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An Integrated Renewable Energy System Field Testing and Process Simulation for Energy Flexibility and Sustainable Development in India

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ABSTRACT

This paper presents an integrated approach to the steady state simulation model of biomass gasification, molten carbonate fuel cells (MCFC) and power generation processes. It provides a useful tool for Energy Flexibility and Energy Sustainability in India. A 10 kW Biomass based Gasifier working on 100% producer gas has been installed and working successfully, which is supplying power to the energy center building of RGPV. Further expansion includes the integration of PV- Solar panels and Molten Carbonate Fuel Cell. Two energy conversion options are under evaluation: First, Gasification of wood chips to generate producer gas and run gas engine-generator set, and second for use in a Carbonate Fuel Cell. The field tests are conducted and options are derived for various types of biomass, to optimize the results. Recommendations are made with respect to commercializing biomass gasification technology in India.

Keywords: Biomass gasification, Energy Sustainability, Greenhouse gases, Molten carbonate fuel cells, Small-scale gasifier system.

1. Introduction

Deregulation of the electric power industry and more stringent emission controls are stimulating investments into renewable energy systems. They can convert chemical energy directly into electricity with greater efficiency than most other devices, thus conserving fuel resources and reducing CO2 emissions. Utilization of renewable energy sources such as biomass offers environmental benefits while providing sustainable power generation for utilities and industry. It offers market for dedicated energy crops such as switch-grass, while providing needed energy for power generation. The application of fuel cells is particularly attractive in the renewable energy arena: biomass could be used as fuel for the hydrogen production, thus addressing the problems of generation of carbon dioxide at the same time. This topic is also of interest to developing countries for off-grid power generation with low impact to the environment. Among the different fuel cells developed so far, molten carbonate fuel cells (MCFC), also referred to as “second generation” cells, have been deeply investigated in the last decade for several advantages with respect to other technologies. Although the furnace and boiler technology may differ substantially, virtually all biomass power plants of this scale will operate using the same thermal cycle: combustion of biomass will raise steam which will be passed through a turbine-generator to generate electricity. Since natural gas is the most used fuel in fuel cells, the use of biomass as fuel introduces many differences in the process. This is mainly due to the strong difference in the composition of the gas fed to the fuel cell.

The main differences are:

(i) The external reforming is less important since the gas out from the gasifier contains only a few per cent of methane

(ii) The gas out form the gasifier needs to be cleaned from impurities and

(iii) Heat is produced in the gasification at higher temperature (850-900°C), underlining the importance of a good heat integration and recovery.

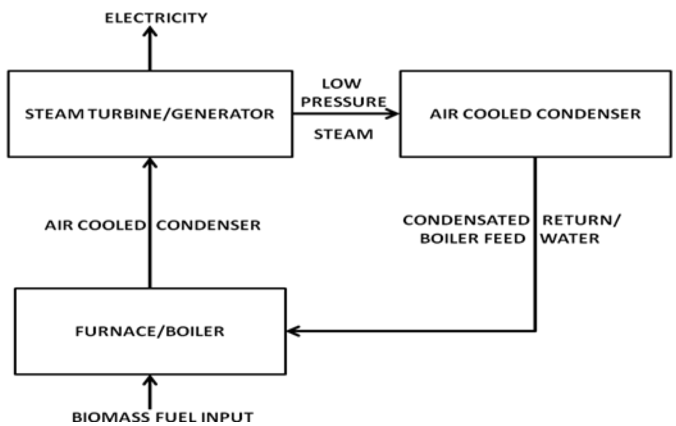

Fig. 1.1 A Steady State Model-I

This paper presents a steady state model for the simulation of a biomass gasification and energy production in molten carbonate fuel cells.

