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Biomass gasification—a substitute to fossil fuel for heat application

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Abstract

The paper addresses case studies of a low temperature and a high temperature industrial heat requirement being met using biomass gasification. The gasification system for these applications consists of an open top down draft reburn reactor lined with ceramic. Necessary cooling and cleaning systems are incorporated in the package to meet the end use requirements. The other elements included are the fuel conveyor, water treatment plant for recirculating the cooling water and adequate automation to start, shut down and control the operations of the gasifier system. Drying of marigold flower, a low temperature application is considered to replace diesel fuel in the range of 125–150 l h^{-1}. Gas from the 500 kg h^{-1}, gasifier system is piped into the producer gas burners fixed in the combustion chamber with the downstream process similar to the diesel burner. The high temperature application is for a heat treatment furnace in the temperature range of 873–1200 K. A 300 kg h^{-1} of biomass gasifier replaces 2000 l of diesel or LDO per day completely. The novelty of this package is the use of one gasifier to energize 16 burners in the 8 furnaces with different temperature requirements. The system operates over 140 h per week on a nearly nonstop mode and over 4000 h of operation replacing fossil fuel completely. The advantage of bioenergy package towards the economic and environmental considerations is presented.
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Keywords: Biomass; Thermal; Diesel substitution; Gasifiers; High temperature; Drying

1. Introduction

Fossil fuel based technology has been primary source in the last two decades to meet the thermal energy required in small as well as large industries. The number of small-scale industries that uses liquid fuels in the range of 100 l h^{-1} to meet the heat requirements is quite large. This has led to development of efficient combustion devices for the fossil fuels over the decade, to meet both efficiency and emissions standards. Over the years, many of the solid fuel based devices have been converted to petroleum-based fuels due to the availability and the compactness of the combustion system; without serious concern on the economics of operation. With the present changes in cost of petroleum fuels, the overall economics are being affected. Economics along with the environmental considerations has resulted in looking at alternate sources of energy.

Industries have adopted the use of petroleum-based fuels for various applications, apart from generating electricity using internal combustion engines. Some of the applications are the low temperature requirements

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like, drying of various food and non-food items, hot air for specific process requirements, etc. While the high temperature requirements are in, boilers for steam generation, thermic fluid heaters, furnaces in heat treatment industries, steel processing, ceramic sector, etc. This has led to the use of petroleum fuels for stationary applications, which other wise could address the transport sector.

About 92 MT of oil has been consumed during the year 1998–99, amounting to about 24% of the total energy consumption in India. A significant part of this fuel is used for industrial applications to meet the thermal energy requirements. Further, the petroleum fuel usage has an impact on the GHG emissions. Combustion of petroleum fuels degrades air quality with adverse impacts. It leads to emission of pollutant such as particulates, SO_2, NO_x, CO and GHG (largely CO_2).

Even though many of the above mentioned applications could be addressed using biomass, the industrial sector has not taken note. With the adaptation of gasification technology, nearly all the advantages of using petroleum fuel as a thermal source of energy can be availed. Further, the use of biomass has an economic advantage along with environmental benefits.

The paper addresses two applications, a low temperature for drying and a high temperature for heat treatment process. The performance of the system is presented in relation to the amount of biomass used to replace the diesel, having implications on the efficiency and also the hours of operation, indicating the reliability. One important parameter to indicate the overall performance of the gasifier system in relation to the existing fossil fuel system is the amount of biomass used to replace a liter of diesel. This also has the bearing on the economics of operation. The case studies presented here are clear indicators towards the shift for clean development mechanism—a tool to use renewable energy.

2. The low temperature application

Synthite Industrial Chemicals Limited is a group company, dedicated towards chemicals from agricultural and horticultural crops. The plant in Tamilnadu located at Karamadi is devoted for extracting chemicals from flowers for the purpose of fragrance and also as food colours. The industry operates for about 8 months in a year, approximately 3500–4000 h per year.

This industry process flowers for fragrance and also carry out major extraction from marigold flowers to produce an oleoresin leading to chemical called Xanthophylls. The process is energy intensive for drying operations. The industry has a capacity to dry about 800–900 kg of marigold flower during the season. This is carried out by two driers about 400 kg h^{-1} output capacity each. The industry has installed a solar air heater to reduce the oil consumption and is also installing a biogas plant to recover energy from the spent wash.

M/s Agro biochem (India) Pvt. Ltd. Karnataka also has similar set up for drying marigold flower. Agro biochem (India) Pvt. Ltd. is located in Davangere district of Karnataka. The company has established a network of 6000 farmers, with whom the company has arrangement to grow and procure the flower.

These companies individually process about 35,000–40,000 ton of marigold flowers annually. These industries are turning out to be like the sugar industry to protect the input raw material by establishing direct contact with the people growing it. The product from these industries is exported to Mexico, USA, Singapore and other countries. These industries were using liquid fuel burners, which are energy guzzlers and are environment unfriendly.

The wastes from these industries are dust like material, which is a residue from the marigold flower after the chemical extraction and has a fair amount of inorganic, identified as spent meal with ash content in the range of 3–5%. Further, during handling, plucking, transportation, digesting and other operations, inorganic material like mud/sand gets into the parent material. Utilization of the material in the form of powder with available technologies poses severe problems, for sensitive thermal applications aiming at near constant temperature for drying operations along with severe environmental implications.

