International Journal of Scientific Research in Multidisciplinary Studies
Vol.6, Issue.7, pp.72-76, July (2020)
Research Paper
E-ISSN: 2454-9312
P-ISSN: 2454-6143

Design & Development of Combustion cum Gasification System for Solid Biomass

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Available online at: www.isroset.org

Received: 18/July/2020, Accepted: 24/July/2020, Online: 31/July/2020

Abstract: Biomass resources are the world's largest and most sustainable energy source potential for power generation in the 21st century. Numbers of technologies are available to harness this potential energy from biomass; however, biomass gasification is a promising technology among them. To increase the efficiency and applications of gasification output, modifications have been made in gasification technology.

In continuation of that combustion cum gasification system was designed and developed at the School of Energy & Environmental Studies, Devi Ahilya Vishwavidayala, Indore (MP), India**,** and its performance was evaluated. It was working satisfactorily; however, some problem was noted. Charcoal from the gasification chamber to the combustion chamber was not flowing properly and some interruption in the flue gas pipeline was noted. These problems were solved by creating the proper slope at bottom of the gasifier chamber and providing mild steel (MS) sieve at the outlet of the flue gas pipe. Although the modified combustion cum gasification system gives better performance with medium size biomass (60 x 40 x 30 mm) and gives about 77% cold gas efficiency, however, to be used for industrial application some more systematic study is needed.

Key words: biomass, combustion cum gasification system, biomass size, cold gas efficiency.

I. INTRODUCTION

Biomass resources are the world's largest and most sustainable energy source potential for power generation in the 21st century. About 32% of the total primary energy used in India is derived from biomass and more than 70% of the country's population depends on it for their energy needs. As per one estimate, the current availability of biomass in India is about 500 million metric tons per year. Among that about 120 – 150 million metric tons per annum biomass are surplus, which has the potential of about 17,000 MW electrical power generation [1, 2]. Numbers of technologies are available to harness this potential energy from biomass; however, biomass gasification is a promising technology among them. Gasification has the advantage of low environmental impact, high effective conversion, and reduced global CO_2 emissions [3]. The biggest advantage of the gasifier is its high conversion efficiency up to 80% but it produces tar with producer gas which is the major feedback of the gasifier. To reduce the Tar from the producer gas up to the level of internal combustion (IC) engine quality fuel and different applications of producer gas fuels, numbers of works have been done. In the present study, the hypothesis is made if the combustion zone is separated from the gasifier and flue gas produced from combustion is supplied to the gasifier. It is believed that it may improve the conversion efficiency of biomass.

II. RELATED WORK

Sansaniwal et al 2017 [4] reviewed the recent advances in the development of biomass gasification technology. They suggested that although gasification technologies have been well demonstrated and established by the researchers and the unremitting progress in this direction is also going on but still, incorporation of heat recovery devices, improved tar cracking methods, reuse of bio-char as feedstock, the transformation of ash and tar contents into the value-added products, steam gasification for hydrogen yield, pre-treatment of raw feedstock, etc need to be tried. In connection to that Singh and Dubey, 2019 [5] Developed a gasifier waste heat-based feedstock dryer and reported that it took about 8 to 13 hours to reduce the moisture of biomass up to 12% (recommended moisture for gasification), depending upon the initial moisture content of the biomass. The size of biomass play important role in the drying of biomass. Smaller size biomass took more time than larger size biomass, to reduce the moisture up to the desired limit (12-15% wb), even though the moisture content of the biomass was maintained the same. Singh et al, 2019 [6] also utilized waste heat of producer gas generated from a force-updraft gasifier for the production of low-pressure steam. To harness the heat of producer gas a pipe to pipe counter-flow heat exchanger was designed, developed, and are used for waste heat recovery of producer gas. It was reported that on an average about 3.5 L/h water is converted into low-pressure steam at atmospheric pressure from waste heat of producer gas. Pier et al 2007 [7] designed and modeled an efficient reactor, consisting of two parallel interconnected fluidized bed gasifiers for the gasification of low-density biomass. Here solids circulate through the system as a result of the different fluidizing fluxes maintaining on each side of a partition plate which separates the two beds at their air inlets. A key feature of the design relates to the ability of the circulating solids inventory to carry with it the buoyant biomass particles, thereby opposing their tendency to segregate to the bed surface, and at the same time reduce the elutriation of fine Carbon particle. Both of these conditions favor the yield and quality of the product gas. Loof and Bhattacharya, 1994 [8] experimented concept of two-stage gasification. In which the pyrolysis zone (1st stage) from the reduction zone (2nd stage) was separated. The gasifier has two levels of air intakes, primary air supply at the top section, and secondary air supply in the middle section of the gasifier. The high temperature achieved in the second stage due to the addition of secondary air helps in reducing the tar level (about 50 mg/m^3). It is about 40 times less than a single-stage reactor under similar operating conditions. However, most of the tars were formed during the warm-up period. This could be avoided by filling the gasifier with a bed of char. It almost eliminated the tar formatting during start-up in the reactor.

