EXPERIENCE OF USING VARIOUS BIOMASS BRIQUETTES IN IBG (IISC BIORESIDUE GASIFIER)

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ABSTRACT: This paper discusses the development and test results of agro residues in the Indian Institute of Science Bioresidue gasifier (IBG) which is an open top re-burn downdraft system. While most gasifier designs are intended to operate with wood chips, the current design is aimed at handling agro-residues that are light, fine sized and with varying ash content. The reactor design replaces the grate by a screw for extracting ash and residual carbon. The problems of handling fine biomass and low melting ash created by the presence of alkalis in the biomass are overcome by briquetting the fine Bioresidue to solid pieces of high density and low moisture content. Some residues like coconut shell or corncobs can be used with sizing as required, residues like coir pith, sugarcane trash, discardable soiled notes, classified urban solid waste can all be handled after the material is dried, sized if required and briquetted. Rice husk is also handled similarly. A single reactor design handles all the bio-residues.

With this reactor configuration and the use of briquettes, gasifier tests have been conducted. The remarkable feature is that the ash fusion problems that are very serious at high loading (throughputs) with fine biomass – like with rice husk or sugarcane trash, peanut shell or coir pith, got nearly completely obviated when used in briquetted form. These features are characterized by testing with a model reverse downdraft gasifier and the key parameter, namely, the superficial velocity of air at which incipient ash fusion occurs is obtained as a design parameter. The results from a commercial plant designed based on these features are presented. The biomass power plant uses sawdust briquettes for captive power generation in an industry that produces the sawdust as a waste as a part of its operations (a pencil making plant). The gasification systems have been coupled to dual fuel engines and have saved diesel at a substitution of 70 %, this limitation is due to the use of an engine with a low pressure fuel control system. In addition, the gasifier has already been coupled to two natural gas engines converted to operate on producer gas. These are Cummins make naturally aspirated natural gas engines capable of delivering 80 kWe and 160 kWe in producer gas mode.

Keywords: briquettes, gasification, Clean Development Mechanism

1 INTRODUCTION

The basic design of WW II closed top gasifier design arose with the intent of using sized wood pieces. While many European countries have a fair amount of forest wealth and short rotation biomass plantations and can therefore continue with the thinking that solid biomass from tree` base would be the fuel, the situation is not the same in other countries like India. The running theme in public discussion on societal matters is the denudation of forest and indiscriminate felling of trees. Hence, there has been a pressure on the central government to seek alternate bio-fuel sources for small scale power generation (up to 1 MWe). This naturally leads to the consideration of using agro-residues. Current estimates of the *net bio-residue availability* for power generation stand at 100 million tonnes a year amounting to 15000 MWe installed capacity in

India. These residues arise from sugarcane trash (and bagasse that is a captive fuel in a sugar industry and is not therefore counted here) rice husk, coconut shell, corncobs, coir pith, tapioca branches, and a whole host of others. Some of this is wastefully or inefficiently utilized leading to pollution of the environment.

While some of these residues are already used in direct combustion – steam turbine route, power generation at smaller power levels (< 2 MWe) can be shown to be techno-economically viable when used through gasifier - reciprocating engine route. It need not be emphasized that the utilization of agro-residues is truly renewable and hence is CO_2 neutral and qualifies for CDM benefits under Kyoto Protocol.

The two decade R & D effort at the Combustion, Gasification and Propulsion Laboratory (CGPL) of Indian Institute of Science (IISc) has led to the development of an open top, re-burn reactor based gasifier unique in terms of minimizing the tarry compounds in the reactor itself and the gas being cooled and cleaned in another unique way helping continuous long uninterrupted operations of the gasifier and generating superior quality producer gas [1, 2, 3]. The design, in addition, allows for fuel flexibility. This technology has been tested extensively including those *by external international agencies* and field tested over several years in a large number of systems in different conditions and results found acceptable [3]. This paper enumerates the experience and adaptation that have gone into the gasification system for accepting variety of
biomass in solid form and the experience in operating the system in an industry with sawdust briquettes for over two years.

2 ISSUES WITH UTILIZING LOOSE BIORESIDUES FOR GASIFICATION

2.1 Characteristics of loose biomass

The loose bio-residues generated from agricultural and industrial activity have fine sizes, generally high ash content and low bulk densities. The bulk density is determined as the mass per unit volume in a container which accounts for void spaces in between the particles. The characteristics of the agricultural wastes on dry basis are shown in Table I.

