Field experience of IISc gasification systems

H.V.Sridhar, G.Sridhar, S.Dasappa, N.K.S.Rajan. P.J.Paul, H.S.Mukunda
Advanced Bioresidue Energy Technologies Society
Combustion gasification and Propulsion Laboratory
Indian Institute of Science
Bangalore.

Nearly two decades of research and development in the field of gasification at IISc have culminated in to a technology package of open top down draft reburn gasification system. Recently certain modifications to ash extraction and air distribution system were made to accommodate variety of fuels. Presently, more than 20 systems of this design are operational in India and overseas with cumulative operations of more than 50000 hours. The systems have catered to both thermal and electrical power generation requirements. The thermal requirements met are both at high and low temperatures at varying heating rates. The electrical systems in the field are from 20 kWe to 1000 kWe power level right from stand alone application to grid connected application. The experience shows that for success and safe operation of a gasification plant, the system should be designed as a power plant with facilities for automation, water treatment, biomass preparation and biomass drying. The package has been able to operate on a 24 hours cycle over 2 weeks amounting to about 300 hours continuously.

Introduction

Biomass is a plant derived organic matter formed due to photosynthesis. During photosynthesis, solar energy is harnessed and hence biomass fuels offer a cheaper alternative to solar energy utilization (direct solar energy utilization means high cost of collection and intermittent operations). In energy context, biomass refers to all forms of plant derived material that can be used for energy like wood, herbaceous plant matter, crop residues, forest residues etc. [1]. Biomass can be converted by the process of gasification into a gaseous fuel which can be used for thermal or electrical power generation. Gasification is a two stage process; during the first stage, the biomass undergoes partial combustion to produce gas and charcoal; during the second stage, the charcoal reduces the product gases (Chiefly carbon dioxide and water vapor) to form carbon-mono-oxide (CO) and Hydrogen (H_2). The process also generates methane (CH_4) and other higher hydrocarbons depending on the design and operating conditions of the gasifier. The combustible gas obtained is termed as Producer gas with final composition as 18 to 20 percent carbon –mono-oxide, 18 to 20 percent hydrogen, 2 to 3 percent methane, 10 to 12 percent carbon-dioxide and remaining nitrogen. The gas will have a typical lower calorific value of 4.6 to 5.0 MJ/m^3 of gas. This gas can be piped and combusted at various end use equipment for thermal power generation or combusted in a diesel engine with diesel replacements of 75 – 85 % for electrical power generation. The recent developments have made it possible to combust the gas in a spark ignition engine thereby eliminating the necessity of any petroleum fuel.

Gasifier is the device for gasification of biomass and producing gas clean enough to meet the end use requirement. The development of gasifiers is mostly need based as is evident from the history of gasifier development. There was an intense development during World War II due to petroleum fuel shortage in civilian military sectors. These are the standard closed top design gasifier presently adopted by many manufacturers with little modifications. However, at IISc development of open top down draft reburn gasification system took place with inputs from basic research and field experiences. The advantages of the modern open top design as compared with closed top design are well argued by researchers [2].

At present, there are 6 thermal and 14 electrical gasifiers operational in the field. This paper discusses the configuration and experiences of these installations.

Gasifiers for thermal applications

The thermal gasifiers are generally used in process industries to substitute petroleum fuels like HSD, LDO or FO totally. In most of the cases, diesel is used as the fuel where the flue gases are brought in direct contact with the product. The main reason for this is to have clean flue gases as they come in contact with the product. Any traces of unwanted material could result in change in properties of the product. Thus, it becomes imperative in many situations that the gas should be of high quality, to maintain the product quality and also the devices handling the gas. This would ensure the maintenance of the system to a minimum. This is crucial as the demand for uptime of these gasifiers is highest as process downtime causes production and product losses (especially high temperature applications). Hence, the system design should account for uninterrupted long duration operations and high levels of safety. In order to achieve this, the gas is processed through a cooling and cleaning system to ensure clean and cold gas for further handling. In order to use the water in a closed loop system, water treatment is installed for the recirculation of cooling/scrubbing water. The systems have catered to various temperature needs and duty cycles. The application vary from drying at 100 to 110 ^{0}C to heat treatment of ferrous alloys at 900 ^{0}C to brick firing at 950 ^{0}C. The typical system configuration of an open top down draft gasification system for thermal application is shown in figure1.

