Design and Development of a Novel Hybrid Gasifier for High Ash Content Coal as feed stock.

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Abstract

India has large proven reserve of coal but most of the coal has large quantity of ash. Utilization of this high ash content coal is again a very challenging task. Presently, gasification of high ash coals has not yet been in application due to the difficulties arising from the ash handling processes. In this work an attempt was made to design a partially fluidized bed reactor that can handle 30 kg/hr coal as a feedstock. By using an appropriate design procedure a complete design of a hybrid gasifier was studied deeply. The major aim of present research is to determine the air flow rate for proper gasification, reactor diameter and reactor height, feed particle diameter, nozzle orientation and number nozzles, reduction zone diameter and height. Experiments were carried out with feeding rate of 9.8 kg/hr with high ash content coal having 39.83% ash. Satisfactory results have been found during experiments. The average producer gas generation during trial run was found to be 29.8 Nm^3/hr while average calorific value of producer gas was about 4500 kJ/Nm^3. The work described here favours us understand the real gasification process for high ash content coal and thus facilitates the industrial application of gasification technology.

Keywords: Gasification, High ash coal, Thermo chemical conversion, Hybrid gasifier

1. INTRODUCTION

The electricity demand in India is increasing at a very fast rate. In India, around 60% of the country's commercial energy and 70% of its electrical energy comes from coal. While there is growing push to adopt non-fossil fuel electricity-generating technologies, coal remains the go-to energy source for the foreseeable future due to its large reserves and low cost [1]. Utilizing the clean coal technologies can only be option for effective usage of coal. One important coal utilisation process in the suite of clean coal technologies is coal gasification. Here coal is converted into gaseous fuel used to power a turbine and thereby to generate power. Gasification allows for an increase in power plant generation efficiency from coal combustion's 35 percent to between 45 and 55 percent. Additionally, CO_2 emissions into the atmosphere can be decreased. The organic and inorganic material goes through a number of physical and chemical transformations during gasification. Ojolo et al. [2] designed and fabricated 11.19 kW laboratory scale updraft gasifier and experiment was carried out by using sawdust and palm kernel shell as feedstock. The fuel properties of the pulverised feedstock samples were examined. The investigation determined that the palm kernel shell and sawdust are appropriate for the developed and constructed updraft gasifier. The gasifier was created to satisfy a wide range of energy demands using materials that were readily available locally. It may be expanded to serve a variety of heating and electricity-generating needs as well as to produce the necessary combustible gases when fuel supplies are inadequate. The sawdust and palm kernel shell performance tests show that these biomass having good potential for gasification. Konda et al. [3] did experiment in updraft fixed-bed-gasifier. Oil palm fronds from Malaysia were to be gasified using a 50 kW updraft gasifier. The gasifier was altered to be extremely adaptable, enabling the air to be fed through a number of sites. The findings of OPF's air gasification revealed volumetric percentages of 22.61–23.36 percent CO, 6.48–6.68 percent H_2, 1.2–1.5 percent CH_4, 9.51–9.65 percent CO_2, and 59.20–58.1 percent N_2. The product gas mixture's heating value ranged from 4.1 to 4.4 MJ/Nm^3, while the gasifier's cold gas efficiency, carbon conversion efficiency, and specific gasification rate were in the range of 57 to 59 percent, 95 to 97 percent, and 103 to 109 kg/h-m^2, respectively. Preetha Devi and Kamaraj [4]designed a pilot scale updraft gasifier by using various biomass as feedstock such as wood chips, coconut husk etc. at used weight of 30kg. During the actual operation of the gasifier, the air flow rate was the most crucial factor. Due to high velocity of incoming air and activated reaction in the combustion and reduction zones, the gasifier was able to produce high energy release rates. It was discovered that the gasification temperature and operating conditions are directly affected by the air flow rate. The temperature of the oxidation zone rose sharply from 600°C to 1025°C, the air flow rate increased from 21 to 28 m^3/h, and the gasification intensity rose significantly from 98 to 456 kg/h-m^2, proving that the temperature of the combustion zone could accurately reflect the intensity of the gasification process. Yang [5]did experiment on high ash content inferior coal for gasification and kinetic characteristics under CO_2 atmosphere. Here, the gasification of one subpar coal was experimentally evaluated in relation to heating rate and particle size. In this study, a thermo gravimetric analyzer was utilised to examine Chongqing Nantong (NT) coal, which possess high amount of ash. They come to the conclusion that decreasing coal particle size and increasing heating rate can improve gasification reactivity. Additionally, coal ash contributes somewhat as a catalyst to gasification. It was also shown that raising the ash-to-coal weight ratio from 1:2 to 2:1 will greatly speed up the reaction rate. Chavan et al. [6]worked onhigh ash Indian coals in fluidized bed gasification under different operating conditions. Studies were conducted with selected coal samples and bed temperature was maintained in the range from 725°C to 1000°C. Air/coal ratio was varied between 1.5–2.4 Nm^3/kg of coal and steam/coal ratio was varied between 0.2–0.6 kg/kg of coal. They conclude that HHV of the product gas increases with volatile mater and fixed carbon, whereas decreases with mineral matter, air and steam. But in case of temperature, initially HHV increases, passes through maximum and then decreases. On the other hand, it was found that carbon conversion increases with volatile matter, air, steam and temperature, whilst decreasing trend was observed with the fixed carbon.Vajpeyi et al. [7]did experiments on high ash content Indian coals. The gasification of coal samples obtained from two distinct mines in the Singrauli coal fields, India, has been studied in terms of the impacts of temperature, particle size, steam/coal ratio, and coal quality. They draw the conclusion that the quality of the coal is crucial in boosting steam decomposition because higher ash content coal showed a higher rate of steam decomposition. Because of the contaminants in the ash, the rate of gasification increases with increasing steam decomposition. Maniatis [8] developed a fluidized bed gasifier for biomass gasification. He developed a design methodology for fluidized bed gasifier. During the experiment it was found that equilibrium gas composition reached at 900°C and 775 to 825°C temperature range provided satisfactory results in terms of gas composition. Air factor was one of the most critical parameters. Robert Ryan Mota [9] designed and developed a fluidized bed gasifier by using lignite coal as feedstock. Fluidization parameters were calculated and designed gasifier was constructed. Due to impurities present in lignite coal, bed agglomeration found during gasification reaction. Some researchers ware design methodology of down draft, updraft as well as fluidized bed gasifier [13,15,16,17,18]. Moreover, kinetics of gasification mechanism and Hydrogen reactivity and methane conversion rate were also studied by various researchers [14, 19]. There has been scope of research in design of a novel gasifier which is viable for wide variety of feedstock. In this regards, the present study focuses on design of a novel hybrid gasifier for high ash content coal. The designed gasifierwas developed and test run carried out by using high ash content Indian coal at site. Experiments were carried out which provides the satisfactory result and validates the novel design.