Table I: Typical characteristic of loose biomass [4]

Biomass	Typical Size	Ash content	Bulk density
	mm	%	kg/m3
Rice husk	8 - 10	20	100 - 130
Saw Dust	< 3	1 - 3	200 – 250
Coir Pith	< 3	8	80 -100
Groundnut shells	8 - 20	6	120 – 140
Pine needle	1 (dia)	3	80-100

These residues cannot be directly gasified in a packed bed downdraft gasifier for several reasons – (a) the material movement by gravity will be hampered by low bulk density and wall friction, (b) tunneling of air can occur by the creation of a hole in the bed somewhat randomly affecting the gas quality, (c) operation of the gasifier at high throughputs particularly in a classical closed top design leads to high temperature near air nozzles because of the influence of high velocity air flow from the air nozzles on the char and this can lead to ash softening and clinker formation. The last mentioned feature reduces the effective area for flow through the reactor, further deteriorating the performance of the gasifier; (d) thin walled bio-residues when exposed to high temperature can undergo fast pyrolysis due to high surface area available for reaction. This leads to generation of higher amount of tarry compounds (higher hydrocarbon compounds that can condense and cause deposits in pipe lines and downstream elements) an undesired component for the smooth operation of the system.

Certain gasification technologies have used open top packed bed gasifier for bio-residues (mostly rice husk) allowing shorter residence time and extraction of the char at a higher rate. In this case the reactor acts more as a pyrolyser than gasifier as the carbon conversion will be low.
It is the understanding and experience on such systems over years that focused the attention on the use of the light and fine residues by converting them into solid form. Tests and trials with some difficult residues showed the

remarkable betterment in the robustness of the operation in solid form that the concepts using briquetting were developed significantly.

2.2 Briquetting

The process of briquetting is generally well known; it involves subjecting the biomass to high pressure and temperature which helps in release of lignin from the biomass. This lignin acts as a natural binder and the loose biomass matter gets tightly packed and takes the size and shape of the die. The briquettes ensuing from the briquetting machine will be hot and upon cooling will become hard with individual briquette density varying from 900 to 1100 kg/m^3. This can be preserved for a long time in packed condition. There are two types of briquetting machines, Ram type and screw type. The ram type uses reciprocating mechanism of a punch and a taper die while the screw type uses a rotary mechanism with tapered screw in a heated barrel. The briquette density is found higher in screw type machine than the other one. The bulk densities of loose biomass before and after briquetting are shown in table II, it can be seen that rice husk which is briquetted in screw type machine has a higher briquette density as compared to others done in Ram type machine.

Table II: Bulk densities of loose biomass before and after briquetting

Biomass	Bulk density before briquetting	Briquette density	Bulk density after briquette
	kg/m3	kg/m3	kg/m3
Rice husk	100 -130	1000 – 1100	400 - 450
Sawdust	200 - 250	900 – 1000	300 - 400
Coir pith	80 -100	900 - 950	350 – 400
Ground nut shell	120 -140	800 - 850	300 - 350

2.3 Ash fusion

The agro residues are characterized with medium to high ash content as shown in Table I. This ash additionally has alkali salts that lower the ash fusion temperature. The in-organic content in biomass is not fixed and can vary from region to region and practices adopted for cultivation. A reference data taken from [5] is shown in Table III.

Table III: Ash deformation and fusion temperature of a few agro-residues

Biomass	Ash Deformation temperature (°C)	Ash Fusion temperature (°C)
Rice husk	1430 – 1500	1650
Coir Pith	1100 – 1150	1150 -1200
Groundnut shells	1180 – 1200	1220 – 1250
Pine needle	1250 – 1300	1350 – 1400

The temperature in the oxidation zone can vary between 1200 – 1400 °C and hence most of the agroresidue ash can fuse in this zone. The problem gets aggravated if there are any traces of foreign matter like sand or metal pieces.