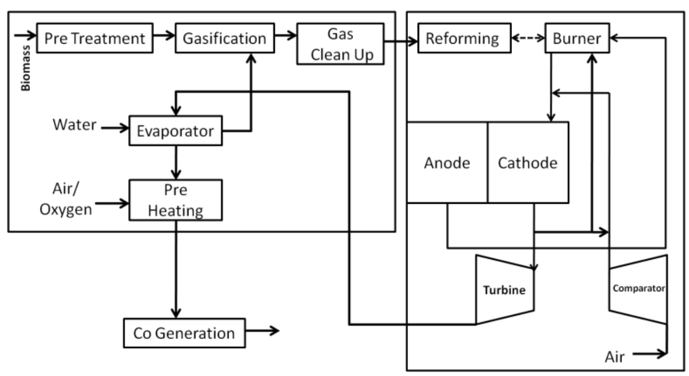

Fig. 1.1 A Steady State Model-II

2. Methodology

The setup at Energy Center of Rajiv Gandhi Technical University, Bhopal (India), includes a pilot scale Biomass Gasifier (10 kW & 100% producer gas based) which became a major distributed power source for electrification of Energy Center Building in an environmentally sustainable manner. Presently, the output of gasifier is producer gas, which is fed into Diesel Engine Gen-set. The biomass is fed into the hopper of gasifier unit together with air at atmospheric pressure (air enriched in O_2).The hot flow gases (producer gas) is produced in gasifier which contains CO, CO_2, CH_4, H_2, N_2, Tar, Fly ash, C, etc. then fuel gas and air are compressed and pre-heated in the recuperator using heat recovered from the fuel cell exhaust.

The fuel gas then distributed into two lines. Through one line, it fed to the fuel cell along with air and through second line it fed into gas engine generator-set. The fuel cell releases waste heat in the electrode exhaust stream. The fuel cell exhaust is cooled in the recuperator and if necessary, the warm stack gases could be used for biomass feed stock drying. Fuel cell consumes CH4+ H2 and directly converts into electricity. On the parallel end, gas engine-set also consume producer gas (60-70%) and diesel (30-40%) to generate 3-phase, 15 Amp. 420 Volts A.C. Power.

3. Proposed Steady State Simulation Model of Biomass Gasification

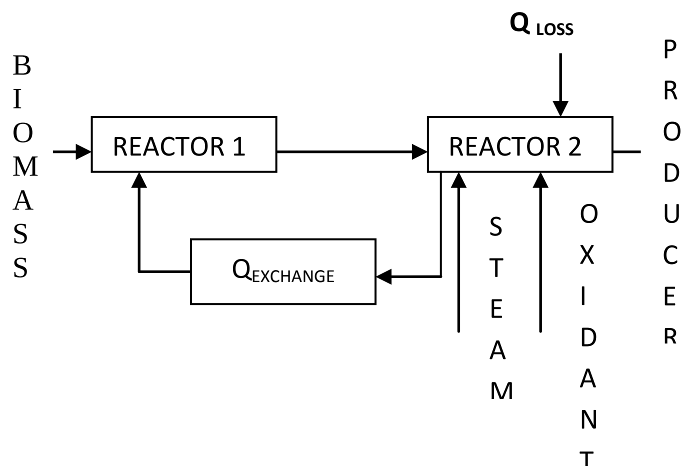

Fig. 3.1 Model for the simulation of the biomass gasification

A simplified model was adopted for the gasifier. Starting from the composition, temperature of the producer gas (output of the gasifier) and the proximate. The model developed for the simulation of the biomass gasification. The model has been implemented in Aspen Plus^{TM} by using two standard chemical reactor unit operations models. Reactor 1 and Reactor 2.The first reactor basically splits the biomass in its fundamental elements (H2O, N2, O2, H2, S, C, ASH and Cl2). It is a hypothetical reactor whose task is to convert a non convectional stream, the biomass, to a conventional one, a gas mixture of elementary molecules. The inlet biomass composition is based on the experimental ultimate analysis, which must be available for the simulation.
The second reactor receives the hypothetical gas generated from the first reactor, the oxidant and the steam and generates all the reaction products (CH4, H2, CO, CO2,.*)* that are present in the real mixture of gas after gasification.

4. Results and Discussion

The set-up used has been tested for various types of biomass fuels and in various situations. A comparison of all type of feedstocks considered and the net electrical efficiency has been evaluated. The electric efficiency is in the range of 36-40% depending on the type of biomass considered. The model developed is used for the simulation of 3 different biomass feed conditions:

(i) Sugarcane bio gas (BG) which is a residue from sugar cane treatment,

(ii) Switch grass (SW) and

(iii) Nut shells (NT), which is a mixture of 20% nut shell, 40% hazel nut shell and 40% wood.