2. DESIGN PROCEDURE FOR HYBRID GASIFIER

Designing a gasifierinvolves determination of physical dimensions like diameter, height, etc.. Here rather than selecting the existing gasifier, an attempt was made to design a novel hybrid gasifier. A pilot scale Hybrid gasifierwas designed for experimentation purpose. Gasifierwas designed considering high ash content Indian coal as feedstock. Ultimate analysis of high ash content India coal is shown in table 1.

TABLE 1:- Ultimate analysis of coal

Constituents	**% by Weight**
Carbon (C)	29.27
Hydrogen (H)	3.09
Nitrogen (N)	0.77
Sulphur (S)	0.45
Oxygen (O)	21.23
Moisture	6.75
Ash	39.83

Optimum equivalence ratio, syngas composition and syngas calorific value are obtained from the equilibrium model developed during the research work.

During research work MATLAB code has been developed for equilibrium model and is run for such coal to obtain gas composition, calorific value at different equivalence ratio [12]. Maximum calorific value of syngas is generated at 0.405 equivalence ratio. The composition of syngas is shown in table 2.

TABLE 2: Composition of syngas

Equivalence ratio **(Φ)**	0.405
Carbon Monoxide **(CO)**	20.26%
Carbon Dioxide **(CO_2)**	7.72%
Hydrogen **(H_2)**	14.36%
Methane **(CH_4)**	0.35%
Nitrogen **(N_2)**	52.67%
HCV of Syngas	4532.24 kJ/Nm^3
Gas Yield	2.18 Nm^3/kg

Certain assumptions have been made for the design of the gasifier which are listed below

- Fuel consumption rate **(FCR)**was assumed to be 30 kg/hr
- Specific gasification rate **(SGR),** the recommended SGR values falls in the

range of 150-250 kg/hr-m^2. **SGR**was assumed to be 200 kg/hr-m^2.

Reactor Diameter (D_s): It defined the size of a reactor in terms of cylinder diameter where fuel wasgasified. The reactor diameter was calculated by using equation 1[10].

$$D_s = \sqrt{\frac{4 \times FCR}{SGR \times \pi}} \qquad \text{equation 1}$$

$$= 0.437 \text{ m}$$

$$\approx 0.45 \text{ m}$$

The power output is depending on reactor size; bigger diameter reactor can accommodate more fuel and produce more energy.