III. MATERIALS AND METHODS

3.1 Design of combustion cum gasification system

The combustion cum gasification system is an Updraft gasifier in which generated producer gas is also taken from the top zone of the reactor. However, here combustion zone of the reactor has been separated from other zones of the gasifier. Literature [9, 10, 11] indicates that updraft gasifier worked satisfactorily at the reactor length to diameter ratio (L/D) from 1.27:1 to 3.66:1. For keeping the space for further modification in the reactor, 3.66:1 length to diameter ratio was selected. Accordingly, the total length of the reactor was taken as 1095 mm and the diameter as 250 mm. As per the literature, it should be only 950 mm, however more length was taken to accommodate the ash pit of the combustion zone and grate. Grate, which was made of mild steel rod and maintaining the gap between two horizontal rods as 20 mm was provided at 100 mm height from the bottom layer of the combustion zone. In this design, the combustion zone was separated from the main gasifier and connected with two pipelines from the main gasifier (Fig. 1& 2).

The reactor was fabricated with 5 mm thick mild steel, in a local workshop maintaining 360 mm length for the combustion zone and 735 mm of length for the gasification zone (Table1). Further, this combustion and gasification reactor was connected with two pipes. One pipe with 25mm dia. at 30 degrees (from the horizontal) carrying the flue gas generated from the combustion zone and another pipe of 50mm dia. at 60 degrees from the horizontal to feed the charcoal from the gasifier to the combustion zone [12].

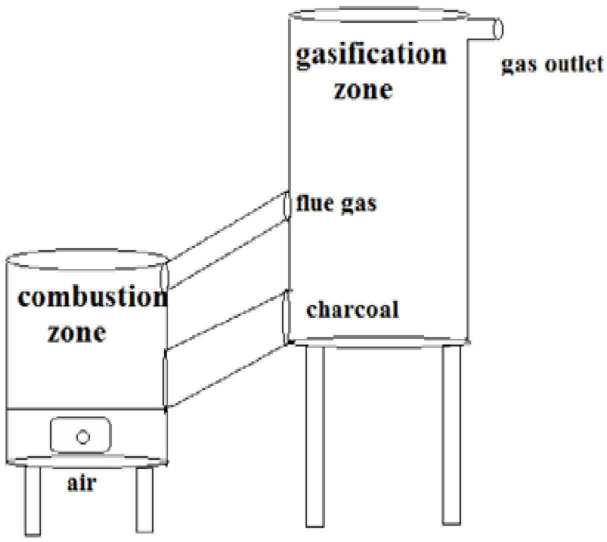

Fig. 1: Schematic of combustion cum gasification system

Fig. 2: Photograph of combustion cum gasification system

One small pipe 12.5 mm diameter was also provided to the combustion zone for the supply of air (Fig.1& 2). Similarly another pipe of 50 mm dia. was provided to take out the generated producer gas from the gasifier. A man whole (75 × 75 mm) was provided in the combustion reactor, which is situated on the opposite side of the air supply pipe. This man whole was used for the removal of ash from the ash pit.

Table 1: Dimensions of combustion cum gasification system

Zone	Thickness	Length
Combustion zone	05mm	360mm
Gasification zone	05mm	750mm
Flue gas carrying pipe	03mm	400mm
Charcoal unloading pipe	04mm	270mm
Gas carrying pipe	03mm	125mm

3.2 Experimental Setup and Measurement

The experimental setup consists of combustion cum gasification system, producer gas piping along with the burner, blower with a control valve for the supply of air to the combustion reactor as a major component. The characteristics of biomass (moisture content, ash content, volatile matter, fixed carbon, calorific value) were carried out as per the ASTM (American Society for Testing of Materials), 1983 standards [13]. For estimation of producer gas and flame temperature K- type thermocouples were used, however for quantifying the amount of producer gas a calibrated orifice plate was used. The energy content of biomass fuel was measure using a bomb calorimeter. However, the Junker gas calorimeter was used to know the energy content of the producer gas. The supply of air to the combustion reactor was control with the help of a pitot tube attached with a flue gas analyzer. To ensure the leakage from the combustion and gasification reactor, it was sealed with asbestos rope and C-clamped. It was further checked by supplying the pressurized air to the empty combustion and gasification reactor.