2.1. The fossil fuel system

The industry works for about 220–250 days in a year with average working hours per day in the range of 16–20. They process about 8–12 ton output flowers per day depending upon the season. As indicated

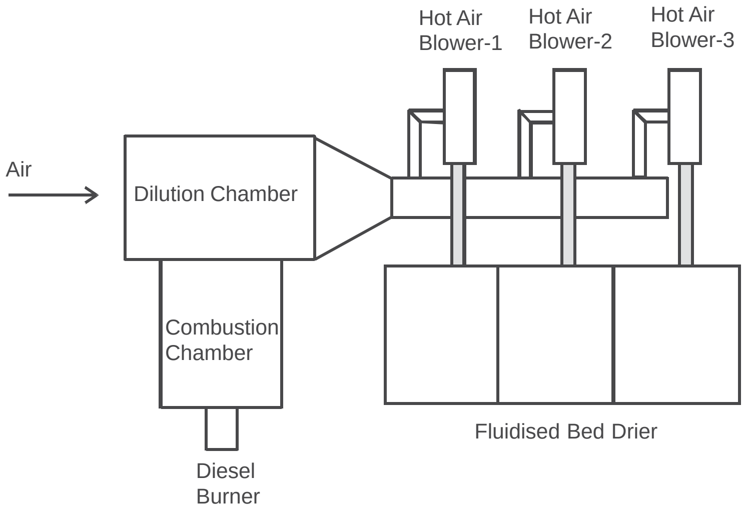

Fig. 1. Schematic of the fossil fuel set up.

above, after the extraction of the oleoresins from the dried flowers, large amount of dried material is considered waste. Even disposal of 8–12 ton of this material is posing a serious problem for the industry. It should be brought out that the current energy utilization pattern in each drier is typically about 2000 kW thermal. Fig. 1 shows the schematic of the fossil fuel set up.

The liquid fuel system consists of a commercially available Wesman burner [1] with diesel as the fuel. Diesel at high pressure is sprayed into the burner with an air–oil regulator in the circuit. This controls the air to fuel ratio. After combustion of diesel in the burner, fresh air is mixed with the products, i.e., dilution, to maintain required temperature in the drier, typically around 373 K. About, 140 l h^{-1} of diesel is consumed to maintain the rated condition of the drier under nominal operating conditions.

2.2. The gasifier system

Biomass gasifiers [2–4] have been used for electricity generation and thermal applications. Most of the specifications drawn on the quality of producer gas are meant for electricity application, while the gas quality for thermal application is considered less stringent. It will be shown in the present technology packaging for specific high quality heat application and at large capacity, the quality of gas that needs to be adhered to, is comparable to that of an engine application.

The 140 l h^{-1} fossil fuel consumption system is being replaced by a installed capacity of 500 kg h^{-1} of gasification system to generate about 2 MW thermal power equivalent hot gases at 373 $\pm$ 5 K. The key elements of the system are; a reactor whose design should avoid ash fusion, a cyclone and a cooling and cleaning system to cool the gas and also eliminate the dust. After combustion of the gases it is further diluted by ambient air to produce clean hot gas at the desired temperature.

The fuel is conveyed into the reactor using a conveyor. The fuel loading will be automated depending upon the gas flow rate by sensing the level of the fuel in the reactor and setting higher and lower limits.

The system is configured with a PLC to carry out operations related to ash extraction, fuel feeding and other safety regulatory measures for the system. All the data with respect to pressure and temperature are logged continuously on to a computer. The schematic of the gasifier system with other elements are as shown in Fig. 2.

2.2.1. Gasification system

Reactor: The reactor is essentially rolled from mild steel, and has an inner lining of ceramic, composed of high temperature resistant bricks and high alumina

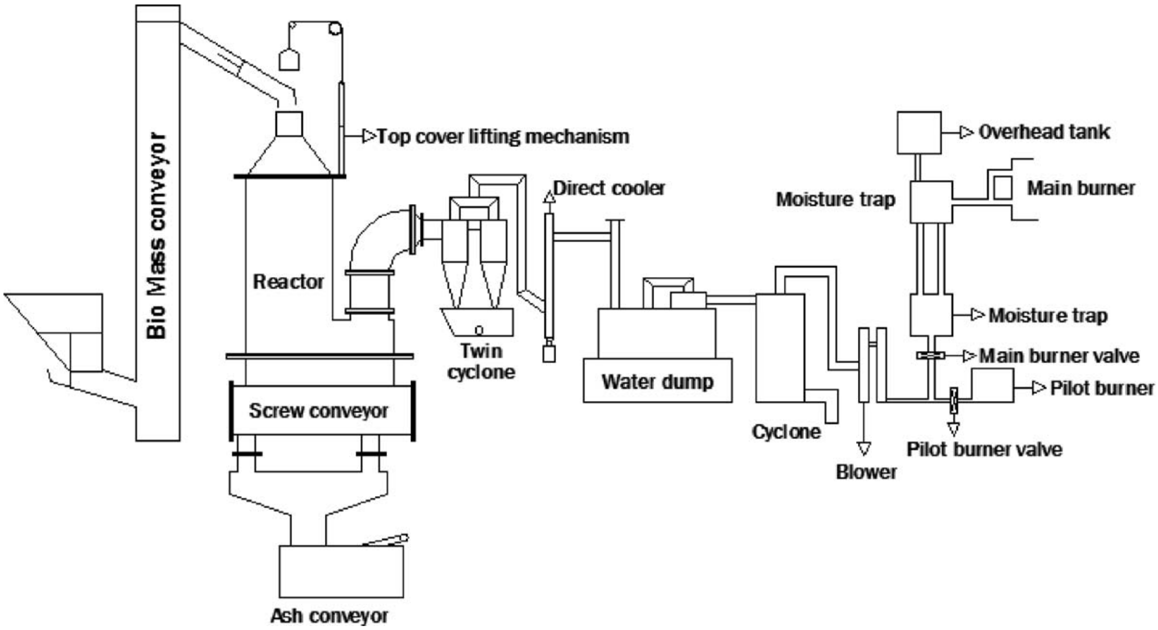

Fig. 2. Schematic of the gasifier system.

tiles. There are air nozzles/tuyers (provided around the combustion zone), which are kept open during the running of the system. For establishing uniform air distribution across the section, air nozzles are located azimuthally at two different heights. The nozzles also penetrate into the reactor zone, which are water-cooled. 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, also helps in the loading of fuel. The reactor at the bottom has an ash extraction system with water seal facility to prevent any air leakage into the reactor.

