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SUGARCANE LEAF-BAGASSE GASIFIERS FOR INDUSTRIAL HEATING APPLICATIONS

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ABSTRACT

In developing countries like India, use of petrol fuels like furnace oil or light diesel oil to meet the thermal energy demands of industries places a heavy burden on the economy. Use of producer gas from indigenously available agricultural residues is an attractive alternative. This paper reports the commercial scale (1080 MJ h^{-1}) development of a low-density biomass gasification system for thermal applications. The gasifier can handle fuels like sugarcane leaves and bagasse, bajra stalks, sweet sorghum stalks and bagasse etc. The system was tested for more than 700 hours under laboratory conditions at 288-1080 MJ h^{-1} output levels. The HHV of the gas was 3.56-4.82 MJ Nm^{-3}. The system also produces char, which is about 24% by weight of the original fuel. It can be briquetted to form an excellent fuel for wood stoves or can be used as a soil conditioner. After successful laboratory testing, the system was also tested in a metallurgical company, where it was retrofitted to a specialty ceramics baking LDO-fired furnace. The furnace was operated exclusively on the gasification system and the product quality was on par with, if not better than, that obtained during LDO-fired operation. The economics of the system is also presented in this paper.

Key-words : Biomass; gasification; thermal applications; low density and leafy biomass, bagasse, sugarcane leaves

1. INTRODUCTION

Rapid industrialization in India has resulted in an ever-increasing demand for process heat and steam. Most of these industries are in the metallurgical and food processing sectors and have to use petro-fuels like furnace oil, light diesel oil (LDO) or diesel to meet their energy demands. However, due to uncertain supplies and high cost of these fuels, there is an urgent need for other sources of energy.

India produces about 320 million tones of agricultural residues comprising of mainly rice husks, paddy straw, sugarcane leaves and wheat residues[1] . It is guesstimated that about a third of this, or ~ 100 million tones of residues are not being utilized and are disposed of by burning them in the open fields. These solid fuels can be effectively harnessed by converting them into a gaseous combustible fuel termed as “producer gas” in suitably designed reactors. This producer gas which has a gross calorific value of 3.5-5 MJ Nm $^{-3}$ comprises mainly of carbon monoxide (25% v/v) and hydrogen (15-20% v/v). It can be combusted in suitable burners with flame temperatures exceeding 1000^0C and can be used for industrial thermal applications.

There are reports of gasifiers being used for thermal applications both in India[2, 3] and elsewhere[4, 5]. However, all of them use either wood, wood waste or rice husks as the fuel for gasification. This paper reports the development of a commercial-scale (1080 MJ h^{-1}) model of a gasifier, which can handle low density and leafy biomass materials like sugarcane leaves and bagasse, and its subsequent tests in an actual user-industry. Its techno-economic feasibility analysis has also been presented in this paper.

2. GASIFICATION SYSTEM DESIGN

Certain critical engineering design norms of the gasification system were first developed on a laboratory-scale model and were then validated on a bench-scale model [6, 7]. These norms were then used to design a full-fledged commercial scale system with a thermal output of 1080 MJ h^{-1}. This system (presently installed in the NARI campus) is seen in Fig. 1. It comprises of a reactor, a gas conditioning system, a biomass feeding system and the instrumentation and controls. A schematic diagram of this system is shown in Fig. 2. The salient features of these components are given below.

Fig 1.

