:

$$A^o = V_{ERsyn\text{-}gas} / V^o_{syn\text{-}gas}$$

11. After correction, the volume of syn-gas could be plugged into the equation to calculate the thermal efficiency.