Gas processing system: The conditioning system consists of a cyclone to remove the dust, scrubbers using water as the medium for cooling and cleaning. Water is used in a closed circuit with a treatment facility. Blower provides the required suction effect to draw out the gas produced in the reactor. The rate at which the producer gas is drawn is controlled by using a variable frequency drive. The variable frequency drive also helps the controller to regulate the flow rate after sensing the hot air temperature at the fluid bed drier.

Burner: A specially designed burner for producer gas is fitted near the liquid fuel burner. Both the burners exist on the same system. The burner management system is installed to take care of the safety aspect, to eliminate any flash back, etc.

Instrumentation: A control system is provided along with data acquisition to carry out few operation related to the gasifier, like automatic fuel loading, ash extraction, shut off during power failures as the part of safety measure. The system is also provided with water tube manometers at strategic locations for monitoring the health of the gasifier.

Biomass conveying system: Operation of the gasification plant requires loading of biomass into the reactor in batch wise or on a continuous basis. At full load of operation, the system consumes at a rate of 500 kg h^{-1}. This scale of operation requires a conveyor for continuous or batch wise loading of biomass into the reactor. The system consists of a storage dump, a conveyor and associated electrical and electronic components.

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 bed filter to remove the particulate.

2.2.2. Operations at M/s Synthite Industrial Chemicals Pvt. Ltd.

The gasification system at Synthite Industrial Chemicals Pvt. Ltd. was installed in June 2000 and the testing was conducted during June–July and actual production was started in August 2000.

The initial trial operations of the system were carried by using marigold briquettes as the fuel, which was prepared by another industry producing only briquettes. During the course of the run the ash content in the fuel feed indicated an alarming level of contamination; though the parent material has only about 5–6% ash, the ash content in some of the samples was found to be in the range of 23–27%; basically consisting of extraneous materials like, sand, brick, concrete, etc. Even though the gasification process was not seriously affected, the throughput got reduced. After about 150 h of using the briquettes, the system was shut down and examined. A large amount of fused material was found inside the reactor below the air nozzles. Towards the end of this run it was necessary to use the support of fossil fuel to maintain the inlet temperature at the drier; i.e., with partial diesel fuel.

The above problem has arisen from the fact that during the period of 150 h about 65 ton of briquettes were used, amounting to about 10 ton of ash estimated at an average ash content of about 15%. The ash extraction was set to about 8–10% as the virgin raw material had about 6% ashes. The excess inorganic that was not discharged resulted in a fused mass. Further, it must be stated that presence of sand, mud, etc., acted like a flux and hence accelerated ash fusion.

During this period, in the initial stages the energy generated by gas was sufficient to meet the drier requirements by maintaining the hot air temperature around 373 K. Later with the poor quality fuel, dual fueling using supplementary diesel was necessary to maintain the process requirements. It was found that about 20–30% of diesel was found necessary at varying operating conditions.

In order to derive benefits from the system, alternate biomass was looked into until the briquettes of right quality to be produced in-house. The industry found sourcing requisite coconut shells from the surrounding region was possible. Table 1 provides hours of operation since the change over from briquettes to coconut shells. About 3800 h of operation has been completed using coconut as the fuel. During this period the industry has consumed about 1520 ton of biomass and replacing about 480 kl of diesel. The system has been operated continuously over 150 h continuously depending upon the process requirements.

Over the 3800 h of operation, issues related to ash extraction system, air nozzle cooling system and the gas cooling had to be addressed in the initial 1000 h. This is evident from the Fig. 3 that the number of

Table 1
Performance of gasifier system at M/s Synthite Industrial Chemicals Limited

Month	Hours of operation	Month	Hours of operation
Oct-2000	130	Jan-2001	173
Nov-2000	105	Feb-2001	122
Dec-2000	175	Mar-2001	253
		Apr-2001	334
Sub total	410	May-2001	381
Total = 3765		Jun-2001	362
		Jul-2001	305
		Aug-2001	363
		Sep-2001	382
		Oct-2001	160
		Nov-2001	284
		Dec-2001	226
		Sub total	3345

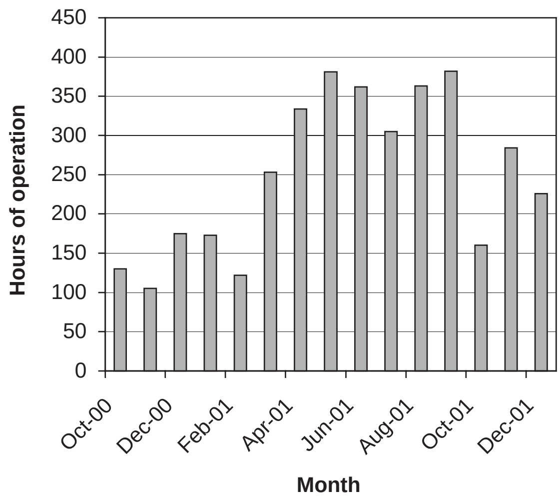

Fig. 3. Hours of gasifier operation using coconut shell for various months.

