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Design and Development of Portable 5 kW_e Capacity Producer Gas Engine Based Electric Generation System for Rural Applications

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Abstract— In a country like India, agricultural residues are in abundance, and availability of biomass is not a problem, and can be utilized for power generation. Among the different rout available for conversion of biomass, thermo chemical conversion especially gasification seem to be more reliable. However most of the works in gasification technologies are focused on development of large system and very little efforts had been made for the development of a portable and small capacity gasifier (1 kWe to 10 kWe gasifier). A portable gasifier system for producing electricity was designed and developed to deliver an electrical power of 5kWe using 100% producer gas engine. The system consists of gasifier reactor, two cyclones (one for removal of particulate matter, other for moisture), one wet scrubber, two filters (one biomass and other jute/fabric); 12HP 100% producer gas based IC Engine with alternator capacity of 6kWe and a solar backup system for initial start of blower. Whole setup is arranged in a transportable lorry for easy transportation as per the need of farmer requirements. Functionality test was carried in the lab, however actual performance would be tested for agricultural operations like pumping and community lighting.

Keywords— Gasifier; producer gas; cyclones; wet scrubber; 12HP 100% producer gas based IC Engine

I. INTRODUCTION

Combustion is the most important invention of the mankind, which starts of the use of thermal energy, useful for cooking, heating, drying, and many other comfort applications. Literature indicates that 80% of all form of energies used by humans comes from fossil fuels [1]. India is fortunate to have surplus biomass, which fulfill the energy demands of about 32% Indians [2]. Conversion of energy stored in the biomass for various applications can be accomplished by combustion, gasification and pyrolysis. Combustion is simply a reaction process of carbon hydrogen with stoichiometric oxygen i.e. conversion of all carbon into carbon dioxide, and hydrogen to water.

Gasification is nothing but decomposition of solid fuel under a sub-stoichiometric oxidizing condition; however, Pyrolysis of solid fuel takes place in absence of oxidizing media. The end product of gasification is producer gas (85%), Char (10%) and liquid (5%). In a country like India, agricultural residues are in abundance, and availability of biomass is not a problem, and can be utilized for power generation. Study conducted by Pathak et al, 2005 [3] showed that total estimated biomass generated is of the order of 1000.17 MT out of which nearly 523.44 MT (52.33%) is agricultural waste, 272.62 MT (27.25%) is livestock dung including poultry liter and 157.18 MT (15.71%) is forest residue, remaining 4.71% are biomass waste generated in wasteland and roadsides. As per estimate these surplus agricultural wastes, can generate more than 16,000 MW of power with presently available technologies.

As per MNRE, 2020-21 contribution of Renewable Energy in total Installed Capacity of Power in India is 87669.19 MW or 23-63% [4], in which gasifier share is about 75.85MW.

And hence gasifier seems to be one of the promising equipment for conversion of energy in biomass to power for various applications. Gasifires are the equipment which is used for producing heat and power with very low environmental hazards. Government of India through Ministry of New and Renewable Energy is supporting entrepreneurs, individual and farmers to set up power projects based on biomass gasification of the order of few Mega Watts particularly in those states which have biomass potential is high. Major beneficiaries are population residing in remote and rural locations. However, the focus on developing and supporting small power generation of the order of 1 kWe to 10 kWe is less compared to bigger units. Most of the works in gasification technologies are focused on development of large system and very little efforts had been made for the development of a small 1 kWe to 10 kWe gasifier. The design parameters for such gasifier has not been studied and developed. Also developed gasifier has not been tested for engine coupled system which could be used for irrigation and community lighting in remote areas. Although different types of gasifires are available in the markets, however for engine application downdraft gasifier are more suitable as it can generate almost clean gas, which could be used in IC engine as such after cooling [5].

II. RELATED WORK

Numbers of gasifires has been design, developed and make in use for power generation [5]. Yoshikawa 2007 developed a portable updraft gasifier for electrification of rural area. Carbonized and crushed biomass was converted into briquettes and latter used into gasifier to produce syngas. This syngas was cleaned for Tar and SPM and supplied into 30 kWe gas engine. For sustainability of system, its mass balance and energy balance was analyzed and found satisfactory up to certain limit [6]. Littlejohns et al 2017 experimented wood chips in downdraft gasifier. It is being claim that by dividing the gasification air in two parts primary (85%- 100%) and secondary air (0%-15%), calorific value syngas could be increased. They worked on 10 kWe pilot scale gasifier. Landfill diverted wood wastes were used as a feed stock for gasification. Based upon the study they developed empirical correlation between Tar production and feedstock bulk properties [7].

Critical analysis available literatures indicate that most of gasifier for power generations are working at stationary mode and not fit for the application of Indian formers. As majority of Indian formers have small land holding and during the pick of agricultural operation [3]. Considering that effort was made to Design and development 5 kW_e producer gas based portable electric generation system.

III. MATERIALS AND METHOD

Experimental setup of portable 5 kW_e capacity producer gas engine based electric generation system consists of below mentioned components. Design of each component is carried our separately and is arranged on portable lorry so that it can be moved as per the need of applications.

- 5kWe downdraft gasifier reactor
- Cyclone (two number), one for removal of soot particle and other one is for removal of moisture from the producer gas
- Wet scrubber
- Dry filter
- Producer gas IC engine
- Solar Backup for initial startup of blower

3.1 Design of Gasifier

Design of gasifier depend on final output required this can be in terms of thermal output or it can be electrical output especially gasifier designed for power applications like pumping or power generation. But these are largely empirical. Design of gasifier is carried out partially through computations and partially using empirical relations, experience or some experimental data available.