Height of a Reactor (H): This defined how long would the gasifier be operated in one loading of fuel. The reactor Height was calculated by using equation 2 [10].

$$H = \frac{SGR \times T}{\rho_f} \qquad \text{equation 2}$$

$$= 1.5 \text{ m}$$

Where,

T = Required time to operate gasifier

= 6 hr (Assumed)

ρ_f = 800 kg/m^3 (Assumed)

Time require to consume the fuel: Here total time required to completely gasify the fuel inside the reactor was determined. T is a function of fuel density (ρ_f), reactor volume (V_r) and fuel consumption rate (FCR). This can be computed by using equation 3 [10].

$$T = \frac{\rho_f V_r}{FCR} = 6.35 \text{ hr} \qquad \text{equation 3}$$

Selection of Particle size: Optimum ratio of shell diameter to particle diameter was 4.5 to 6.5 [11].

$$\frac{D_s}{d_p} = 4.5 \; to \; 6.5$$

Select

$$\frac{D_s}{d_p} = 6$$

$$d_p = 75 \; mm$$

Selection of nozzle orientation: Optimum nozzle orientation with respect to radial direction is θ_N = 45^0 to 60^0 [11].

Determination of Air flow rate (AFR):

It can be determined from the optimum equivalence ratio

$$\emptyset_{opt} = \frac{[m_a/m_f]act}{[m_a/m_f]st} \qquad \text{equation 4}$$

To get the AFR, stoichiometric air fuel ratio need to be calculated first. The calculated value of stoichiometric air fuel ratio was 5.5082.

Now, Air flow rate (AFR)

$$\emptyset_{opt} = \frac{[m_a/m_f]act}{[m_a/m_f]st} \qquad \text{equation 5}$$

$$0.405 = \frac{[m_a/m_f]act}{3.5608}$$

$$m_a = 43.26 \text{ kg/hr}$$

$$Q_{air} = \frac{m_a}{\rho_a}$$

$$Q_{air} = \frac{43.26}{1.293}$$

$$= 33.46 \text{ nm}^3/\text{ h}$$

Selection of Number of Nozzle: For a good swirling flow, number of nozzle selected is 5[11].

$$N_N = 5$$

Determination of Nozzle diameter: To calculate the nozzle diameter, optimum velocity of air must be determined. Usually values of optimum velocity of air range from 6 to 8 m/s [11]. For hybrid gasifier, this value would be 20-30% more for partial fluidization.

So optimum velocity of air is selected as 10 m/s. u_a = 10 m/s.

Now, $Q_{air} = N_N \times \frac{\pi}{4} d_N^2 \times u_a$ equation 6

d_N = 0.0196 m

= 20 mm

Selection of Reduction zone bed height: [11]

$$\frac{H_r}{D_s}] = 1.5\ to\ 2.5$$

Select $\frac{H_r}{D_s}] = 2.5$

$$H_r = 1.125\ m$$

Selection of Reduction zone diameter: [11]

$$\frac{D_r}{D_s}] = 2\ to\ 3$$

Select $\frac{D_r}{D_s}] = 2$

$$D_r = 0.9\ m$$

In house experimental test setup gasifier was developed and experiments were carried out on it. It was the "Partially Fluidised bed cum Updraft Gasifier" developed by M/s. Gurukrupa MachTech Pvt. Ltd. Figure 1 shows the 2D diagram of hybrid gasifier with dimension on which experiments were carried out.

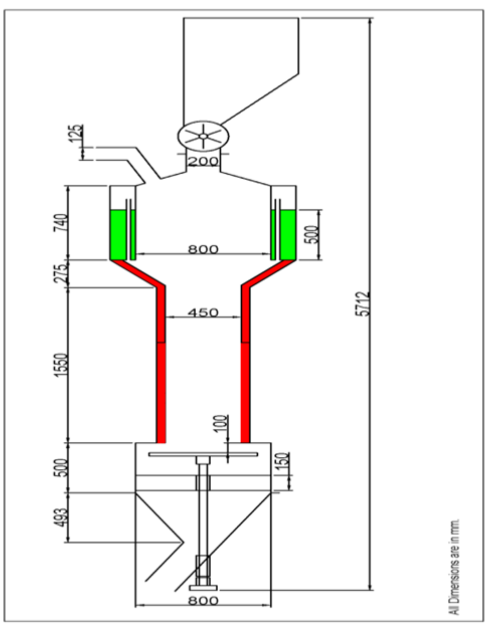

Fig.12D diagram

Series of experiments were conducted on hybrid gasifier set up. During experimentations observations were taken for temperature, flame indication and gas generation rate. All observations were recorded at designed conditions. High ash content Indian coal was used for the experimental work. The proximate analysis of high ash content coal is given in table 3

TABLE 3 Proximate analysis of coal

Fixed Carbon (%)	Volatile (%)	Moisture (%)	Ash (%)
26.01	27.98	6.75	39.83

3. RESULT AND DISCUSSION

Experimental work was carried out with high ash content coal at Morbi site. Operating parameter is tabulated below.

