Production of Gaseous fuel

Preamble

Key words: Gasification, gaseous fuel, producer gas, gasifier

Gaseous fuel is produced by gasifying coal or coke in a reactor called gas producer. Gaseous fuels have several advantages like

- It is easy to handle.
- Combustion is rapid in comparison to coal or fuel oil.
- Less excess air for combustion is required than for combustion of fuel oil and coke.

Thermodynamics of Gasification:

Thermodynamics deals with the conversion of carbon of fuel to gaseous product at equilibrium, which means thermodynamics deals with initial and final states.

Consider gasification of 1 mole of carbon with air. Stoichiometrically ½ mole of oxygen is required to produce 1 mole of CO. One mole of oxygen is obtained from 4.76 moles of air, which means that every mole of oxygen carries 3.76 moles of N_2 with it. Thus if the initial state of reactants is C, O_2 and and final state is CO and N_2 the following gasification reaction can be written:

$$C + ½(O2 + 3.76\,N_2) = CO + 1.88\,N_2$$

(1) $-\Delta H^{\circ}_{fco} = 29.6 \times 10^3$ Kcal/Kg mol

Gaseous fuel produced by gasification of carbon consists of CO and N_2 in which

$\%CO = 34.7\%$ and $\%N_2 = 65.3\%$

Volume of gaseous fuel $= 5.36\ m^3$/Kg mole of carbon (at 273K and 1 atm)

One can also use a mixture of air + steam to gasify the fuel. Now suppose we gasify carbon with a mixture of air + steam. Note that reaction 1 generates $= 29.6 \times 10^3/12 = 2467$ Kcal of heat per Kg of carbon. This excessive amount of heat can generate a very high temperature in the gasifier, if the excessive amount of heat is not properly managed. In large sized gas producers heat losses are very small and there occurs substantial rise in temperature. Steam is utilized to use the heat produced by reaction 1. Steam usage brings the following advantages:

- Decomposition of steam produces hydrogen and thereby producer gas is enriched in calorific value.

- Gaseous fuel is enriched per unit volume since volume of H_2 << volume of N_2
- Excessive heat in the producer is utilized since decomposition of steam is endothermic.
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- Consider the following gasification reaction

$$C + H_2O_{(v)} = CO + H_{2(g)}$$

$$\text{Heat of reaction } \Delta H^{\circ}_R = (-29.6 \times 10^3 + 57.8 \times 10^3) = 28.2 \times 10^3 \text{ Kcal}$$

In the gasification of coal or coke with a mixture of air and steam, it is important to know how much amount of steam can be fed without supplying any heat from outside. Heat balance can yield the amount of steam which can be fed.

Consider gasification of 1 Kg mole of C with a mixture air and steam under adiabatic conditions:

Let X Kg mole of C reacts with air. Assuming that all steam decomposes to H_2 and carbon forms CO.

$$X\,C + X/2\,(O_2 + 3.76\,N_2) = X\,CO + 1.88X\,N_2 \quad (2)$$

$$(1-X)\,C + (1-X)\,H_2O = (1-X)\,CO + (1-X)\,H_2 \quad (3)$$

Heat produced by eq. 2 = Heat consumed by eq. 3

$$29.6 \times 10^3\,X = (1-X) \times 10^3 \times 28.2\,X = 0.488 \text{ Kg mole}$$

Therefore final equations for gasification becomes

$$C + \frac{0.488}{2}(O_2 + 3.76\,N_2) + 0.512\,H_2O = CO + 0.917\,N_2 + 0.512\,H_2 \quad (4)$$

$$\text{Fuel gas analysis is } CO = 41.1\%,\ N_2 = 37.8\% \text{ and } = 21.1\%$$

$$\text{Amount of fuel gas } = (1 + 0.917 + 0.512) \times 22.4/12 = 4.53\ m^3/\text{Kg Carbon (at 273 K and 1 atm)}$$

Amount of steam is 0.768 Kg/kg of carbon

Alternatively a mixture of oxygen and steam can also be used for gasification.Consider the gasification of a mole of carbon by a mixture of pure oxygen +steam

Assuming that all steam decomposes to H_2 and carbon forms CO.

$$X\,C + X/2O_2 + = X\,CO \qquad (5)$$

$$(1-X)\,C + (1-X)\,H_2O = (1-X)\,CO + (1-X)\,H_2 \qquad (6)$$

Heat produced by eq. 5 = Heat consumed by eq. 6

$$29.6 \times 10^3 X = (1-X) \times 10^3 \times 28.2$$

$$X = 0.488 \text{ Kg mole}$$

Therefore final equations for gasification becomes

$$C + 0.488/2\,O2 + 0.512\,H_2O = CO + 0.512\,H_2 \qquad (7)$$

Fuel gas analysis is $CO = 66.14\%$, and $H_2 = 33.86\%$

Amount of fuel gas $= 2.82\ m^3/Kg$ Carbon (at 273 K and 1 atm)

Amount of steam is 0.768 Kg/kg of carbon

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Calorific Value

Calorific vale is the potential enrgy contained in the fuel. The calculation of calorific value is illustrated in the following on the basis of gasification of 1 kg of carbon. The calorific value of gaseous fuel when air is used for gasification is 5633 kcal

Calorific Value of C = 8100 Kcal calculated by Dulong's formula using pure C

Therefore % CV of 1 Kg of C available in producer gas is 69.5%

That means $30.5\ \%$ of calorific value of C represents sensible heat and heat losses.

Calorific value of producer gas when produced by gasifying carbon with a mixture of air+steam is

$= 6077\ kcal$ when standard state of the product is gas.

Calorific value of producer gas as expressed in % of calorific value of $1\ kg\ of\ C = 96.8\%$

We observe that the gasification of C with a mixture of air and steam increases the calorific value of producer gas which is mainly due to addition of hydrogen.

The calorific value of producer gas obtained by a mixture of oxygen and steam is almost similar to that of air + steam. But the volume of producer gas is only 62% that of air + steam and 48% that of air only. Benefit of using steam is self evident.

Is it possible to decompose all steam to hydrogen and C to CO?

Typically, gas producer, operates in a counter-current mode i.e. coal is charged from top and a mixture of air and steam is blown through the coal bed simultaneously and continuously from the bottom. The flow rates of air and steam are adjusted so that the heat evolution in the reaction of with C of coke/coal balances the heat absorption due to endothermic reaction of decomposition of steam. Thus

- Not all steam decomposes to H_2 i.e. some amount of steam remains undecomposed and
- Not all C is converted to CO.

The extent of decomposition of steam to hydrogen and conversion of C to CO depends on temperature, residence time of the reactants in the reactor, reactivity of carbon of coal, reaction surface area and etc. The gaseous fuel produced after gasification with a moisture of air +s team and carbon will always contain undecomposed steam and carbon dioxide besides other components.

For further reading

1. A. Butts Metallurgical problems.
2. O.P.Gupta: elements of fuels, furnaces and refractories
3. S.C.Koria Video lecture on fuel,furnace and refractory, lecture no. 7
4. S.C.Koria Video lecture in the course on material and heat balance in metallurgical processes.