Technologies For Biomass Utilization

PART 2



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PART 2

- Understanding flame temperatures, contd
 - Fixed biomass free convection based stove
 - Fixed biomass forced convection based stove
 - Ejector stove "horizontal gasifier" based
 - Special premixed burner
- Gasification vs Combustion, Air-to-fuel ratio, sensible energy to chemical energy, gas composition vs equivalence ratio
- Distinguishing gasifiers from combustors, power vs time in a traditional stove and a gasifier stove

Theoretical flame temperature vs. A/F ratio



FlameTemperature vs. Moisure fraction



Flat Flame Apparatus

Thermocouple – R type, Bead Size 120 µm

Peak Flame Temperature including radiation correction: **1904 K** (**1623 C**) (Radiation Correction 80 K)

Adiabatic Flame Temperature for this composition from equilibrium calculations with producer gas + air and at stoichiometry: **1914 K**

Conclusion: Under identical conditions, real life data matches with theory.



How come we get low values in practice?

- In ordinary wood stoves, the fuel and air are not well mixed and where mixing occurs it will occur at various equivalence ratios – fuel rich and fuel lean.
- What will happen if these are overcome?

Let us see...

Gasifier stove with free convection



Fixed biomass stove



Combustion in a fixed biomass stove



Temperature Measurements in 100 mm Stove

Thermocouple used: R Type,50 µm wire, 120 µm bead.

Measured temperature at the indicated location including radiation correction = **1843 K (1570 °C)** (radiation correction = 70 K)

Temperature varies between 1000 to 1250 °C in the mean

There is still a difference of 400 K between the two experimental conditions.



Ejector Stove with a horizontal gasifier(!)



A functioning Ejector Stove



Results from a 5 kg/hr Ejector stove (with a horizontal gasifier!)

Thermocouple used: 50 µm wire, 120 µm bead.

Flame region above the nozzles was probed to determine peak flame temperature.

Measured temperature measured at the top region is 1650 K (with 70 K radiation correction).

The measured mean has gone up to 1377 ^oC. The improvement is due to reduced heat losses in a larger system.

Achieved Flame temperatures

Another case of a cyclone combustor with pulverised fuel, when air-to-fuel ratio was maintained near stoichiometry, and heat losses minimised, one would get a flame temperature as high as 1400 °C, slightly lower than the temperatures for large liquid fuel burner operations. Thus....

Fuel	Energy	Max.Flame
	MJ/kg	Temperature, K
Petroleum fuel	40 - 44	1800 - 1900
Wood	13 - 16	1300 - 1700
Rice husk, other shells with high ash	10 - 13	1100 - 1400

Gasification vs. Combustion

In Combustion, the volatiles released burn in the gas phase leading to a visible flame. The char burns up later in surface combustion mode. In both cases, CO_2 and H_2O are the principal products

Gasification is called "Sub-stoichiometric combustion" of fuel with oxidant; it is not simply pyrolysis of the fuel elements; The fuel vapors burn with oxygen of air at less than stoichiometric condition producing H_2 , CO, CO₂, some HHC, H2O and rest Nitrogen Subsequently, these gases react with the char (reduction process that absorbs heat) to generate a richer combustible gas that has lesser HHC.

Most biomass + Air = $20\% \pm 2$ H₂, $20\% \pm 2$ CO, 2% CH₄, $12\% \pm 2$ CO₂, $8\% \pm 2$ H₂O, rest N₂.

Most biomass with water vapour with added heat from external sources \rightarrow 55-65 % H₂, 25 - 30 % CO, rest HHC.