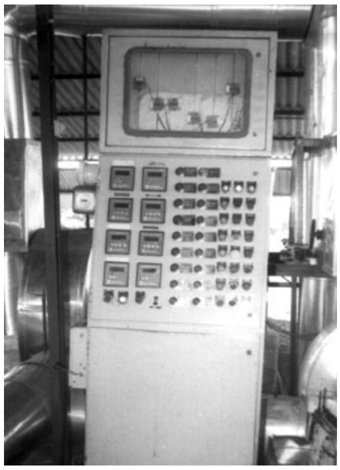

Fig. 3.

a. **Reactor** : This was a downdraft, throatless and open-top reactor with an internal diameter of 75 cm and an active bed height of 1.25 m. It was designed for a heavy-duty cycle of 7500 hour per year operation. High temperature resisting firebricks conforming to IS 8 grade were used for the hot face followed by a cold face insulation.

b. **Gas conditioning system** : A completely dry dust collection system eliminated altogether the problem of wastewater. This consisted of a high temperature char/ash coarse settler and a high efficiency cyclone separator. A specifically designed high temperature resisting induced-draft fan ensured that the entire system is under negative pressure so that in the event of leaks, outside air got sucked into the system, but the combustible gas did not leak out. Thus, this design is very environment-friendly. The char-ash from the coarse settler and the cyclone was collected in barrels and emptied in an ash pit once every forty-five minutes. This char-ash which typically has a gross calorific value of 18.9 MJ kg^{-1} can be briquetted to form an excellent fuel, or can be used as a soil conditioner [8, 9].

c. **Biomass feeding system** : This consisted of a scraper drag-out conveyor and a hopper to convey the biomass fuel from the storage pile to the reactor. The conveyor was completely enclosed.

d. **Instrumentation and Control System** : A Programmable Logic Controller (PLC)-based control system seen in Fig. 3 was designed to take automatic corrective actions under certain critical conditions. Thus, the biomass feeding and ash removal rates were fully controlled by this system. Besides, it also helped the operator in trouble-shooting by monitoring temperatures at various critical points in the gasification system. Automatic burner sequence controllers were provided for ignition of the producer gas.

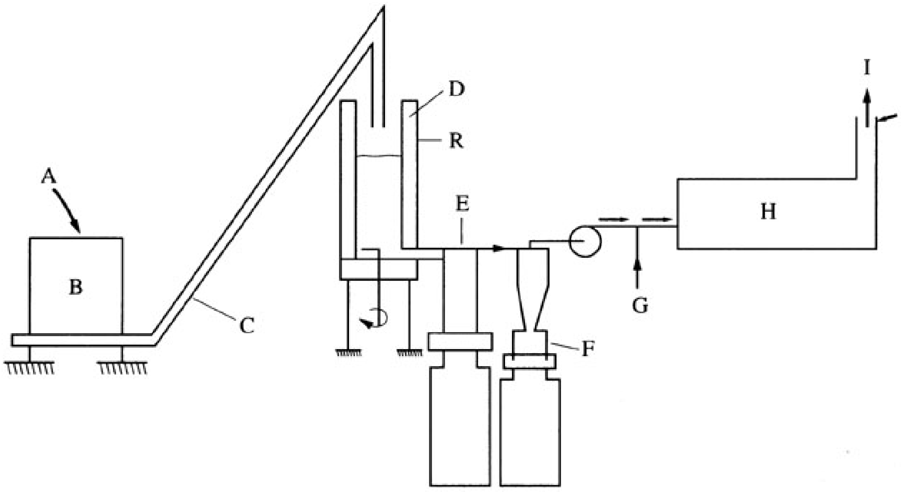

Fig. 2. Schematic diagram of sugarcane leaf–bagasse gasification system: A, biomass from storage piles; B, hopper; C, conveyor; D, refractory; E, char collector; F, cyclone; G, air; H, furnace (1080 MJ h^{-1}); I, chimney; R, reactor.

The gasification system was extremely simple to operate. A cold start took about ten-fifteen minutes whereas a hot start was affected in less than five minutes. Only two operators per shift of eight hours were required to operate the system, including the fuel and ash handling operations.

3. FUEL CHARACTERISTICS

The gasification system was successfully tested on sugarcane leaves and bagasse, sweet sorghum stalks and bagasse, bajra stalks etc. The physical properties of sugarcane leaves and bagasse under the actual operating conditions of the gasifier are given in Table 1[7].

