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Work on Biomass Energy at Indian Institute of Science

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1. Introduction

At the Indian Institute of Science, the work on biomass-based energy is being carried out in two centers: (a) the Centre for Sustainable Technologies that concentrates on bio-methanation of solid and liquid wastes, fixed biomass combustion devices for cooking and other semi-industrial applications, and (b) the Combustion, Gasification and Propulsion Laboratory (CGPL), a part of Aerospace engineering that is concerned with thermo-chemical conversion processes and technologies into which about 450 man-year effort has been put in over the last twenty five years. This report is concerned with the work at CGPL. In a rather unique venture of IISc, this laboratory deals with research, development, testing, training and technology transfer activities all under a single roof with its five faculty and researchers supported by ten engineers and thirty support staff. The commercial activities of technology protection and transfer are dealt with under a society called Advanced Bioresidue Energy Technology Society (ABETS). As a result, five different technologies have been developed and transferred. These are

1. Downdraft gasifier for industrial high grade heat and with a power pack for electricity generation;
2. Downdraft gasifier for high quality charcoal generation;
3. Reversed downdraft gasification concept for cooking and industrial heat;
4. Hydrogen sulfide scrubbing technology for gases from distillery effluents and others;
5. Technology for generating precipitated silica from rice husk ash/char;

The fundamental studies and the field experience in implementing the technologies in several environments both rural and urban, societal and industrial has led to a broad understanding of the issues all the way from research to practical implementation. This has allowed the laboratory to conduct much sought *training programs on biomass utilization* – principles and technology periodically. It has conducted a dozen training programs and workshops for national and international participants. The thirty international participants include those from *Austria, Brazil, Cuba, Thailand, China, Myanmar, Zambia, Kenya and South Africa*.

2. General combustion studies

Fundamental studies on combustion have been performed on premixed and diffusion flames on a number of configurations at low and high speeds to clarify the flame structure. Studies were extended to biomass combustion recognizing the feature that this was far more complex due to shape, size, moisture and ash content effects. It was uncovered that the gasification process is likely to help manage these effects towards higher efficiency and low emissions.

3. Gasification studies

These studies were performed both on individual particles and in reactors with packed bed of particles both as char particles as well as biomass, both natural and briquetted. Laboratory studies - experiments and modeling led to quantitative evaluation of effects of oxygen, nitrogen, carbon dioxide and water vapor on the gasification rates on the size. Exploration of classical downdraft reactors (suitable for cold clean gas generation for electricity or high grade heat) as well as reverse downdraft systems (suitable for domestic stoves) to determine the gas composition including tar and particulates as well as gasification efficiency, flame propagation in packed bed reactors led to important results of fundamental and applicational value. Most of these have been published in refereed journals and international conferences of significance (they can be accessed at http://cgpl.iisc.ernet.in under the head of publications).

4. Gasification technology

The gasification technology developed at IISc is unique in the world – a fuel-flex, open top, staged air entry (reburn) downdraft system that converts any solid bio-fuel of specified size range and with minimum moisture to clean gaseous fuel. It can use a wide range of fuels, both solid as well as fine. The fine sized fuels like sawdust and rice husk need to be briquetted to size. The system elements – reactor, cooling and cleaning systems – have been conceptually evolved based on principles of fluid mechanics with additional aspects of chemical thermodynamics in the case of reactor to minimize the complexity in system design. Adding sensing and control systems is expected to aid in reducing or eliminating dependence on operators.

The technologies involving a host of aspects – ceramic materials for the corrosive hot environment (both oxidizing and reducing in different zones that change with time), staged air entry design for large throughput systems, dry char/ash extraction through a screw with a high temperature valve, and vapor absorption chiller to provide cold water for final stage of cleaning and a special effluent treatment system for recycling the cooling water.

While all the aspects noted above used the know-how available within the laboratory, the power pack consisting of engine – alternator combination depended on engine manufacturers. For producer gas (gas from air gasification system identified above), there are no standard engines across the world; adaptation of natural gas based engine through the design of a different carburetor for air-to-fuel gas ratio control is required. Getting a suitable engine for making adaptations was accomplished after much effort with Cummins, India and they now market producer gas based engines. M/s Jenbacher, Austria is another major industry that has consented to provide engines for IISc gasification technology. There is a choice for the elements involved in the cooling, cleaning section and the safety and control system and the elements are chosen to meet somewhat different requirements between rural low power application (~ 50 kWe) with manual operation and MWe level, 24x7 class automated operational system. In fact, a whole range of technology options from 1 to 1000 kWe electrical systems and 1 kg/h to 1200 kg/h thermal systems to work with a wide range of fuels including *urban solid waste* are available from the knowledge base of the laboratory.