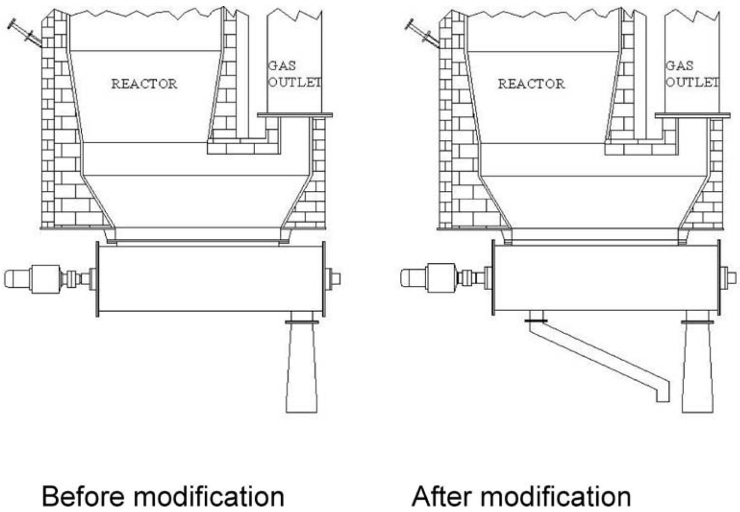

Fig. 4. Changes implemented on the ash extraction system.

hours of operation has virtually doubled after taking care of these issues. One of the important outcome of this exercise was that, the quality of gas required for thermal application, has to be sufficient clean to have relative low maintenance. The scrubbing quality had to be improved to eliminate the problems related to blower blockage due to particulate matter. Estimates show that even at 50 mg m^{-3} concentration, the amount of dust to be handled is about 1 kg per day on a 24 h operation. This has to be handled to eliminate any possible blockage in the gas path until the burner. This was achieved using efficient cyclones and scrubbing system.

The quality of water used to cool the nozzles was found to be a critical parameter determining the life. Use of hard water or with any contamination facilitated scale formation in the cooling section of the nozzles resulting in failure. Soft water had to be used.

2.2.3. Ash extraction issue

The ash extraction system used in the present reactor design is unconventional as far as gasification process is concerned. The entire bed of fuel is supported on a screw, which is further used to remove the ash/residue from the reactor depending upon the requirement. A geared motor drives the screw. The operation of the ash extraction screw is based on the input feed ash content and or the pressure drop across the reactor. Based on the set limit on the pressure drop the screw is operated from a preset time interval. In the initial design as shown in the Fig. 4, it was envisaged that one discharge from the screw at the reactor bottom would be sufficient to extract the residue at the required rate. Though, this operation was being performed satisfactorily, it was found that the gas exit side of the reactor was being loaded with char carried by the gas flow; resulting in the increase of reactor pressure drop. This increase in pressure drop has direct effect on the gas flow rate and thus the temperature at the end user device is also affected.

This problem has been resolved by providing an outlet in line with the gas exit. This zone being in the screw-operating regime, both the outlets were found effective in extracting the ash/residue from reactor while operating the screw. After the above modifications, the issue related to the ash extraction system, resulting in lowering of gas flow was resolved; and the system has been operating satisfactorily.

2.2.4. Operations at M/s Agro Biochem (India) Pvt. Ltd.

This industry has two driers; 250 and 500 kg h^{-1} drier capacity. The driers have different gasifiers as a source of fuel. The industry has been using a 200 kg h^{-1}—first generation gasifier system

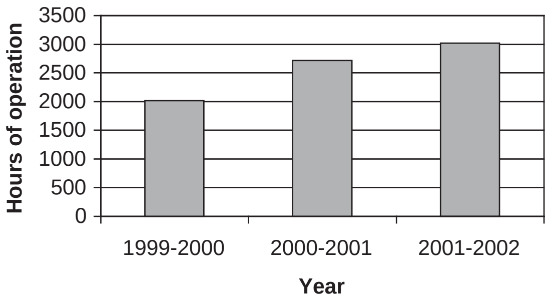

Fig. 5. Hours of operation on the 200 kg/h^{-1} gasifier system.

designed by for over 4 years amounting to about 11,000 h of operation, saving about 1000 kl of diesel. Fig. 5 shows the total number of operations for the last three seasons, amounting to about 7800 h. During this period 1734 ton of biomass has been consumed. About 3200 h of operation was completed during the 1997–1999, probably first time to be using biomass for drying the flower directly.

On satisfactory performance of the earlier system, recently, the industry installed a 500 kg h^{-1} gasifier system similar to the one described in the earlier section, and has operated for about 2900 h replacing 400 kl of diesel. During the initial 500 h of run, some of the operational issues were resolved. Table 2 provides the details of the operations on the gasifier system. In the initial period some diesel was used along with the gas to maintain the inlet temperature to the drier around 373 K. The last column provides the data on the amount of fuel used. Approximately, 0.7 kg of biomass is required for 1 kg of dried product, amounting to a drier efficiency of about 62%.

Even in this project, issues related to ash extraction and air nozzles had to be attended in the similar manner as indicated earlier. The air nozzle failure resulted in water seepage into the reactor and damaging the ceramic lining by quenching under hot condition. The lining in one of the sectors inside the reactor had to be redone. The failure of the air nozzle due to the quality of water used for cooling has been an important lesson learnt in these installations. The nozzles have been replaced using 99% alumina tubes.