To determine at what flux a particular briquetted biomass ash fuse, an experiment is constructed. The set up consists of an inverted downdraft gasification stove with air being supplied in a controlled manner with the help of a blower and flow measuring device. The inverted downdraft gasifier stove is a fixed bed combustion device which is ignited from the top and air supplied from the bottom. The stratification and reaction zones occur as in a fixed bed open top down draft gasifier but in a reverse fashion. The inlet air velocities can be varied to simulate different flux and stove allowed to operate. Upon interruption of the gasification process and cooling, visual inspection indicates whether ash has fused or not. Hence critical superficial velocities for ash fusion to occur for a particular biomass are established. By arranging the gasifier design such that velocities through the system are controlled, the allowable throughput for a particular diameter of reactor to avoid ash fusion is fixed. The critical superficial air velocity for a few briquetted fuels has been shown in table IV.

3.0 IMPROVEMENTS IN REACTOR TO HANDLE BIOMASS BRIQUETTES

The open top design allows for better air distribution both from the top as well as from the nozzles. Even than it was found that near the air nozzles where the air velocity is high, the flux is also higher allowing the local temperatures to go up creating clinkers. The clinkers get attached to the ceramic walls and get hardened in the heating and cooling cycles when the system is operated and stopped. Removal of the clinker calls for unloading of the system, allowing the reactor to cool and chipping off manually using a hard tool. This not only increases down time but also affects the life of the ceramic lining. To overcome this problem, the air nozzle was made to protrude into the reactor and not be flush with the wall. The clinker, even if formed, does not have a surface to adhere to and moves along with the charge. To regulate the ash removal for different biomass briquettes and also to convey or crush the clinker and remove the same, a specially designed screw based ash extraction system is employed in place of a conventional grate. The ash extraction system can also be automated to operate on a periodic basis to remove the ash at a predetermined rate and hence the mass balance inside the reactor is maintained. The reactor lining also has for the inner layer, a high alumina brick that is chemically inert and has high resilience for thermal shock. The smooth surfaces of this layer do not assist adhering of the clinker to the surface. The above improvements have led to a multi-fuel gasification system in which briquettes of various biomasses have been tested for long continuous durations. The improved gasifier has been discussed in references [6, 7]. The results of the tests are shown in Table IV.

Table IV: Results of a few briquetted biomass tests (all tests for more than 10 hours, V_e = Superficial velocity for incipient ash fusion)

Briquettes	V_e m/s	Calorific Value (MJ/kg)
Rice Husk	0.21	3.0 ± 0.5
Sawdust	0.2	4.6 ± 0.2
Coir pith	0.1	2.6 ± 0.1

The laboratory trials conducted on various briquettes were satisfactory and also a system has been deployed for an industry working on wood to gasify sawdust briquettes.

4.0 FIELD SYSTEM PERFORMANCE

4.1 Introduction

M/s Hindustan Pencils is a leading pencil manufacturer. They have two factories in Jammu and two in other locations. The two units at Jammu rely on a large extend to in-house power generation which was basically generated by diesel engine-generator sets. The factory also had problem of disposing the sawdust which was generated in the process of pencil manufacture in various stages. Part of the sawdust was utilized in boiler for steam generation for dryer operations; the remaining was briquetted in a ram type briquetting machine and stored. The industry scouted around to find a suitable gasifier to meet their requirement with briquettes. After a worldwide search for a robust gasifier based power generation system for sawdust, they decided on the IBG to meet their needs. The power requirement of 250 kWe was sought to be met with by operating producer gas engines
to optimize the cost of power generation. The briquettes were 60 mm diameter and cut into pieces of length between 30 – 50 mm. The briquette density was around 1000 kg/m3 and bulk density around 400 kg/m3. The ash content was between 2.5 to 3.0 %. The standard test on reverse down draft gasification stove was performed with material procured from them and the critical superficial air velocity for ash fusion was found to be > 0.2 m/s. The laboratory trials on a 50 kWe open top gasification system also confirmed this number; hence the reactor design was made for superficial air velocity of 0.2 m/s and a 300 kg/hr gasification system was designed to suit the end use requirement. The elements of the gasifier included briquette feeding mechanism, reactor, ash extraction and conveying system, two cyclones in series, a cooler, scrubber, chill water scrubber, fabric filter and water treatment system. The system is also equipped with start-up, normal and emergency shutdown automation. The fabrication and service support has come from a licensee of IISc. The photograph of the installation has been shown in Figure 1.

Figure I: The gasification system at M/S Hindustan Pencils, Jammu

The system was initially operated in dual fuel mode for 18 months and later the gas engines were installed. Cummins make diesel engine of 300 kWe output was dual fuelled to cater to the industry load requirement of 200 – 250 kWe. The diesel replacement was around 70 %. The gasifier operation for a period of one year has been shown in figure II.