The same reactor design with no cooling, but some hot gas clean up is used for specific thermal applications like Aluminum melting, etc. Further, the same reactor design is adopted to generate high throughput charcoal; other system elements required for smooth start-up, shut-down are added to the standard system.

The technology (patented in India and several countries of interest) has been transferred to ten licensees in India and overseas (Japan, Switzerland and Brazil). More than hundred systems have been built – about equal numbers for electrical and thermal applications in various capacities up to 1.2 MWe (1200 kg/h biomass throughput, 1 kg/kWh nominal).

The reverse downdraft design was adopted to build a portable domestic stove that promises very high efficiency in domestic cooking applications. These stoves use high density pellet fuel that is produced and supplied thus main-streaming the solid bio-fuel. This technology is also transferred to a global industry.

5. Hydrogen sulfide scrubbing technology

Distillery industries have a statutory need for doing anaerobic treatment of the effluents that are too high in BOD and COD (bacterial and chemical oxygen demand). This leads to a gas rich in methane. However, the gas also carries 3 to 5 % hydrogen sulfide that is tolerated by power generation systems to no more than 0.1 % because of its extreme corrosive nature. IISc has developed a technology for extracting sulfur selectively so that the gas produced is "sweet". An iron chelate based chemical solution is sprayed to mix it with the "sour" gas. The hydrogen sulfide is converted into elemental sulfur. The reacted iron is then regenerated into active form by bubbling air through the solution. After a number of laboratory studies, plants of 10 to 1000 m^3/h of gas with 3 to 5 % hydrogen sulfide have been built. This gas used for power generation by using standard reciprocating gas engines. This technology has been transferred to two licensees and several plants have been built at MWe power level (~2 kWe per m^3/h of gas).

6. Precipitated Silica from Rice Husk Char/ash

Rice husk has 20 % ash and the ash itself has 95 % silica. Rice husk burns in combustion systems leaving char with about 10 % carbon since it takes a long time for further oxidation to occur. This waste material is an environmental problem as its disposal creates nuisance. An economically meaningful low temperature (~95 ºC) ambient pressure technology for converting rice husk char/ash to precipitated silica has been developed. This uses sodium hydroxide for selectively converting silica in the ash into sodium silicate. This mix is filtered to eliminate the carbon/ash. Carbon dioxide is bubbled through the sodium silicate solution to produce silica and sodium carbonate. This is further regenerated into sodium hydroxide by reacting it with lime. The process has gone through pilot scale studies in which about hundred 50 kg batches have been produced and the properties evaluated both in the laboratory as well as selected industrial users. It is awaiting large scale commercialization.

7. Biomass atlas of India

In order to support distributed power generation from bio-residues on a national scale, a GIS based atlas containing biomass generation and surplus biomass that can be used for power generation has been developed. This was a multi-institutional effort with IISc as the focal group to collect the data and embed them into the map. The data can be seen as a map or in the form of tables. The data presentation can be used to extract the data on a taluk, district or national level residue-wise. It can be used by entrepreneurs for first cut estimate of the data or planners and administrators to help regulate the use. One of the principles followed in the data management is that societal uses for fodder and domestic cooking are considered unavailable for power generation. Thus even though about 500 million tonnes of waste from about 250 million tonnes of agro-produce is a resource, only about 100 million tonnes are estimated to be available for power generation.

This database is internet-enabled and can be accessed at http://cgpl.iisc.ernet.in under biomass atlas.

8. New research and development

Based on the knowledge base of the laboratory, projects on biomass based hydrogen and liquid hydrocarbons have been initiated. The first process uses the classical IISc gasification technology with air as the oxidizing fluid replaced by oxygen-steam mixtures. Optimization of the composition of the mixture and operational procedure is expected to lead to near tar-free gas with high hydrogen ~ 50 % or more. This gas will be used in the next process, known for a long time as Fischer–Tropsch process to generate liquid hydrocarbons. This process is called 2nd generation process for liquid bio-fuels.

9. Acknowledgements

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Supported by MNRE, Indian Institute of Science has now a centre termed Advanced Bioenergy Research Centre located at CGPL to be a focal group on biomass based energy activities in the country.