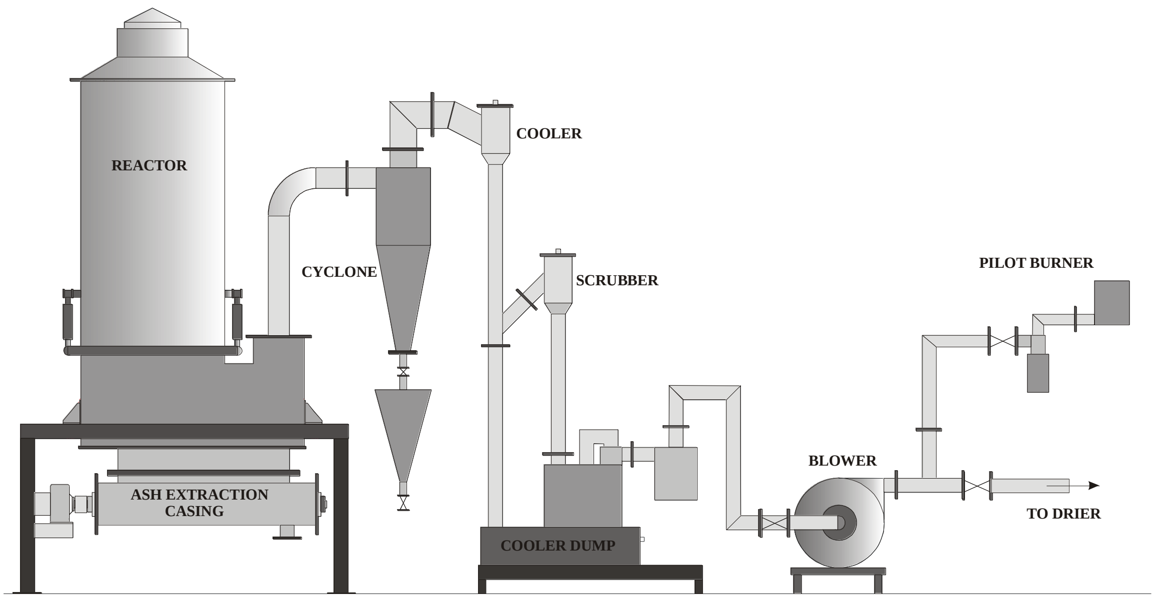


Figure 1: Schematic of Thermal gasifier

Some aspects related to system design

The reactor has been designed to accept various fuels as the input. This is an essential feature that would be necessary for the end user to ensure regular supply of fuel. The temperature inside the reactor which converts biomass to gas is high in the range of 1200 – 1400 ^{0}C and highly corrosive chemical conditions in different zones which no metal can endure. In order to ensure that the reactor is of industrial quality, standard industrial practices are use by lining with alumina tiles to take care of high temperature and thermal shocks along with insulation bricks for providing necessary insulation. All the components which come in contact with gas are built from stainless steel 316 l/304 depending on the temperature to eliminate any corrosion due to flow of gas.

The ash extraction system is of screw design with low rpm geared motor drive. This facilitates ash extraction at a predetermined rate and time. This is an important facility for automatic operations of the gasification system.

Due consideration is given to safety aspect of the system. Most part of the system experience suction and hence leakage of CO to atmosphere is minimized. The other hazard is related to air entering the system and flame flash back. Towards this an oxygen monitoring system is provided which indicates the oxygen level in the cold gas. Any raise in the oxygen percentage in gas above a set level indicates an alarm for the operator to shutdown the system and take corrective action. In any case water seal is provided in the system for any pressure release to occur. A flame failure system is provided to prevent any entry of un-burnt gas into the system. A thermocouple senses the flame temperature at the gas combustor, if for any reason the temperature sensed is less than preset temperature than the gas is diverted to pilot burner. The cooling water pump has a pressure switch which senses the water pressure ensuring cooling water flow. Any drop in the set pressure would lead to system shutdown by directly switching off the blower.