The typical operation of this plant is 20 hours X 6 days a week. The uptime of the gasifier for the entire year has been around 75%. The system operates for more than 1500 hours before the system is unloaded for maintenance. These are due to maintenance on ash extraction system and air nozzles and not due to clinker formation.

Recently, producer gas based engines have been installed in these units replacing the dual fuel operation. This has yielded further fuel cost saving and reflects positively on the performance of the systems. Till date, the system has operated for 12600 hours generating around 1.76 million kWhs consuming 1584 tonnes of biomass and saving 400,000 liters of diesel. This has led to a CO_2 saving of 125 tonnes. A similar system has also been put in the sister concern of this industry for same application. The operations are satisfactory meeting the needs of the industry.

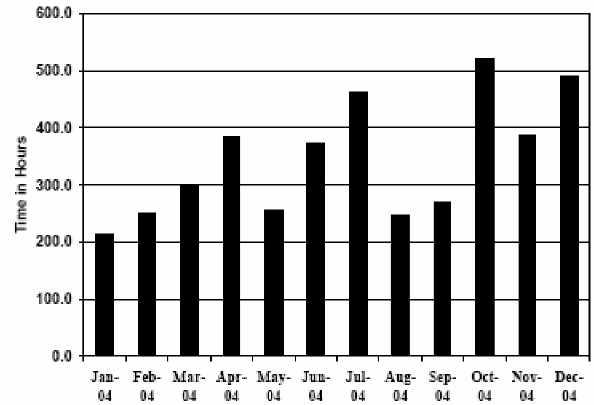

Figure II: Hours of operation of the gasifier in dual fuel mode for a period of one year.

4.2 Issues faced

Three issues faced during the operation have been resolved. (1) Use of incompletely formed briquettes, led to crumpling of the briquettes during the operation and increased the pressure drop across the reactor. This was avoided by use of briquettes of density greater than 750 kg/m^3. (b) Moisture condensation on the top layers during shutdown resulted in the disintegration of the briquettes in the top layers and hence, it was suggested as a practice, charcoal be loaded as final charge before shutdown and the same material to be removed before the next start-up. (c) The air nozzles which were protruding were made of high alumina ceramic material. The portion inside the hot zone broke off in about 500 hours and hence this was replaced by SS 316 L pipes. The length of these pipes will be maintained by welding the melted length during unloading of reactor once in 1500 hours.

4.3 Cost of Power Generation

The industry has an advantage that they are generating the sawdust and is available to them at zero cost (according to environmental pundits of the west, it would be a negative cost due to difficult disposal problems). Briquetting of saw dust is done in two numbers of screw type machines of 150 kg/hr each. Each one has motor of 11 kW and 3 kW of band heater for barrel heating. Thus, 28 kW of power is used for 250 kWe power generation which is around 11%. Two technicians are required for operating these machines. The manpower cost is around 0.2 US cents per kg briquetted and maintenance is around 0.3 US cents per kg. Hence the fuel cost including opportunity cost for sawdust is 0.8 US cents per kg. The operations and maintenance cost of the gasifier is around 1.2 US cents per kWh [2]. For power generation of 1 kWh, 100 ml of diesel is required costing 6.2 US cents, and 0.9 kg of biomass amounts to 0.72 US cents per kWh. The power generation cost including fuel, operation and maintenance is around 8.12 US cents per kWh. The cost of power generation in diesel mode is 20.7 cents per kWh. A saving of 12.5 cents per kWh has accrued leading to a total saving of 0.22 million USD. *The capital recovery on gasification system has occurred in 13 months of operation.*

The recent operation with producer gas engine has shown a requirement of 1.4 kg briquette/ kWh at nearly rated load. The fuel cost presently works out to 1.12 US cents per kWh. The operation and maintenance cost is the same and hence the power generation with producer gas engine operation is 2.32 US cents per kWh which is nearly 30% of that in dual fuel mode of operation and 10% of that in diesel mode.

5.0 CONCLUSIONS

The IBG system has a natural advantage of handling the medium to high ash content bio-residue with its uniform air distribution inside the bed. The improvements with respect to (a) positioning of air nozzles, (b) employing a screw based ash extraction system and (c) lining of the reactor has yielded positive results. The industrial package incorporating the above features has been operating for more than two years with briquetted sawdust as fuel.

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