Issues in Biomass Gasification and Combustion

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Abstract

Biomass gasification and combustion have to be viewed in different light as compared to gasification and combustion of coal, for the simple reason that the scales of operation of coal gasifiers and combustors are simply unsustainable with biomass as fuel. Systems developed for use with biomass need to be of scales not exceeding 100 kWe / 300 kWth, for decentralized use. Design of such systems need a conceptual understanding of the physical phenomena involved. The talk would shed light on the basic physical phenomena of flow, natural convection, heat transfer, drying, pyrolysis, volatile combustion, char oxidation and reduction, that constitute the combustion and gasification of biomass. It would then focus on the technology aspects of combustors and gasifiers for biomass in various forms: woody, loose and powdery. It would then dwell on the work done by the author's group on biomass stove analysis and design, as well as analysis and design of gasification systems. Besides, it would also describe the work done by the group on improved wood-fired pottery kilns for rural applications.

Biomass is composed of Cellulose and Hemi-cellulose, which are long-chain sugars, besides lignin, a cross-linked compound that gives wood its strength. On heating, hemi-cellulose devolatilizes first, at temperatures around 200^{o}C. Cellulose follows, at slightly higher temperatures, while lignin pyrolysis happens at temperatures exceeding 350^{o}C. Depending on the rate of heating, the fraction of wood that evolves as volatiles varies: in the range appropriate for combustion and gasification, the typical volatile fraction is 70%. Volatiles mix with air and burn in gaseous phase, while the char undergoes heterogeneous combustion at the solid surface, in combustion devices. In gasifiers, owing to short supply of oxygen, the products of volatile oxidation are reduced to Carbon Monoxide and Hydrogen when they pass over the char bed. The air required for combustion usually flows in due to natural convection in simple devices such as the biomass stoves and small kilns, while it is forced using blowers in larger combustors and most gasifiers. Thus, modelling of the phenomena in such systems requires a thorough understanding of the basic principles of all the above phenomena.

Combustors need the air supply separated into primary and secondary streams in order to control the combustion process effectively. In natural convection devices such as cookstoves, the balance between airflow induction and heat release by combustion is quite delicate, and design of an efficient device that operates over a range of power outputs can be a formidable task. This explains why most of the biomass cookstoves, even so-called improved cookstoves, have been designed by trial and error; and more often than not, the devices do not perform as well as expected when taken from the lab to the field. Millions of biomass cookstoves in the third world today are believed to be responsible for acute respiratory diseases of the users and their families. Gasifiers, on the other hand, are more of industrial energy sources, and have received substantial research and development inputs. Out of the several possible designs, the downdraught gasifiers are today known to generate the cleanest producer gas, with minimal tar content. Gasifier-cookstoves are fast catching up as domestic devices. Quite sophisticated products, with battery-operated fans and thermoelectric battery chargers, that use waste heat from the cookstove to generate electricity to charge the battery, are available in the market today. There is substantial interest in corporate world to mass-produce these devices in millions for the kitchens in the third world.

The group at IIT Delhi has carried out detailed modelling and computer simulations of the phenomena in a sawdust stove, both using Computational Fluid Dynamic models and thermodynamic models. Experiments have been performed to validate these computer models. The phenomenological relations that could be derived from the results of CFD simulations were used to supplement the basic governing thermodynamic equations in developing the thermodynamic models. These simple models can subsequently be used for optimization of the design parameters of the stove. A similar approach is being developed for simple woodstoves as well. In another work, a zone-wise thermodynamic model was developed for a downdraught biomass gasifier, and coupled with a simple model for a single-fuel and dual-fuel engine, to predict the combined performance of gasifier-engine systems.

The group has also been active in developing new gasifier hardware for powdery biomass such as sawdust in small scale: upto 20 kWe. The design is similar to that of an entrained flow gasifier system, using air in place of oxygen to entrain the powdery biomass and flow through a bed of hot charcoal. The system is being extensively tested for parametric optimization. In a field-oriented project, updraught wood-fired pottery kilns were studied in potters' clusters in Bhadrawati (Maharashtra) and Kondagaon in Bastar (Chhattisgarh) and their energy audit carried out. On the basis of the findings, an improved kiln was designed and installed from first principles of heat transfer. The new kiln was able to save 40-60% of wood as compared to the traditional kilns of the same size and payload. The cost of the new kiln was also lower than that of the traditional kiln by about 10-15%.

The talk would conclude with prospects for challenging fundamental and applied scientific research in the areas of heat and mass transfer in biomass gasification and combustion, and an invitation for more researchers to join the exciting area, whose rewards lie not just in the research findings, but also in the improved technology outputs that would reach sectors of the society that have seldom had the benefit of cutting edge scientific research.