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Full Length Research Paper

Design and techno economic evaluation of biomass gasifier for industrial thermal applications

N. S. Rathore[1], N. L. Panwar[2]* and Y. Vijay Chiplunkar[2]

[1]College of Dairy and Food Science Technology, Maharana Pratap University of Agriculture and Technology Udaipur 313 00, Rajasthan, India.

[2]Department of Renewable Energy Sources, College of Technology and Engineering, Maharana Pratap University of Agriculture and Technology Udaipur 313 00, Rajasthan, India.

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This paper addresses the design, performance and economic evaluation of biomass based open core downdraft gasifier for industrial process heat application. The gasifier is having feed rate as 90 kg h^{-1} and producing about 850 MJ h^{-1} of heat. The gasifier has been installed in M/S Phosphate India Pvt. Limited, Udaipur (27° 42' N, 75° 33' E) for heating and concentrating phosphoric acid. The system is in position to save 20 L of light diesel oil per hour. The techno economics of the designed system is also presented in the paper.

Key words: Biomass, gasifier, downdraft, feed stock.

INTRODUCTION

The continuous growth of global energy consumption raises urgent problems related to energy availability, safe operation and its efficiency. The larger part of mineral oil and gas reserves energy supply is located within a small group of countries, forming a vulnerable energy supply. Moreover, this supply is expected to reach its limits. On the other side, the use of fossil fuels causes numerous environmental problems, such as local air pollution and greenhouse gases (GHGs) emission (Carlo et al., 2005).

A possible way to deal with these problems is the deve-lopment of cleaner and renewable energy sources. Mod-ern use of biomass is an interesting option, because bio-mass is worldwide available, it can be used for power generation and biofuels production, and it may be pro-duced and consumed on a CO_2-neutral basis (Hall et al., 1993; Rogner, 1999; Turkenburg, 2000). Biomass is used since millennia for meeting myriad human needs include-ing energy. Main sources of biomass energy are trees, crops and animal wastes. Until the middle of 19th cen-tury, biomass dominated the global energy supply with a seventy percent share (Grubler and Nakicenovic, 1988). Biomass gasification is the process of converting solid into combustible gases; it is a thermochemical process in which the fuel gas is formed due to the partial combustion of biomass (Tripathia et al., 1999; Pletka, 2001; Dasappa et al., 2003). This technology was developed around 1920 and played an important role in generating motives power till other fuels made their appearance (Rathore et al., 2007). The use of biomass as an energy source has high economic viability, large potential and various social and environmental benefits (Ravindranath, 2004). Inex-pensive materials such as forest residue, wood residue, and rice straw are few potential feedstocks for biomass gasification. However, the cellulose, hemicelluloses and lignin composition of these materials may differ signifi-cantly (Minowa et al., 1998). Keeping in view importance of biomass gasifier, an open core down draft biomass gasifier of 90 kgh^{-1} capacity has been designed and install-ed in M/S Phosphate India Pvt. Limited, Udaipur for con-centrating phosphoric acid.

*Corresponding author. E-mail: nlpanwar@rediffmail.com. Tel: +91 294 2471068. Fax: +91 294 2471056.

Nomenclature: **η_g,** The hot gas efficiency of the gasification system; **SGR:** Specific gasification rate, kg $h^{-1} m^{-2}$; **CV_g,** Calorific value of gas, MJ m^{-3}; **CV_g,** Calorific value of feed stock, MJ kg^{-1}; **PG_{out},** Producer gas output from wood chip, $m^3 kg^{-1}$; **FCR,** Feed consumption rate kg h^{-1}; **LDO,** Light diesel oil; **NPW,** Net present worth, $ US; **C_t,** cost in each year; **B_t,** Benefit in each year; **t,** 1, 2, 3................n; **I,** Discount rate.

MATERIAL AND METHOD

The generation of producer gas in gasification system occurs in two significant steps. The first step involves exothermic reactions of oxygen in air with the pyrolysis gas under rich conditions. The se-cond step involves the endothermic reaction of these gases largely CO_2 and H_2O with hot char leading to producer gas (Di Blasi et al.,

Table 1. Assumption for design a down draft gasifier.

The hot gas efficiency of the gasification system (η_g)	60%
Specific gasification rate(SGR)	110 kg $h^{-1}m^{-2}$
Calorific value of gas (CV_g)	4.6MJ m^{-3}
Calorific value of feed stock(CV_f)	16.75 MJ kg^{-1}
Gas output from wood chip(PG_{out})	2.2 m^3kg^{-1}

Table 2. Dimensions of the designed gasifier.