Another sector that called for attention has been the water treatment plant used for recycling the water. Even though the treatment circuit functioned satisfactorily in terms on overall performance, the amount of water used for washing the sand bed and further handling of this water was found to a critical area calling for further investigation. It has been found by laboratory scale experiments, cost effective coagulation and flocculation. Flocculation helps in removal of particulate and some organics. This is being currently implemented at the project site.

M/s Agro Biochem (India) Pvt. Ltd. were proud to declare for the year 2001–2002, the industry has never used a drop of oil for drying of the flower.

Table 2
Performance on the 500 kg h^{-1} gasifier system at M/s Agro Biochem

Month	Number of hrs of operation	Diesel used (l)	Biomass used (tonnes)
Jan-2001	287	15,371	84,691
Feb-2001	378	20,456	112,929
Mar-2001	49	2527	13,573
System not used during this period			
Sep-2001	88	0	33,443
Oct-2001	18	0	7012
Nov-2001	126	0	51,933
Dec-2001	313	0	131,717
Jan-2002	279	0	116,509
Feb-2002	267	0	86,648
Mar-2002	433	0	147,417
Apr-2002	328	0	116,805
May-2002	291	0	101,850
Total	2857	38,354	1,004,527

3. The high temperature application

The high temperature application is for a heat treatment furnace in the temperature range of 600–920°C. The industry was using 2000 l of diesel/LDO per day as the fuel to meet the above temperature in the furnaces. A gasifier of 300 kg h^{-1} of biomass consumption capacity is replacing the liquid fuel completely.

3.1. The fossil fuel system

The company works for about 250–300 days in a year on a 24 h per day basis. There are eight furnaces to carry out. This industry provides services like; Heat

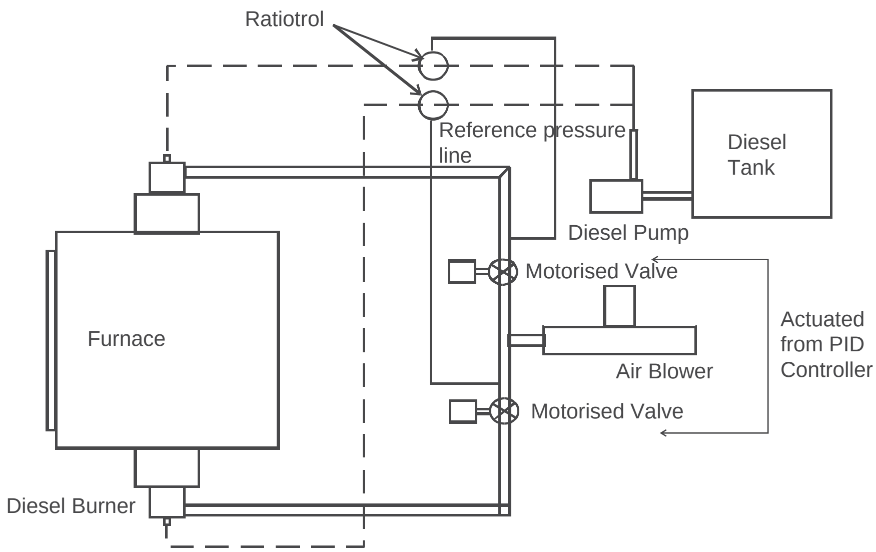

Fig. 6. Fossil fuel system for high temperature application.

Treatment and Fettling to the castings and forging industry. The industry was using LDO for operating its eight normalizing and tempering furnaces. Fig. 6 shows the fossil fuel system for all the eight furnaces.

It should be brought out that the energy utilization pattern is typically in the range of 1200 kW thermal. Typical daily LDO consumption is about 2000 l.

The fossil fuel system consists of two burners for each furnace. The temperature is controlled using a PID controller, with the air to fuel ratio controlled using the ratiotrol—operating on the principle of balancing the pressure by using pressure regulator. The thermal cycle of the process has a closed loop control, where heating cycle and soaking periods are controlled.

3.2. *The gasifier system*

The present design is aimed at gasification about 300 kg h^{-1} of the bio residue to generate about 1.2 MW thermal power. The novelty in this package is the use of one gasifier to energize eight furnaces with different temperature requirements. This has been possible by using ratio controller to maintain the air to fuel ratio; with a control parameter from the furnace temperature. Two burners are located for each of the furnace, thus a total of 16 burners use producer gas generated from the gasifier. With the use of pressure regulator and ratiotrol on the gas line to attain the air–fuel ratio, the demand on the quality gas was high; comparable to the one expected for an internal combustion engine—contaminants less than 50 ppm level. The cleaning system in this package is better than the one used for the drying application presented earlier to take care of critical passage in the gas flow path.

The system is configured with a PLC to carry out operations related to ash extraction, fuel feeding and other safety regulatory measures for the system. All the data with respect to pressure and temperature are logged continuously. Gasification system is as shown in Fig. 7.