TABLE 1 : PHYSICAL PROPERTIES OF SUGARCANE LEAVES (CHOPPED) AND BAGASSE[7]

Sr. No.		Chopped sugarcane leaves	Bagasse
1.	Particle size, cm	1-10	< 5
2.	Bulk density, kg (dry) m^{-3}	25-40 for loose leaves	50-75
3.	Moisture content, % w/w (wet)	< 15%	10-15%

Sugarcane leaves are normally 1-2 m long. They were chopped into 1-10 cm long particles using a 2.3 kW (3 HP) chaff cutter. Bagasse, as available from the sugar factories was almost powdery in form and did not require any size reduction. However, it had typically ~ 50% moisture, and so it needed to be air-dried before it could be used in the gasifier. Table 2 gives the Proximate and Ultimate analysis of these fuels [7, 10] .

TABLE 2 : PROXIMATE AND ULTIMATE ANALYSIS OF SUGARCANE LEAVES AND BAGASSE (TYPICAL VALUES) [6, 10]

	Sugarcane leaves (% w/w; dry)	Bagasse (% w/w; dry)
A. Proximate Analysis		
1. Fixed carbon	14.9	20.1
2. Volatile matter	77.4	75.8
3. Ash content	7.7	4.2
4. Higher heating value, MJ kg^{-1}	17.43	18.11
B. Ultimate Analysis		
1. Carbon	39.8	44.1
2. Hydrogen	5.5	5.26
3. Oxygen	46.8	44.4
4. Nitrogen	0.19	-

4. GASIFIER SYSTEM PERFORMANCE

The gasification system was extensively tested on the fuels listed above at NARI. A synopsis of the data is given in Table 3.

TABLE 3 : GASIFIER PERFORMANCE DATA AT NARI.

No. of hours of operation	: 700
Fuel consumption	: 40-100 kg h^{-1} (dry)
Gas characteristics	:
(i) Flow rate	: 80-225 Nm^{3} h^{-1}
(ii) Higher heating value	: 3.56-4.82 MJ Nm^{-1}
Char characteristics	:
(i) Amount generated	: ~ 24% of input biomass by weight
(ii) Higher heating value	: 18.9-23 MJ kg^{-1}
(iii) Ash content	: 35-45% w/w
Process Parameters (^{0}C)	:
(i) Gas outlet temperature	: 450-550
(ii) Gas temperature at burner inlet	: 300-400
Gasifier Performance (MJ/h)	:
(i) Total thermal output	: 468-1620
(ii) Energy content of gas	: 288-1080
(iii) Energy content of char	: 180-540

The gasifier was operated on both sugarcane leaves and bagasse either interchangeably or mixed in any proportion. The output was in the range of 288-1080 MJ h^{-1} (thermal). It is seen from Table 3 that the steady state temperature of the gas at the inlet of the burner was greater than 300^{0}C and so there was no condensation and accumulation of tars and particulate matter in the equipment and piping even after 700 hours of operation with mainly cold starts. In most gasifiers, water or oil is used to cool the gas before it is fed to the burner or the prime mover. This results in condensation of the tar in the gas steam. In the presence of particulates, the tars and the particulate matter tend to accumulate in the pipes and equipments thereby choking them. The gasifier system has then to be shut down and the pipes/equipments cleaned before it can be operated again. In the present system, the gas temperature was maintained above the condensation temperature of the tar compounds right upto the burner. Thus, there was no condensation of tars, and so, this problem did not arise due to the use of a hot gas cleaning system. The blower impeller was also free from any deposits/scales. Thus, a major source of downtime in most gasification systems, namely that of choking of pipes/equipment with tars and particulate matter[11] , appeared to be successfully tackled by employing a hot gas cleaning system.