Feed stock consumption rate	90 kg h^{-1}
Cross sectional area	0.8 m^2
Height of reactor	3.5 m
Insulation material	Insutyle 11 U (Mahavir Refractory Corporation, India)
Grate (rectangular)	
Type	Rectangular
Size	1.25 m x 0.65 m
Material	SS 304
Water sealing trough	1.6 m x 1.0 m
Cyclone	Medium efficiency (Kauppa and Goss, 1984)
Blower	
Type	Centrifugal type, air tight
RPM	2800
Flow rate	600 m^3 h^{-1}
Impeller material	SS-304
Gas outlet	0.20 m below the grate
Air inlet	Ø 14 mm, 4 nos, 400 mm above the grate.
Grate agitator	
Type	Combing action
Materials	SS-304
Biomass size	0.60 mm x 0.60 m

2000; Mckendry, 2002). The industry consumed 20 L of light diesel oil (LDO) per hour to meet out the process heat. Since the total accumulate from 20 L of LDO is about 850 MJ. On this basis an open core downdraft gasifier to produce 850 MJh^{-1} was designed for multiple applications including concentrating phosphoric acid for in-dustrial uses. The capacity of a gasifier determined permissible grate loading. The

gasification rate 100 to 250 kg of agriculture resi-dues per sq/m of grate area has been suggested by Kaupp and Goss. The design detail of this gasifier is as follows:

System design

Capacity of the gasification system

A biomass based open core down draft gasifier has been designed for multiple uses. Various assumptions were made in the design (Table 1).

Feed stock consumption rate

The system was designed to meet the required heat for various applications in industrial sector including concentrating phosphoric acid. The heat requirement in industries was calculated through energy audi-ting and it was found that 850 MJ process heat is re-quired per hour to perform the required operation.

$$\text{Feed stock rate} = \frac{PG_{out} \times CV_g}{\eta_g \times CV_f}$$

Dimension of the reactor shells

It was calculated by using the following formula:

$$\text{Reactor cross sectional area} = \frac{FCR}{SGR}$$

Height of the reactor

The height of the reactor was decided on the basis of required feed-stock holding capacity and the duration of operation of the system. In this case the total duty hour is 11 h and bulk density of wood taking 395 kg m^{-3}. The working height of the reactor was fixed 10% more in order to (a) accommodate grate, and (b) provide space for ash col-lection at the bottom.

System description

The dimension of designed biomass gasification gasifier for industrial thermal application is given in Table 2. The schematic of designed system is presented by Figure 1.

Economic evaluation

For the success and commercialization of any new technology, it is essential to know whether the technology is economically viable or