3.2.1. *Gasification system*

The gasification system is similar to the one described earlier except for the cleaning circuit as the gas is taken through a ratiotrol for controlling the air to fuel ratio, in the case of gas firing. The cooling system consists of two stage water scrubbers; co and counter current configuration. The gas is further processed in a scrubber-using diesel as the medium to reduce the contaminants in the gas. The rate at which the producer gas is drawn through the blower is controlled by the requirements of the burners. The air to fuel

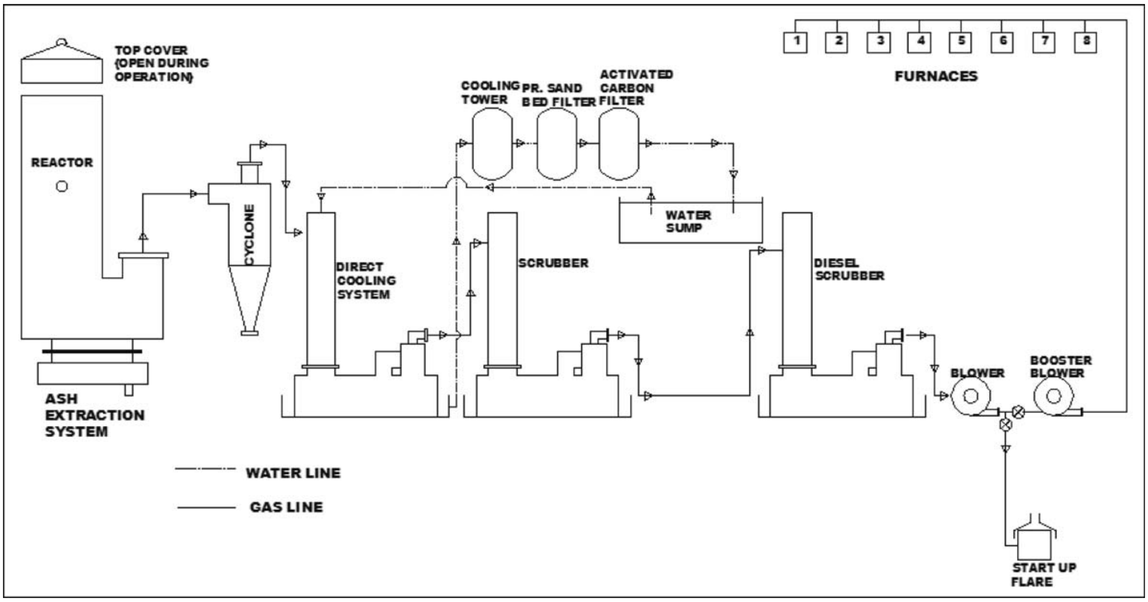

Fig. 7. Schematic of the 300 kg h^{-1} gasifier system.

ratio is controlled for each of the burner is carried out using ratiotrol. The gas air mixture is led into each of the gas burner.

Furnace and burners: The furnace is a $2 \times 2 \times 2$ m^3 in size, which is insulated using bricks and a front pneumatically operated door used for loading and unloading the charge. Two burners are located as shown in the Fig. 6. The fuel gases are drawn from the chimney located at the top of the furnace.

3.2.2. Performance

Producer gas from the gasifier system, drawn through the blower is around 10000 Pa, a requirement to maintain the gas pressure for the ratiotrol to function. The nozzle dimension has been suitably adopted to draw necessary amount of gas into the burner, without much modification on the oil system. This aspect has been an advantage for the industry to switch over to the fossil fuel system in a short duration in case of biomass availability or during gasifier maintenance.

Table 3 shows the details on the performance of the furnaces using light diesel oil (LDO) and producer gas as the fuel. The daily fossil fuel consumption was found to be about 2000 l. Of the eight furnaces five had requirements of temperature in the range of 900°C and the remaining to be maintained around 873 K. Normalizing and Hardening process involves operating the furnace operation at 773–873 K and 1073–1173 K, respectively. It is a two-stage operation involving heating for 2.5 h followed by soaking for another 2 h. From the data presented in Table 3, the time taken by the producer gas operation is about 25% more compared with the LDO fuel based operation. This probably is true because of the radiation from the liquid flame being higher than that of the gaseous flame. Observation of the flame in the burner with liquid fuel is a yellowish sooty flame in comparison to nearly colorless gas combustion. Further the peak temperature achieved in liquid fuel combustion system is higher than producer gas operation.

Fig. 8 provides the temperature time history in one of the furnace for diesel and gas. In case of normalizing furnace, the initial rate of heating with producer gas till the stock is admitted into the furnace is almost the same as liquid fuel. Subsequent to the admitting of the material for heat treatment, there is a gradual fall in the rate of heating with producer gas, which is reflected in terms of furnace temperature. The reach time in diesel is lower than that of producer gas operation. Similar trend is observed with the hardening operation

Table 3
Details on the performance of the furnaces using LDO and producer gas as the fuel

		Max. temp. (K)	Time to reach temp. with LDO (h)	Time to reach the temp. with gas (h)	Fuel used (l)	Rate of consumption (l h^{-1})	LDO per day (l) (l)
F1	H	1173	1.45	2.15	20	9.3	97.0
F2	T	873	0.45	1.05	50	47.6	303.8
F3	H	1173	1.45	2.05	50	24.4	242.4
F4	H	1173	1.45	2.15	20	9.3	97.0
F5	T	873	0.45	1.05	75	71.4	455.7
F6	H	1333	2.15	3.30	70	21.2	297.3
F7	T	923	0.45	1.05	50	47.6	303.8
F8	H	1173	1.45	2.15	60	27.9	290.9
	Total						2087.9