Average Coal Consumption	9.8 kg/hr
Average Gas Generation	29.8 Nm^3/hr
Average Gas CV	4500 kJ/Nm^3

TABLE 4 Experimental conditions

Sr. No	Time	Coal Consumption (kg/hr)	Gas Generation (Nm^3/h)	Gas Temp. (°C)	Reduction Zone Temp. (°C)	Steam Temp. (°C)
1	12:30	9.8	44	115.1	801.2	99.8
2	12:45	9.8	46	127.1	809.4	99.7
3	13:00	9.8	44	135.3	798	99.8
4	13:15	9.8	38	112.7	797.2	99.7
5	13:30	9.8	30	126.4	802	99.7
6	13:45	9.8	45	133.9	794.4	99.7
7	15:05	9.8	40	111.8	773.5	99.7
8	15:20	9.8	41	136.6	770.2	99.7

Experiments were carried out with a feeding rate of 9.8 kg/hr and steam was fed to gasifier at 0.78kg/hr and 100^0C. Temperature against time for product gas outlet and reduction zone as well as steam was computed and is shown in figure 2 and 3. Gas generation rate was also computed against time and is shown in figure 4.

In each set, when experiments were conducted, lighten matches was kept in an exit of chimney to put fire from outlet gas. When gas was burning with flame, it indicates syngas generation inside gasifier. During experiments, self sustained flame at chimney outlet was recorded. Figure 5 show detected flame while performing experiments on hybrid gasifier.

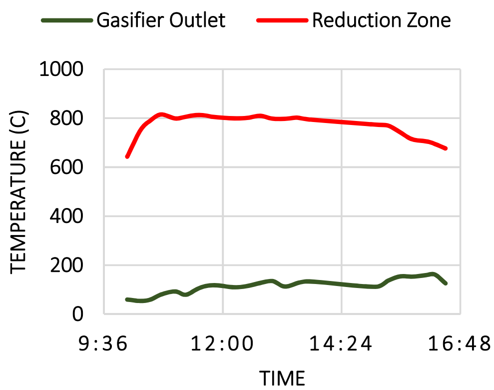

Fig.2Temperature of Gasifier outlet and Reducion zone Vs Time

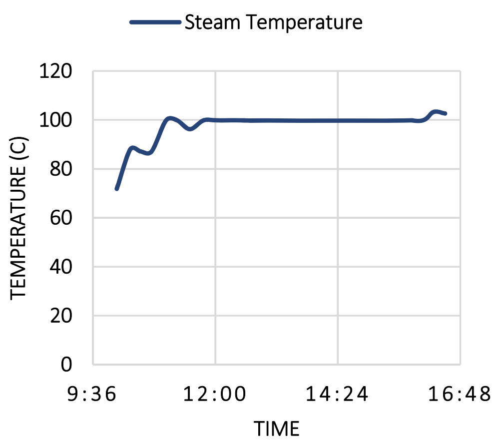

Fig.3Temperature of Steam Vs Time

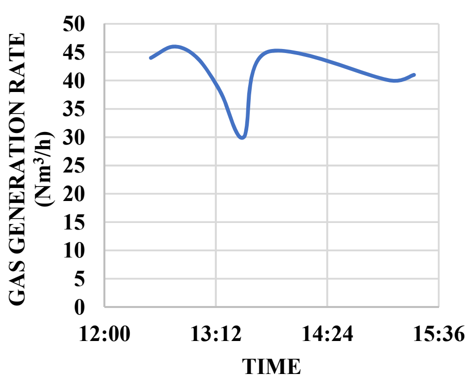

Fig.4Gas generation rate vs. Time

Fig.5Flames from Gasifier

4. CONCLUSION

30 Kg/hr feed capacity novel hybrid gasifier was designed, fabricated and tested in this study with high ash content coal as feedstock. Experiments were conducted on a designed gasifier at the plant site. During the test run, the gasifier performed well and satisfactory results wereobtained. The sustained flame was achieved with high ash content coal which validates the present design of hybrid gasifiers. Temperature inside the gasifier should be less than 1000°C for partially fluidised bed/Hybrid gasifier. During experimental work, temperature was achieved in the range of 700° C – 800° C which validates the design. Experiments ware done with an average feeding rate of 9.8 kg/hr high ash content coal and test show the 29.5 Nm^3/hr of product gas generation with 4500 kJ/Nm^3 heating value.

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