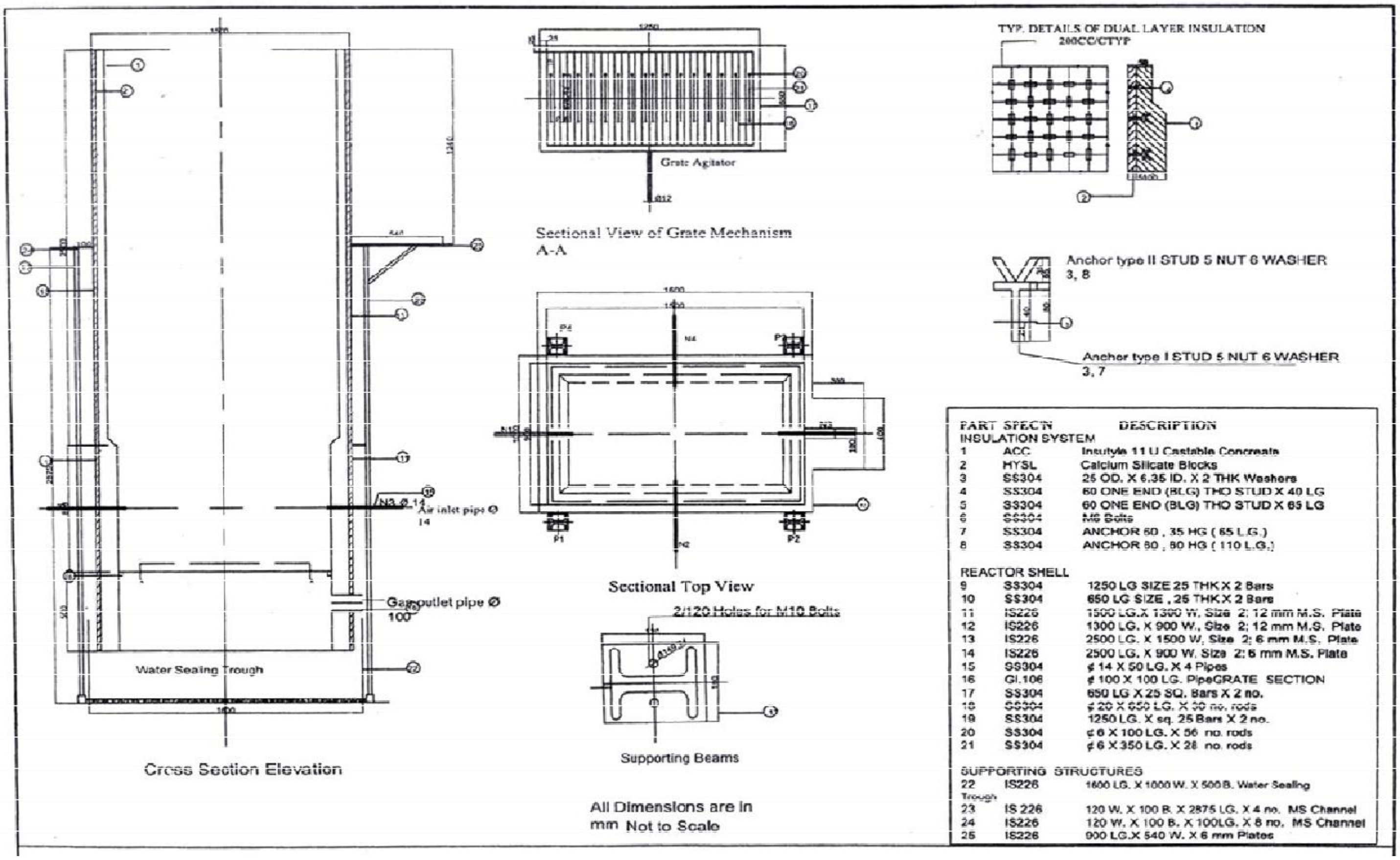

Figure 1. Schematic of downdraft open core gasifier for industrial application.

not. Therefore, an attempt was made to evaluate economics of the biomass gasifier with heat exchanger system. Economic analysis of the system was carried out by employing following indicators.

i.) Net present worth.
ii.) Benefit-cost ratio.
iii.) Payback period.

The following parameters have been considered to carry out economic analysis of heating system.

i.) The life of biomass gasifier and heating system is 10 years.
ii.) Salvage value at 10% of Initial Investment.
iii.) Interest at 10% of Initial Investment.
iv.) Depreciation at 20% of Initial Investment spread over 10 years.
v.) Repair and Maintenance cost at 20% of Initial Investment spread over 10. years.
vi.) The discount rate is assumed 10%.
vii.) The electricity cost at Rs. 5 kWh^{-1} (Rs. 40 US $\$^{-1}$ exchange rate on June 2007).
viii.) Annual operation 300 days.

Net present worth (NPW)

The difference between the present value of all future returns and the present money required to make an investment is the net present worth or net present principals for the investment. The present value of the future returns can be calculated through the use of discounting. Discounting essentially a technique by which future benefits and cost streams can be converted to their present worth. The interest rate was assumed as the discount rate for discounting purpose. The mathematical statement for net present worth can be written as:

$$NPW = \sum_{t=1}^{t=n} \frac{B_t - C_t}{(1+i)^t}$$

Benefit cost ratio

This is the ratio obtained when the present worth of the benefit stream is divided by the present worth of the cost stream. The formal selection criterion for the benefit cost ratio for measure of project worth is to accept projects for a benefit cost ratio of one or greater (Rathore and Panwar, 2007). The mathematical benefit-cost ratio can be expressed as:

$$\text{Benefit-cost ratio} = \frac{\sum_{t=1}^{t=n} \frac{B_t}{(1+i)^t}}{\sum_{t=1}^{t=n} \frac{C_t}{(1+i)^t}}$$

Payback period

The pay back period is the length of time from the beginning of the

Table 3. Physical and thermal properties of feed stock.