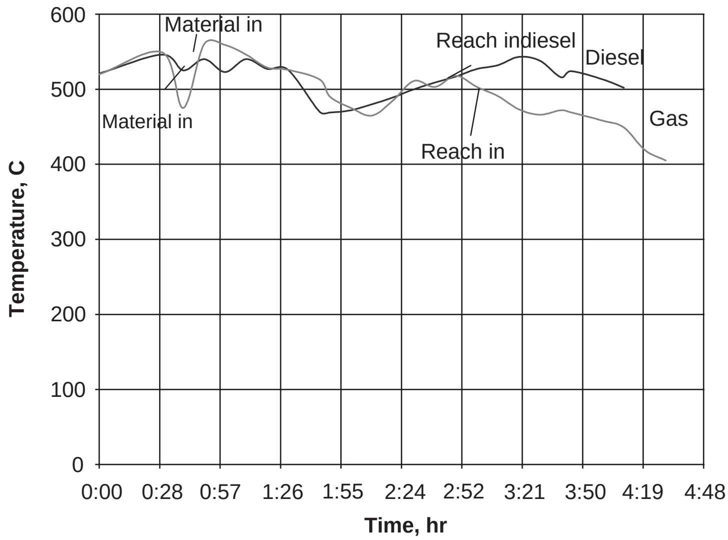

Fig. 8. Comparison of temperature inside a furnace using diesel and gas.

with the exception that the initial rate of heating with producer gas is lower compared to the liquid fuel.

Table 4 provides the summary of the runs on the gasifier system. It is clear that the availability of the system was about 85% in the month of July 2001. The major issues that had to be addressed were related to the air nozzle cooling and the quality of gas. At present the water-cooled stainless steel nozzle has been replaced by a silicon carbide material to withstand the reactor environment and the performance is found satisfactory. Due to the failure of the stainless steel nozzle the refractory lining had to be attended to once. Inspection at regular intervals has indicated that the lining is good condition. Cleaning of the gas has been made effective by introducing an efficient scrubber, with diesel as the working medium.

After the initial trials of about 100 h, the system has operated for over 3700 h using coconut shells. The system has been operational since April 2001 on an average of five furnaces. Fig. 6 shows the number of hours of runs per day, for the month of August and the biomass consumption. In this month on an average

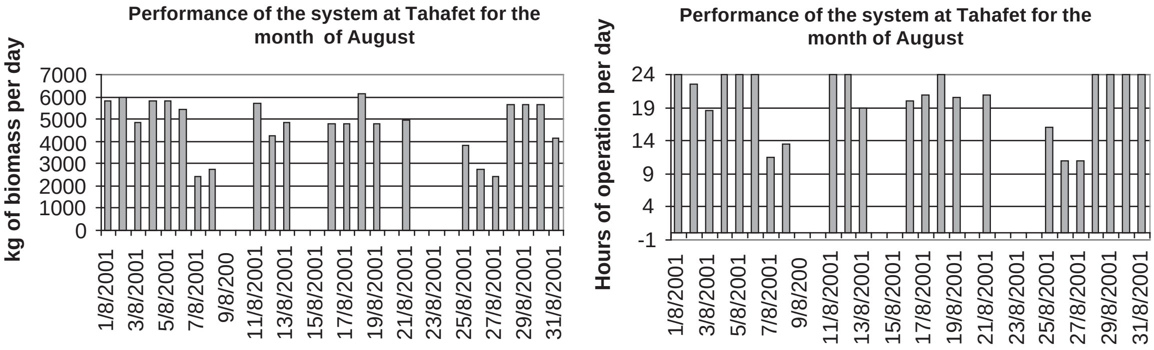

Fig. 9. Performance data for the month of August 2001.

Table 4
Overall performance of the system at Tahafet

Month	Hours of operation (h)	Bio-mass consumed (kg)	No. of furnaces
Year 2001			
March	165	11192	
April	67	8500	5
May	72	10250	6
June	421	83760	5
July	627	117077	6
August	470	105240	8
September	501	106993	5
October	380	82176	6
November	410	88750	6
December	275	59050	6
System not operating—biomass availability and system maintenance			
	Hours of operation (h)	Bio-mass consumed (kg)	No. of furnaces
Year 2002			
February	367	97349	7
March	80	46205	8
April	244	51225	8
May	46	11970	8
June	239	46205	7
Total	4364	925942	

of 20 h per day has been achieved. The industry has replaced a significant amount of LDO (in excess of 500 kl) by gas during these runs.

The average biomass consumption has been between 5 and 6 ton per day. The non-operation days are mostly related to the job availability in the furnace or biomass availability. During this month, all the furnaces have been in operation and about 105 ton of biomass has been used to replace about 26 kl of LDO.

It is important to bring out the performance of the gasifier-based heat treatment in relation to the quality of product. The liquid fuel system invariably has excess air for combustion of poor quality fuel. The presence of oxygen at elevated temperature (~ 873 K and above) results in the formation of scales on the material being heat-treated. The presence of sulphur in the liquid fuel, further affects the surface (Fig. 9).

4. Results and discussions

The operation of the gasifier systems for the two applications under consideration; a high temperature and a low temperature, for about 22, 000 h in total (as on June 2002) has resulted in establishing the bio-energy package for fossil fuel substitution.

4.1. Energy balance

4.1.1. Low temperature application

Many of the controlled tests have indicated that the average coconut shell consumption is about 410 kg h^{-1} against 135 l h^{-1} of diesel. At 16 MJ kg^{-1} the thermal input from biomass is about 1820 kW. Based on the fuel flow rate the energy content in the gas at about 1025 kg h^{-1} is 1360 kW. The energy from diesel is about 1340 kW. While the energy content in the gas roughly matches with the diesel input, the overall efficiency is lower by about

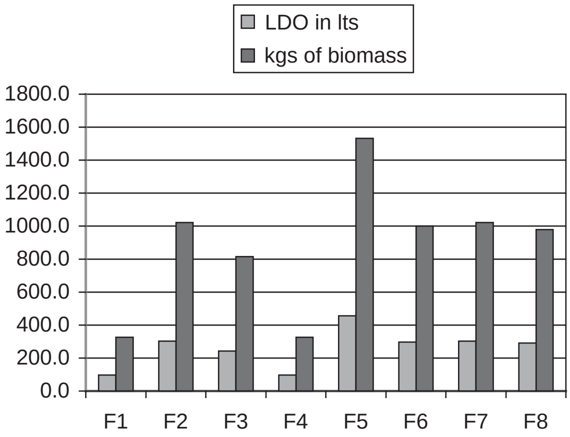

Fig. 10. Fuel requirement for various furnaces.