3.3 System Operation

The combustion cum gasification system was operated as per the procedure prescribed by the Ministry of Non-Conventional Sources of Energy (MNES) [14] followed by Parikh and Arikkat 1985 [15] and Reed and Das 1998 [16]. The performance of the system was evaluated in terms of fuel consumption rate, quality & quantity of producer gas, and flame temperature. Initially, combustion and gasification reactors were loaded with 3.0-3.5 kg charcoal pieces (10–50 mm diagonal length) and 10-12 kg biomass (25-100 mm diagonal length) respectively. In the beginning, the combustion zone lid was open and charcoal was put in the fire. Later, the combustion zone lid was closed and the air was supplied in the combustion reactor with the help of 0.5 hp blower. Generated flue gas from the combustion zone was feed in the gasification reactor. Within 15 minutes combustible gas was received from the gasifier reactor and it was burned in the producer gas burner.

Performance measurements were taken after the stable operation of the system, i.e., constant raw gas temperature. The fuel consumption rate (FCR) was measured by quantifying the biomass loaded in both reactors dived by total operating time. A calibrated orifice plate was used to determine the flow rate of producer gas. The measurement parameters; fuel consumption rate, the temperature at different points of the gasifier reactor, producer gas temperature at the gasifier exit, flame temperature, and calorific value of producer gas were constantly monitored.

IV. RESULTS AND DISCUSSION

The physical and proximate analysis was carried out to analyze the feedstock. The parameters studied included moisture content, volatile matter, and ash content, and energy content of biomass. Fixed carbon (FC) was determined using material balance and energy content was measured through a bomb calorimeter. Data are summarized in Table 2.

Table 2: Thermal properties of feedstock

Parameter	Quantity
Moisture content (M.C.), % wb	10.64
Fixed carbon (F.C.), % db	16.31
Volatile matter (V.M.), % db	70.14
Ash, % db	2.91
Calorific Value, kCal/kg	4140.20

Although the encouraging results were obtained (Fig. 3 & Table 3), however, some problems were also observed. It includes leakage of temperature from the combustion and gasification reactor. Obstacles in the flow of charcoal from the gasification zone to the combustion zone, blockage of flue gas pipe due to charcoal were also noted.

Fig. 3: Working of Combustion cum gasification system

Table 3: Performance evaluation of combustion cum gasification system

Parameter	Temperature Profile, °C
Combustion Reactor	824
Gasification Reactor	
T1 (400mm from bottom)	435
T2 (550mm from bottom)	335
T3 (700 mm from bottom)	231
Producer gas temperature	180
Flue gas temperature obtained from combustion	655
Flame Temperature	800

The above said problems were solved up to a certain extend by providing insulation (Cerawool Blanket & Asbestos Rope) to reactors and flue gas pipeline respectively. Curved shape slope with the help of a mild steel plate at the lower portion of the gasifier reactor was also provided for the smooth delivery of charcoal from the gasifier reactor to the combustion reactor. The placement of 5 mm mesh at the outlet of the flue gas pipeline helped to reduce the blockage of the pipe. The later modified system was again operated. The air-dried wood was collected from the local timber market. To see the effect of biomass size on the performance of the combustion cum gasification system, three sizes of biomass were selected (Random size available in the markets, 60 x 40 x 30 mm, and 110 x 70 x 30 mm). Before feeding the woods in the combustion and gasifier reactor, it was again sun-dried for 2 hours to ensure the desired moisture in the biomass. The study indicates that the combustion cum gasification system gives better performance at uniform and average biomass size (60 x 40 x 30 mm.). At this size of biomass, the cold gas efficiency of the system was 77.12% (Table 4 & Fig.4).

Table 4: Temperature profile of combustion cum gasification system with different size of biomass

Parameter	Size of biomass (Random)	Size of biomass (60 x 40x30mm)	Size of biomass (110x70x30mm)
Combustion Temperature, ˚C	784	810	792
T1 (400mm from)	365	395	383
T2 (550mm from bottom)	341	371	363
T3 (700 mm from bottom)	202	221	218
Gas Temperature, ˚C	135	151	142
Flue gas temperature , ˚C	412	438	426
Flame Temperature , ˚C	766	792	778
Cold gas Efficiency, %	51.42%	77.12%	66.11%

Fig. 4: Working of modified Combustion cum gasification system

Conclusion:

Combustion cum gasification system was designed and developed at the School of Energy & Environmental Studies, Devi Ahilya Vishwavidayala, Indore (MP), India**,** and its performance evaluated. Developed system worked satisfactorily. Being a 1st prototype, some problems were observed during operation. Charcoal from the gasification chamber to the combustion chamber was not flowing properly and some interruption in producer gas generation was also recorded. These problems were solved by creating the proper slope at bottom of the gasifier chamber and providing MS sieve at the outlet of the flue gas pipe. Although the modified combustion cum gasification system gives better performance with medium size biomass (60 x 40x30mm) and the cold gas efficiency of the system was 77%, however, to be used for industrial application some more systematic study is needed.

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