The system elements are:

Reactor

The reactor is a mild steel cylinder, and having an inner lining of ceramic, composed of high temperature insulation bricks and high alumina tiles. There are air nozzles provided around the combustion zone, which are kept open during the running of the system. A water seal forms the top of the reactor with a removable cover. This cover is kept open during the entire operation of the system, to facilitate loading of wood chips and movement of air inside. The reactor at the bottom has a screw based ash extraction system with facility to extract at a preset rate on an hourly basis. The extracted char/ash goes to water seal below.

Gas processing system

The gas has to be cooled and cleaned before being combusted. This requirement is both from safety angle and system maintenance aspect. The gas processing train consists of a hot cyclone, cooler and scrubbing system with mist separator. The gas after passing though this will be at ambient temperature and clean to be handled by the down stream elements.

Blower

This device provides the required suction effect to draw out the gas produced in the reactor and through gas processing system. The rate at which the producer gas is drawn is controlled by means of a gas control valve provided at the inlet of the blower or in a few cases by an AC drive to follow a certain heating curve.

Burner

The burners are specially designed to coexist with the existing liquid fuel burner. In case, such provision is not possible, then commercially available dual fuel burner has been fitted to the end use device. By this arrangement there is always a conventional fuel backup to prevent any down times.

Instrumentation

The system is provided with water tube manometers at strategic locations for monitoring the health of the gasifier. An oxygen indicator is provided to detect any leakage of air into the system.

Water recirculation system

The operation requires gas to be cooled and cleaned before combustion. Water is used as cooling and cleaning medium. The contaminated water is taken through the cooling tower to cool the water and a sand bed filter and activated carbon bed filter to remove the contaminants.

Summary of few installations of Industrial thermal systems:

Table – 1: List of Installations of Thermal Systems with operational summary

Sl. No	Installation	Rating	Application	No of hours operated	Oil saved Kl	Biomass consumed T
1	Synthite Industrial Chemical Ltd Coimbatore	500kg/hr	Marigold flower drying	4500	600	1800
2	Agro Bio Chem. (Pvt) Ltd Harihar	500kg/hr	Marigold flower drying	4100	550	1600
3	Tahafet Plot A-17, Sidco Industrial Estate, Hosur	300 kg/hr	Heat Treatment	10500	850	2800
4	Comorin Polymers and Plantations Ltd Kanyakumari	90kg/hr	Crumb Rubber drying	4800	90	320
5	Ideal Crumb Rubber Factory, Sri Krishnapuram post, Palakad,	90 kg/hr	Crumb Rubber drying	4850	100	350

Performance of the systems

The biomass used has been agro residues like, coconut shells, cashew nut shells and wood chips. The first two installations for marigold flower drying are seasonal in nature and depend on the availability of the flowers. These operate on an average 3000 – 4000 hours per year, with 24 hours of operation in a 6 day cycle as required by the industry.

However, all the systems have generally operated continuously, averaging about 150 hours a week. The biomass consumption for low temperature requirements for replacing 1 liter of petroleum fuel is around 3 kg and the same for high temperature application is around 3.3 kg. The higher biomass requirements at high temperature is due to the fact that the time taken for operational cycle slightly increases in producer gas mode due to difference in peak flame temperature of petroleum fuel and producer gas [3].

Operation and Maintenance

Based on the capacity and the system configuration intended at specific site, the additional accessories like the fuel feeding, data acquisition and automation are included. Typically, the higher power level systems are automated and have PLC controls. The system can be started and shutdown with a press of a button at control panel. These systems also have conveyors for fuel feeding. All the systems will be equipped with minimum safety devices to handle the fuel gas and provide safety for equipment and operators. Fuel feeding and material movement in the case of the open top design is simple and good. This ensures consistent gas quality and thus maintains a set temperature. This has been possible in applications within a tolerance of $\pm 2\ ^{0}C$

In the high temperature application, the gas has been taken through a standard industrial burner with small port, without disturbing the existing liquid fuel facility. This has been possible due to the fact the gas is clean. The cleanliness has improved the quality of product compared with the liquid fuel system being used earlier.