(iv)

A series of experiments is conducting for optimized various process parameters, like,

Table 4.1 Various Process Parameters

1	Size of feedstock (C.V.of fuel)
2	Air/fuel ration
3	Feedstock moisture
4	Fuel feed rate
5	Steam injection
6	Lime stone content of gasifier bed material

Fig. 4.1 An Actual Setup of Biomass Gasifier (10 kW)

Table 1 reports the ultimate and proximate analysis of the three feeds and the moisture. Table 2 contains the composition of typical Producer gas produced from this gasifier operating on wood chips.
In addition to the proximate & ultimate analysis of input biomass and compositional analysis of producer gas, the following results were obtained:

Table 4.2 Comparison of Various Types of Biomass

Type of Analysis	Composition	BG	SW	NT
Proximate Analysis	Ash	6.63	5.23	2.52
	Volatile matter	81.05	81.05	76.27
	C residual	12.99	14.66	21.35
	HVA (MJ/kg)	17.79	18.63	19.8
	Moisture	21%	11.50%	12.50%
Ultimate Analysis	C	45.46	47.72	48.5
	H	5.45	5.55	5.66
	N	0.18	0.66	0.76
	S	0.06	0.01	0.01
	Ash	8.51	4.55	3.06
	O	39.37	40.63	41.9
	Cl	0.039	0.1	0.01

Table 4.3 Compositional Analysis of Producer Gas

S.No.	Elements	Percentage
1	CO	21.7
2	CO2	12.5
3	H2	4.1
4	CH4	3.3
5	N2	48.4
6	O2	0
7	Moisture	10
Total		**100%**

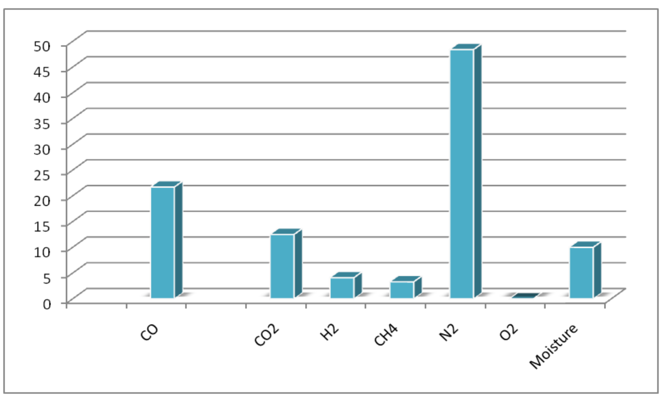

Fig. 4.2 Compositional Analysis of Producer Gas

Here the Gasifier gets connected to a Gas-Engine-Generator-set (the Gen-set is suitably modified). The electrical energy is produced using no diesel at all-only producer gas, which in turn is produced from biomass, is used.

To generate 1 unit of electricity, we need 1.5 kg of Wood or 1.8 kg of Rice Husk. (1.5kg wood/kWh). The cost of a kg of Wood or Rice Husk is Rs. 1 (India specific). Thus to generate 1 unit of electricity the fuel cost would be Rs. 1.8.

$$Power\ Developed = \frac{420 * 15(Amp) * 0.8(p.f.)}{\sqrt{3}} - 1KW(for\ internal\ accessories)$$

Where, I=Current=15 Amp at full load p.f. =power factor=0.8

V= Voltage=420V

Gas flow=55 Nm^2 /hr

Gas C.V. = 1000 kcal/Nm^3

Temperature of Gas = 525-700°C

5. Conclusion

The field-testing has been applied to three different biomasses allowing us to compare the performances of the different feeds and to understand the details of the entire process. The results of the simulation presented allow us to take the following conclusions. The efficiency obtained by coupling the biomass gasifier and the MCFC is around 36 – 40 %, depending upon the biomass used: considering the low performances of the biomass as fuel the efficiency obtained indicates that the energy production process by using fuel cells is feasible. In the gasification process a lot of valued heat is produced (20% of the total input HHV at 870°C), underlining the importance of the thermal integration in the process. The producer gas tar energy content is about 10% of the total biomass HHV, thus showing the importance of a cracking to recover tar heating value. The endothermic reforming is able to convert thermal energy into chemical one; at the same time it increases the hydrogen and carbon monoxide availability for the fuel cell stack. By means of the reforming, 6% of the biomass HHV becomes electricity. Among the three biomass considered, the bagasse permit the lowest electric efficiency because of its difficulties in being gasified, performing the worst gasification cold efficiency and then the lowest fuel content in the producer gas.

The technology describes here enabling rural areas to generate income by attracting electricity-consuming industries by exporting surplus electric power to urban demand centers. The export of Biomass–Electricity can benefit rural communities by providing local farmers with a buyer for biomass energy crops. Indian government & MNES are giving considerable subsidies for biomass gasification systems. Rs. 10-15 Lacs / 100 kW, for power generation application based on 100% producer gas systems.

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