Characteristics	Biomass fuel Vilaytee babool ***(Prosopis Juliflora)***
Diameter (mm)	30-40
Length (mm)	40-75
Bulk density (kg m^{-3})	395
Angle of slide (deg.)	19.2
Moisture content (% wb)	10.5
Volatile matter (% db)	82.95
Ash content (% db)	1.12
Fixed carbon (% db)	15.93
Calorific value (MJ kg^{-1})	16.75
Oil content (%)	Not measured

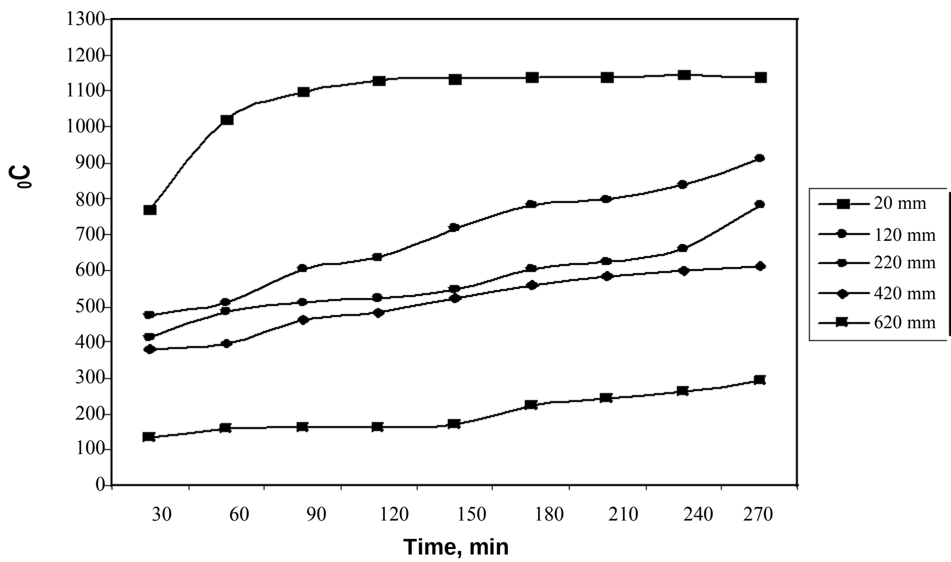

Figure 2. Temperature distribution across the reactor height for wood gasification.

project until the net value of the incremental production stream reaches the total amount of the capital investment. It shows the length of time between cumulative net cash outflow recovered in the form of yearly net cash inflow.

SYSTEM OPERATION AND MEASUREMENTS

The designed gasifier system was operated according to the procedure prescribed by the Ministry of New and Renewable Energy (MNRE, 2000). The proximate analysis of fuel was carried out be-fore the test using the method suggested by ASTM (Annual book ASTM, 1983). A bomb calorimeter (Advance Research Instruments Company) was used to calculate the gross heating values of biomass fuel used. Initially 60 kg of charcoal pieces of 20 - 60 mm long were loaded up to air nozzle level, the fuel biomass was loaded up to the top of gasifier. The blower was switched on; air was drawn by blower through top of the gasifier and air nozzles. By holding an ignition torch near the air nozzle, the fuel was ignited in the bed. Subsequently, the combustible producer gas was generated and was tested through ignition at the flare burner. When quality combustible was obtained, the gas turned to heat exchanger to get req-uired process heat. Proximate analysis as per standard method was made to analyze the feed stock. Fixed carbon (FC) was deter-mined using material balance (Annual book ASTM, 1983; Singh and Patil, 2001). A physical and thermal property of feed stock is given in Table 3.

Performance evaluation

This unit so far been operated for a total of about 300 h, the longest single run stretching over eight hours. The K-type thermocouple with digital temperature indicator (Analog and Digital Instrumentation, Vadodra) was used to record the temperature. Temperature distribution across the reactor of developed gasifier with 600 kg of biomass feed is illustrated in Figure 2. After 90 min of

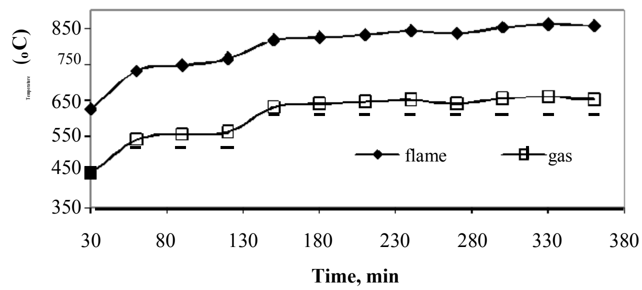

Figure 3. Flame and producer gas temperature.