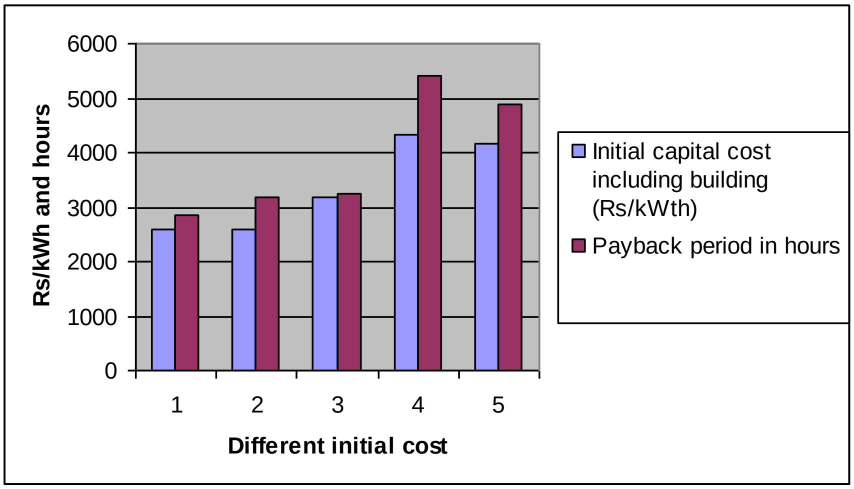
The maintenance required for the system is daily removal of particulates from cyclone which can be done online with the help of lock hopper mechanism, cleaning the blower once in 300 hours of operation. The air nozzles used for drawing air into the combustion is made of ceramic. These nozzles get eroded depending upon the fuel used. Typically life of in the range between1200 to 1500 hours of operations has been recorded. During maintenance schedule at few locations the ceramic tiles at one or two locations have been dislodged, particularly if any clinker is found sticking to it. This minor maintenance can be attended at the site. Taking all this into consideration, the system maintenance have turned out to be 3% of investment cost for higher power level system and 6% for lower power level system. Further developments in the area of air nozzle and ceramic lining have taken place which will probably bring the maintenance costs further lower.

Economics of operations

With the performance of 1 liter of diesel / ldo substituted by 3 – 3.3 kgs of biomass depending upon the end use device (high or low temperature application), the economics of operation are very attractive. Saving of the fuel costs is in the range of 75 %. Accounting for servicing and other additional cost involved in using the gasifier, the return on the investment is about a year. Figure 2 shows the initial capital cost for various configurations (1- 5) and the pay back in hours of operations. Even under the worst scenario of about Rs. 4000 per kW thermal, the pay back is about 4000 hours, say 8

-12 months of typical industrial operation. Thus it is evident from the figure 2 most of the systems have earned back the investment on gasification system.

Figure 2: Comparison of payback period for different cases



Gasifier for Electricity generation

The gasifier configuration for electrical application has additional cleaning elements in addition to the thermal configuration. Chill water scrubbing system and a fabric filter is added to clean the gas to particulate levels of less than 25 ppm to operate a turbocharged diesel or gas engine. The high power level systems have automation and gasifiers up to 100 kWe are manually operated. The design aspects and safety issues considered are similar to previous case.

Summary of few installations of Electrical systems

Table – 2: List of Installations of Electrical Systems with operational summary

Sl. No	**Installation**	**Rating**	**Application**	**No of hours operated**	**Oil saved , Kl**	**Biomass consumed, T**
1	Arashi Hitech Bio power Ltd, Coimbatore	1000 kWe	Grid connected	2800	154	1200
2	Senapathy Whiteley Pvt Ltd, Ramanagaram	500 kWe	Captive power generation	2100	32	122

3	Sir MVIT, Bangalore	2 X 120 kWe	Captive power generation	3200	25	180
4	Department of Electricity, Kavaratti, Lakshadweep	300 kWe	Grid connected	20	-	-
5	Ideal Crumb Rubber Factory, Sri Krishnapuram post, Palakad,	100 kWe	Captive power generation	650	6	36
6	Xylowatt SA Bulle Switzerland	60 kWe	Third Party sale of power	2000	-	145

The installations at 1 and 3 are continuously operating plants and others are intermittently operational according to the need. The diesel replacements achieved are on an average 75%. The average fuel consumption at lower power level is around 1.0 kg/kWh for the said replacements where as at higher power levels it is around 0.8 kg/kWh. This is due to increase in system efficiencies at higher power level.