Tests with different moisture contents of the fuel indicated that excellent performance was possible if the moisture content was less than 15% w/w (wet basis). A pilot flame to sustain gas combustion was found to be necessary for moisture levels between 20-25%. However, combustible gas was not formed at all if the moisture content exceeded 25% w/w (wet basis).

This system was then subjected to more rigorous testing by installing it in an actual user-industry, which was engaged in the manufacture of specialty ceramic refractories. The gasifier was retrofitted to an LDO-fired ceramic baking furnace in this factory. This was a tunnel furnace, 5m long x 3m wide x 3.5m high. The ceramic products were loaded on trolleys each carrying between 200-250 kg depending on the nature of the product. The product had to be dried from ~ 35% moisture content to less than 1% on wet weight basis. At any given time, seven trolleys were inside the furnace. Every hour, one trolley was removed from, and one fresh trolley entered the furnace. The furnace was operated at a fairly constant oil-firing rate. Thus, whenever the furnace doors were opened to remove and add one trolley each (roughly once every hour), the temperature of the furnace tended to drop. Once the furnace doors were closed, the temperature then tended to rise. This frequent variation in the furnace operating temperature is seen in Fig. 4. The major requirement of the process was that the temperature inside the furnace should be maintained in the range of 150-200^{0}C at all times. Since the furnace loading varied depending on the product mix, the oil-firing rate had to be adjusted intermittently to maintain the furnace temperature within the specified limits of 150-200^{0}C.

Only a part of the flue gases from the tunnel furnace was vented into the atmosphere through a chimney. The rest of the gases were mixed with the hot combustion gases and recirculated inside the furnace. The combustion chamber was 3m long x 2m wide and was designed to combust 20 lph of LDO (720 MJ h^{-1}). The producer gas burner was inserted adjacent to the LDO burner in the combustion chamber. This entailed minimal changes in the chamber construction and at the same time, allowed the furnace to be operated either on LDO alone, or on the gasifier alone, or in any combination of the two. This was essential to maintain the quality of the product and to prevent disruption in the production schedule in case there was some problem with the gasifier.

During these trials, the furnace was operated exclusively on the gasifier in most cases. Occasionally, both oil-and gas-firing was carried out simultaneously. The results were as follows :

1. The quality of the baking and the color of the refractory product using the gasifier was found to be as good as, if not better, than that obtained using LDO (light diesel oil). Moreover, there was no deposition of particulate matter either on the product itself or on the furnace walls. This meant that the level of particulates in the gas was quite acceptable for applications involving drying and baking of ceramic products, or for generating steam through boilers.
2. The sizing of the gasifier reactor was also quite satisfactory. The temperature profile of the furnace could be easily maintained on the gasifier alone, as is seen in Fig. 4. The gas flow rate had to be adjusted intermittently to maintain the temperature within 150-200 C. It was seen that the response of the gasifier to the change in the gas flow rate was quite satisfactory in the range tested (100-170 Nm^3 h^{-1}). Its response was almost instantaneous, and the gas did not extinguish at all even momentarily. Further, there was no change in the furnace operating routine. Data were collected on the gasifier operating parameters. These are given in Table 4.