25% due to the fact that gasification efficiency has to be considered, typically about 80–85%. It must be brought out here that the energy content in the char extracted is about 10%; due to the fact that 5% of the input feed is extracted as charcoal. The charcoal, which is extracted, has an iodine number in excess of 500 that could be used as activated charcoal for a large number of applications.

It is clear from the above analysis about 3 kg of biomass replaces about 1 l of diesel, while the drier efficiency being held the same.

4.1.2. High temperature application

Fig. 10 presents the equivalent biomass required to replace the LDO operation by producer gas. In obtaining the equivalent biomass, the additional time required to meet the process temperature has been accounted. It is found that 1 l of LDO is replaced by about 3.3 kg of biomass. The overall efficiency from fuel to energy to meet the process specification for the end use is lower by about 25% compared with that of fossil.

Comparing the overall performance of the two applications, the equivalent energy substitution for both these applications works out to be 1 l of diesel being substituted by about 3 kg of biomass in the case of low temperature drying application and about 3.3 kg in the case of high temperature heat treatment application. The possible reasons for about 10% change in the Specific Energy Consumption arise from the fact that there is difference in the adiabatic flame temperature for these two fuels. Table 5 shows the adiabatic flame temperature for diesel and producer gas calculated using NASA SP 273. There is a difference in the adiabatic temperature by about 10%, between the two fuels. Further it has been noticed that the flame is sooty during diesel fuel combustion in the furnace. The two factors contribute towards the radiation heat transfer significantly, resulting in a difference on the specific energy consumption.

Table 5
Adiabatic flame temperature diesel and producer gas

Fuel	T_{adi} (theory) (K)	Temperature factor
Diesel	2290	1
Producer gas	1925	0.87

5. Environmental considerations

In these industries the fossil fuels are totally replaced by technology using only biomass as the fuel. The benefit on the environment is significant. The amount of CO_2 saving that has resulted in these industries is about 6500 ton; which is substantial at a microscale. Along with the CO_2 saving, a large amount of other pollutants like sulphur oxides and nitrogen oxides is also in much lower concentration than the fossil system. The emissions from the gasifier based system are; CO—0.6–2.2 g MJ^{-1}, NO_x—0.3–0.7 and particulates less than 0.15 g MJ^{-1}. The lower level of NO_x is related to the lower peak temperature in the gaseous flame compared with that of the fossil fuel based system.

6. Economic considerations

A simple calculation based on the mass balance would result in the biomass fuel cost amount to about 25% of the fossil fuel cost. Based on the fuel cost, 1 l of fossil fuel (0.42 USD per liter) is replaced by about 3.5 kg of biomass (32 USD per ton); resulting in a net saving of about 0.3 USD per liter of diesel replaced. The life cycle costing is presented in Table 6, assuming 25 years as the life of the equipment and replacement and maintenance of the components are considered as required by the design. In presenting the

Table 6
Economics of gasifier based operation for thermal application

Life cycle cost estimates	Gasifier based system	Diesel based system
Initial capital cost (USD per kW thermal)	118.75	10.00
Life cycle O&M cost (USD per kW thermal)	37.82	15.13
Life cycle fuel cost (USD per kW thermal)	189.11	1210.27
Total life cycle cost (USD per kW thermal)	345.68	1239.50
Overall unit cost of energy (cents per kW thermal)	0.97	3.42

economic analysis, various costs are indicated as the input energy cost. This approach would eliminate the efficiency factor of the conversion device. The investment cost of the gasifier based system is 110 USD per kW thermal while it is about 10 USD per kW thermal for the fossil fuel based system including the building cost. With a discount rate of 10%, the cost of fuel at USD 21 per ton for biomass and fossil fuel at USD 0.42 per liter, the economics of operation are as presented in Table 6. The economics are fairly attractive even without the CO_2 cost benefits. The entire investment is realized in about 2 years.

7. Conclusions

The bioenergy package using thermo-chemical conversion has been shown to replace fossil fuel in high quality heat application. It is also clear from the experience that the quality of gas required for meeting the end use to be comparable to an internal combustion engine. About 2400 kl of fossil fuel has been saved in the above four installation by using about 7300 ton of biomass and a net saving of 6300 ton of CO_2.

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References

[1] North American Combustion Handbook, vols. 1 and 2. Cleveland, USA: North American Manufacturing Company, 1986.

[2] Mukunda HS, Dasappa S, Paul PJ, Rajan NKS, Shrinivasa U. Gasifiers and combustors for biomass—technology and field studies, Energy for Sustainable Development. The Journal of the International Energy Initiative 1994;1(3).

[3] Somashekar HI, Dasappa S, Ravindranath NH. Rural bioenergy centers based on biomass gasifiers for decentralised power generation: case study of two villages in southern India. The Journal of the International Energy Initiative, Energy for sustainable development 2000;IV(3).

[4] Mande S, Kishore VVN. Biomass gasifier systems for sustainable development of rural India. In: Biomass gasifier systems for sustainable development of rural India, Proceedings of the National Workshop on Renewable Energy and Energy Conservation Awareness & Strategies, 15–17 December, 2001, Coimbatore.