Table 4. Economic Indicator of heating of phosphoric acid under biomass gasifier and heating system.

Economic Indicator	Biomass gasifier and heating system
Net Present Worth, US $	87400
Benefit –Cost ratio	1.65
Pay back period, years	2 year and 11 months

starting, constant temperature above 20 mm of grate was recorded, this indicates that the combustion bed is stabilized. As height from the grate is increased, the temperature also increased due to proper combustion of biomass. It is observed that during operation, the producer gas exit temperature lies between 450 to 650°C, where as flame temperature varied from 625 to 850°C (Figure 3). The flame temperature increased with time as it reached up to 850°C; it indicates the complete combustion of biomass which means no gasification process takes place. The total heat generated is utilized for heating and concentrating phosphoric acid in the factory. Earlier, the industry was consuming 20 litters per hour of light diesel oil (LDO) to meet out their process heat. In present context, the whole LDO has been replaced by biomass.

Economic evolution

The amount of net Light Diesel Oil (fossil fuel) saved is 66,000 L/year. The net saving of money was 36014 US $ per year when biomass gasifier based heating system was used. The cost of operation for industrial biomass gasifier and heating system was worked out as US $. 00.81 h^{-1}. The detail of income and expenditure for heating phosphoric acid is presented in Appendix-A

Table 4 present the net present worth of investment made on industrial biomass gasifier and heating system for heating phosphoric acid in a year is 87400 US $. Based on net present worth, it can be concluded that the construction of industrial biomass gasifier and heating system is economical and there is substantial increase in income of an industrialist by thermal application of this system. The benefit cost ratio for industrial biomass gasifier and heating system come out to be 1.65. The pay back period for biomass gasifier and heating system come out to be 2 year and 11 months. The pay back period for biomass gasifier and heating system was less because of low cost of operation and maintenance.

Conclusion

A biomass gasification system was designed to produce 850 MJ h^{-1} of heat for industrial application at M/s Phosphate India Pvt. Limited, Udaipur. It is essentially open core downdraft of gasifier, which is simple in design and can be integrated for meeting various industrial applications. The developed gasifier is working successful in the industry from last one year for concentrating Phosphoric acid and replacing 20 L of LDO consumption per hour through production of 850 MJ h^{-1} heat. It is economical viable option to replace the fossil fuel for various industrial thermal applications.

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Appendix A

Economic analysis

Cost of operation

Description	Amount (US $)
Annual Fixed cost US $ per year	
Initial investment	10429
Interest	1043
Depreciation	209
Repair and Maintenance Cost	209
Annual operating cost, US $ per year	
Electricity 9 kWh/day x 300 @ 5 per kWh	313
Fuel (wood) cost 90 kgh^{-1} x 11 h/day x 300 x 579 US $ ton^{-1}	17207
labour cost 2 labour /day x 300 @ 80 /day	1112
Total	**20093**

Cost of operation = $\dfrac{20093}{300\ Day/year \cdot 11h/day}$ = 6 US $ h^{-1}

Cost of operation when L.D.O. used as fuel per year

= 20 kg/hr x 11 hr/day x 300 day/year x 0.81 US $ kg^{-1}

= 53534 US $

Cost of operation when Wood used as fuel per year

= Wood cost + Electricity cost

= 17207 + 313

= 17520 US $

Net saving of money by operating biomass gasifier and heating system per year

= 53537 - 17520

= 36014 US $

Cash flow (US $) for heating of phosphoric acid through biomass gasifier.

Year	Cash outflow	PW of Cash outflow	Cash inflow	PW of cash inflow	NPW
0	10429	10429	0	0	-10429
1	20093	18266	36014	32740	14474
2	20093	16606	36014	29764	13158
3	20093	15096	36014	27058	11962
4	20093	13724	36014	24598	10874
5	20093	12476	36014	22362	9886
6	20093	11342	36014	20329	8987
7	20093	10311	36014	18481	8170
8	20093	9373	36014	16801	7428
9	20093	8521	36014	15273	6752
10	20093	7746	36014	13884	6138
		133890		221290	87400

Computation of pay back period for the gasifier system

Year	PW of total cash outflow in 10 years (US $)	Cash inflow (US $)	Present worth of cash inflow	Cumulative cash inflow
0	1985032			
1		36014	32740	32740
2		36014	29763.64	62503.64
3		36014	27057.85	89561.49