Combustion $CH_{1.4} O_{0.74} N_{0.005} + 0.98 (O_2 + 79/21N_2) \rightarrow CO_2 + 0.7 H_2O + 3.69 N_2$ A/F = 5.25

Gasification

 $\begin{aligned} \mathsf{CH}_{1.4} \ \mathsf{O}_{0.74} \ \mathsf{N}_{0.005} + 0.337 \ (\mathsf{O}_2 + 79/21 \ \mathsf{N}_2) \\ & \rightarrow 0.57 \ \mathsf{CO} + 0.485 \mathsf{H}_2 + 0.028 \mathsf{CH}_4 + 0.343 \mathsf{CO}_2 + 0.157 \ \mathsf{H}_2\mathsf{O} + 1.27 \ \mathsf{N}_2 + 0.028 \ \mathsf{C} \\ & \rightarrow 2.857 \ (0.2\mathsf{CO} + 0.17\mathsf{H}_2 + 0.01\mathsf{CH}_4 + 0.12\mathsf{CO}_2 + .055\mathsf{H}_2\mathsf{O} + 0.44 \ \mathsf{N}_2 + 0.01 \ \mathsf{C}) \\ & \rightarrow 0.157 \ \mathsf{H}_2\mathsf{O} + 0.028 \ \mathsf{C} + \\ & 2.7 \ (0.211 \ \mathsf{CO} + 0.18 \ \mathsf{H}_2 + 0.0105 \ \mathsf{CH}_4 + 0.1275 \ \mathsf{CO}_2 + 0.471 \ \mathsf{N}_2) \end{aligned}$

A/F = 1.805; Hot gas/Fuel = 2.805; Cold gas/Fuel = 2.62

The products of combustion, CO_2 and H_2O pass through a reduction zone made of hot char bed, to convert CO_2 and H_2O into CO and H_2 and in part, CH_4 . The net effect is reduction in air consumed.

Sensible heat to Chemical energy – what gasification is about



The sensible heat in the first part of combustion is converted into chemical heat in the second part.

Gas composition vs. equivalence ratio



Distinguishing Gasifiers from Combustors

- If complete burning is over the solid fuel, it is combustion. A clear test for this is this:
- Pass the hot gases through a duct, cool the gases, on the way, perhaps, and examine if the gases burn. If they do, it is gasification. If not, it is combustion.
 - Very faint fluctuating flame implies weak gasification.

Distinguishing Gasifiers from combustors

- In a combustor, if the combustion of the solid biomass has no yellow structure or large soot tongues, then one has decoupled the volatilization process from combustion.
- This is a desirable condition to achieve.
- To appreciate this, we must know as to how power varies in a traditional stove.

A Traditional Stove



Power variation in a normal biomass stove

When biomass is loaded, power Increases a little afterwards, since it takes a few seconds to a few minutes depending on the size for the wood to heat up and begin to give off volatiles. When all the volatiles are consumed, biomass becomes char whose weight is about 20 to 25 % of the biomass. After this char oxidation **OCCUIS**.



Power variation in a gasifier stove.

(mass loss varies linearly - power is nearly constant)

Mass (g)



Water temp. vs time (output power is constant)



Why is the power nearly constant in gasifier mode?

- In the gasification process, excess carbon is always present in the form of charcoal.
- Only that amount of carbon that is required to cause the reduction reactions is consumed.
- The propagation of the thermal profile against the flow of air occurs at a rate to reach equilibrium composition or conversion.
- With the use of sizes of biomass not widely different, the amount of biomass covered by the thermal profile is also nearly same.
- This keeps the consumption rate constant.

Why is the power nearly constant in gasifier mode?

- Suppose you take two well arranged sets of wood sticks in the form of a crib. You light one of them at the top and another at the bottom, We now examine what happens
- When lit from the bottom, the heat propagates to the top by free convection and the availability of oxidant (air) from outside will let it burn up. Hence all the biomass will burn up together till it becomes char. The power level will come down, then. Thus the power variation has a peak and steep fall.
- When lit at the top, the stratification process flame propagation process regulates the weight loss rate. Then the passage of the gases through the char bed controls the conversion to combustible gases again and this gas burns at the top. Power level is nearly constant till the end.
- Both the above processes are controlled by the size distribution of biomass and their moisture content.