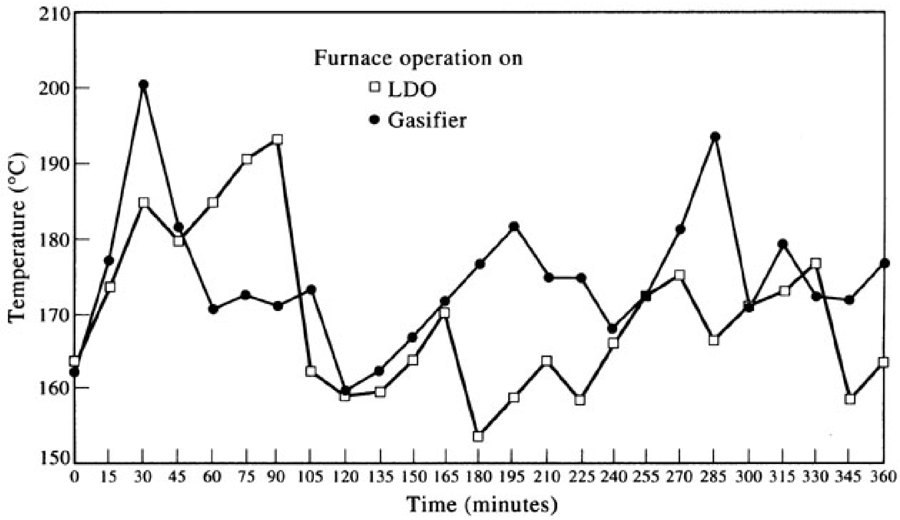

Fig. 4. Furnace temperature when operating on LDO and on the gasification system.

TABLE 4 : GASIFIER PERFORMANCE DATA DURING FIELD TESTING

1. Gasifier Output	: 396-684 MJ h^{-1}
2. Biomass consumption rate	: 55-72 kg h^{-1} (dry)
3. Gas flow rate	: 100-170 Nm^3 h^{-1}
4. Gas outlet temperature	: 400-600^{0}C
5. Burner inlet temperature	: 200-300^{0}C

It is evident from Table 4 that the gasifier was operated at only 684 MJ h^{-1} (maximum) whereas the rated capacity of the system was 1080 MJ h^{-1} (Table 3).

The biomass consumption rate during these trials normally varied between 55-72 kg h^{-1} (dry) depending on the furnace loading. At full blast, the biomass consumption was 72 kg h^{-1} (dry), whereas the corresponding LDO consumption was 18.75 l h^{-1} . So the economics of the system was evaluated by using an equivalence of 72 kg (dry) biomass for every 18.75 l of LDO, or 3.84 kg (dry) biomass for every liter of LDO.

The economic analysis of the system was evaluated both at its rated capacity of 1080 MJ h^{-1} and at an output level of 675 MJ h^{-1} which was usually required during the field tests. The data used for this analysis are given in Table 5.

TABLE 5 : ECONOMICS OF THE NARI GASIFICATION SYSTEM

Economic data (Gasifier rating = 1080 MJ h^{-1})	
1. Cost of the gasifier system	: Rs. 5,25,000 (1 US $ = Rs. 31) (1995 prices)
2. Civil construction cost	: Rs. 25,000
3. No. of intended hours of operation	: 7500 hours $year^{-1}$
4. Depreciation	: 20% per annum by straight-line method
5. Interest	: 18% per annum annualized over 5 years
6. Wages + Salaries	: 2 persons/shift x 3 shifts/day x 365 days/ year x Rs. 50/person/day
7. Maintenance cost	: 20% of the capital cost spread over 5 years
8. Electricity cost	: 6 kW x Rs. 2.5 kWh^{-1}
9. Biomass consumption	: 118 kg GJ^{-1}

Table 6 gives the energy cost for a net landed biomass cost of Rs. 1,000 T^{-1} (dry). The costing for other biomass prices is given in Fig. 5.

TABLE 6 : ENERGY COST DELIVERED TO THE FURNACE (1995 prices) (1 US $ = Rs. 31)

A. Fixed Cost Components	**Rs./year**	
1. Depreciation	1,10,000	
2. Interest	53,750	
3. Maintenance	22,000	
4. Wages + Salaries	1,10,000	
5. Electricity	1,12,500	
Total fixed cost, Rs./year	4,08,250	
ENERGY COST, Rs./GJ	**Gasifier output**	
	675 MJ h^{-1}	**1080 MJ h^{-1}**
1. Fixed cost, Rs./GJ	79.6	50.4
2. Fuel cost, Rs./GJ (@ Rs. 1000/T)	118.0	118.0
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TOTAL ENERGY COST, Rs./GJ	197.6	168.4
	====	====
Light Diesel Oil (LDO) Cost, @Rs.7.5/l	Rs./GJ 280.3	