The plant at Switzerland is an independent power producing company, servicing part of energy needs of a saw mill at Bulle. This is a completely automated system with once in a day fuel dumping to the bunker. If at all a problem occurs, the system goes into shutdown mode and an alert message goes to the mobile of the plant operator. During operations, the gas generated is send to a producer gas engine of 60 kWe capacity. The long duration operations have revealed a specific biomass consumption of 1.1 kg/kWh. This also confirms to tests at the laboratory at 4 different power levels of 20, 50, 100 and 180 kWe. In this way a major dent has been made in power generation without the support of fossil fuel.

Operation and maintenance

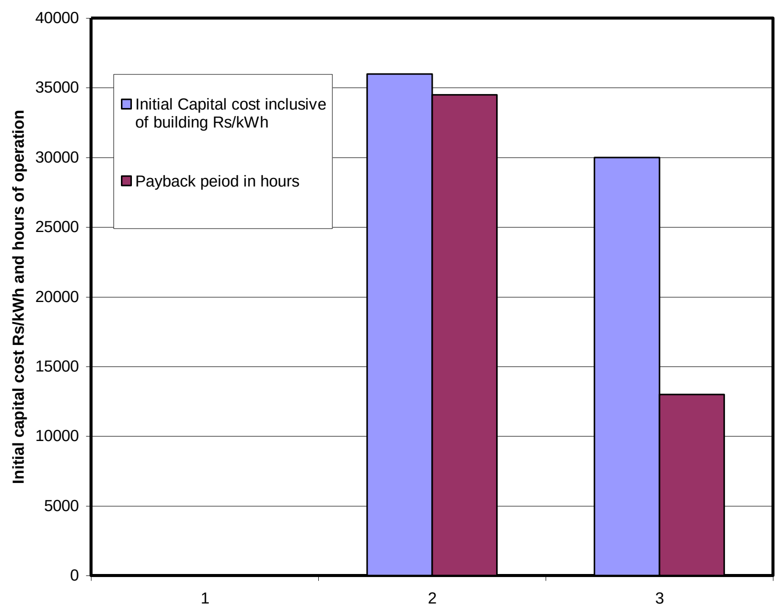
The aspects of operations and maintenance are same as that of the thermal systems with additional maintenance requirements of the filter. The blower is located after the filter and hence the cleaning of blower is called for once in 1500 hours. The fabric filter gets choked periodically and needs to be cleaned. This event is a function of operations and any unsound operations brings down the operational life of the filter. The filter should be cleaned with a solvent and dried before being reused. However, duplex arrangement of filters is done to allow for continuous operations. The typical times between cleaning of filters are between 150 – 200 operational hours.

Economics of operation

The cost of power in dual fuel mode with biomass as 1.2 Rs /kg and diesel at 22 Rs /ltr is around 3.2 to 3.5 Rs/kWh while in gas alone mode of operations it ranges from 2.2 to 2.5 Rs/kWh. The operations and maintenance costs vary from 0.4 Rs/kWh at higher power level to 0.75 Rs/kWh at lower power level.

The economics for a grid linked 1 MWe system shows that the payback is between 4 to 5 years in dual fuel mode. This can be substantially lower for captive power generation system which does not have electricals for up linking. The other area for optimization is the building cost. Figure 3 shows the payback of two systems at 1 MWe grid linked and a 200 kWe captive.

Figure 3: Comparison of Payback



Conclusion

The operations in this millennium have showed that IISc designed gasifiers operate reliably to industrial standards. The system has been designed for enabling automation at all the power levels. The system has an over all out look of a power plant.

The economics of thermal gasifier are attractive and irrespective of power levels has around 1 year of payback. The electrical gasifiers based on dual fuel mode have 2 – 5 years payback based on system components.

The char extracted from gasifier can be activated and has byproduct value. This is not considered in economic calculations.

The use of gas engines for power generation further reduces the running cost and there by better payback can be realized.

Reference:

[1] Biomass for Energy: Supply Prospects – David O. Hall, Frank Rosillo-Calle, Robert H. Williams, Jeremy Woods, Renewable Energy Sources for fuels and Electricity, Island Press.

[2] Open-Top wood gasifiers – H.S.Mukunda, S.Dasappa, U.Shrinivasa, Renewable Energy Sources for fuels and Electricity, Island Press.

[3] Biomass gasification - a substitute to fossil fuel for heat application –S.Dasappa, H.V.Sridhar, G.Sridhar, P.J.Paul, H.S.Mukunda, article to be published in Journal of Biomass and Bioenergy.