Fig. 5 shows that the system is economically attractive if the biomass cost (dried, sized and landed cost at the gasifier site) is less than Rs. 1,100 T^{-1} (dry) when the LDO price is Rs. 7.51^{-1} and when the

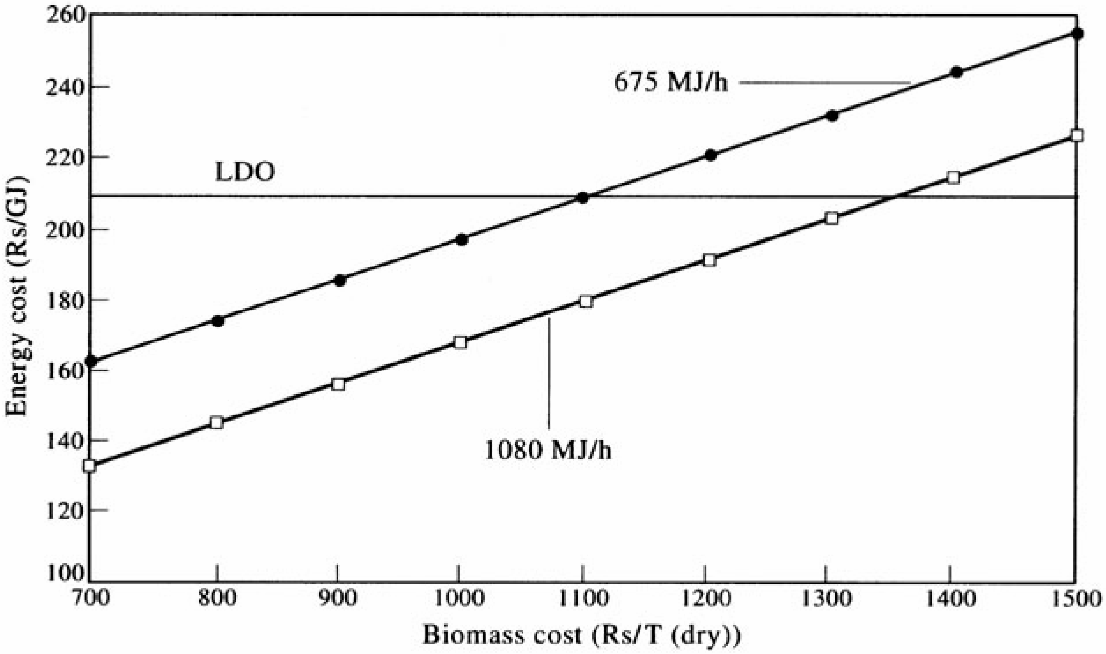

Fig. 5. Economics of the gasification system.

gasifier system is operating at 675 MJ h^{-1} . However, if the gasifier system operates at its rated capacity of 1080 MJ h^{-1} , the economics is attractive even for biomass cost of Rs. 1350 T^{-1} (dry).

Data collected over two years in a sugarcane growing area show that the landed, sized and dried cost of sugarcane leaves is Rs. 900-1100 T^{-1} if the material is procured from within a 20-30 km radial distance [9] . For industries located in such areas, the gasifier system can affect considerable savings in their fuel oil costs. Further, larger-scale units of capacities upto 3600 MJ h^{-1} can be designed based on the engineering data generated on the present system.

1. CONCLUSIONS

The present study clearly demonstrated that low-density biomass gasifiers running on sugarcane leaves or bagasse can be successfully retrofitted to existing oil-fired furnace/boilers in metallurgical and other industries. The product quality was on par with, if not better than, that obtained during oil-fired production. The economics of the system is also very attractive if the landed cost of biomass, including drying and sizing, is less than Rs. 1350 T^{-1} for capacity of 1080 MJ h^{-1} . At higher capacities, the economics will be even more favourable for the gasification systems.

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