In case of down draft gasifier technical challenges was faced and looked upon seriously are long residence time, temperature distribution, low productivity and high char or tar contents in the producer gas. Gasifier reactor diameter is the most critical parameter for the design of throat less gasifier. Mostly gasifires are designed either considering Specific Gasification Rate (SGR) or Kinetic mode l [8, 9, 10. Here SGR approach was used to design the gasifier reactor. Initial data assumed for designing the gasifier are tabulated in Table 1. These assumptions are based on literature and research experience of authors.

Table 1. Assumption made for designing of gasifier

S. No.	Parameters	Values
1	Final out put required	5 *kWe*
2	Efficiency of gasifier	70%
3	Specific gasification rate	200 $kg/\ hr\ m^2$
4	Bulk density of dried biomass	350 kg/m^3
5	Biomass consumption rate to generate 5 *kWe @1.25 kg per kWe*	6.25 kg/h
6	Considering the smooth operation, efficiency and safety factor, Biomass consumption rate to generate 5 *kWe was considered as*	8 *kg/hr*
7	Producer gas generation rate, @ 2.5 Nm^3*per kg of biomass*	20 Nm^3/h
8	Considering calorific value of biomass	2500 *kCal/ kg*

Cross sectional area of the gasifier reactor can be calculated using the relation suggested by Kauppa and Goss, 1989 [11].

Specific gasification rate

$$(SGR) = \frac{\text{Weight of biomass to be gas}}{\text{Cross Sectional Area of the G}}$$

Considering cylindrical shape reactor, area of gasifier reactor **(A_r)** would be $(\pi / 4) \times D_r^2$

Where D_r = Gasifier reactor diameter

Therefore, $D_r = \{(8 \times 4) / (200 \times \pi)\}^{½} = 0.2256m \approx 9$ inches

To make the system portable, height of gasifier reactor (H_r) was restricted only 0.61 m or 24 inches. This is sufficient to run the gasifier for more than hours. As the gasifier reactor is designed keeping in mind for agricultural operation such as water pumping, oil extraction, grinding of flour est. the gasifier reactor has to continuously run for minimum 8 hours. Hence remaining hour's backup of the dried biomass is fed in the hopper.

The air flow rate requirement has to be maintained uniformly within the combustion zone hence 6 air nozzles of diameter 1 inch (0.0254 m) each were kept at a distance of 6 inch apart along the periphery of gasifier reactor. These air nozzles were kept 6 inches [0.15 *m*] above grate. Height of the nozzle plane is calculated from the graph as suggested by the Swedish Academy of Engineering Sciences, FAO 1984 and taking the superficial velocity as 0.4 m/sec [12, 13, 14]. Considering the above dimensions, gasifier shell was made of 5mm Mild Steel [MS] sheet

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(outer body), layered with 1.5 inches or 38 mm thermal resistant cement (ACC fire grade cement). Although the system looks like one single unit but virtually it consists of three different zones, which would be integral part of the gasifier. This main gasifier section is cylindrical in shape. Other than the cylindrical shell main gasifier body, a frustum of right circular cone shaped hopper is mounted on the top of the main unit. This will make the gasifier reactor in two different parts one is main gasifier body other is hopper to store extra biomass. Details dimensions of gasifier reactor is Tabulated in Table 2. It was fabricated using 5 mm mild steel.

Table 2. Dimensions of gasifier reactor

S. No.	Parameters	Values
1	Gasifier reactor diameter (D_r)	0.2286 m or 9 *inch*
2	Height of Gasifier reactor (H_r)	0.6096 m or 24 inch
3	Number of Nozzle	6
4	Nozzle Diameter	0.0254 m or 1 inches
5	Placement of nozzle above the grate	0.1524m or 6 inches

3.2 Design of Cyclones

The cyclone is the element of cleaning mechanism of the dust loaded gas. It collects fine carbon dust and removes it from the loaded gas. Due to high velocity of loaded gas, cyclone acts as cooling device and reduces temperature of gas up to 150°K, depending on inlet temperature of the cyclone [15]. High efficiency cyclone was selected and standard procedure was used for designing of cyclone [16]. Before fabrication of cyclone it was insured that velocity of producer gas entering to the cyclone inlet should be equal to the superficial velocity of the reaction zone (0.4m/s) within permissible limit (5-10% less than the superficial velocity of gasifier reactor). Details dimensions of cyclone is Tabulated in Table 3. It was fabricated using 2 mm mild steel.

Table 3. Dimensions of Cyclone

S. No.	Parameters	Values
1	Diameter of cyclone (D_c)	0.1905 m or 7.5 *inch*
2	Diameter of inlet of cyclone (D_{ic})	0.0375m or 1.5 inch
3	Diameter of outlet of the cyclone (D_{oc})	0.0375 m or 1.5 inches
4	Height of the main body of cyclone	0.254 m or 10 inches
5	Height of the lower (tapered) body of cyclone	0.4572m or 18 inches

3.3 Design of Wet Scrubber

From the literature and the experience of authors it was observation that the retention time of producer gas with the scrubbing medium and the velocity of producer gas entering to wet scrubber is the most important parameters in designing a wet scrubber. Assumptions and calculation made during designing of wet scrubber is tabulated in Table4.

Table 4. Assumption and calculation made during designing of wet scrubber

S. No.	Parameters	Values
1	Retention time (RT) of producer gas in the scrubber	3 Sec
2	Bed Height of wet scrubber (H_{ws})	0.9144 m or 36 inches
3	Velocity of producer gas in wet scrubber (V_{pgw})	0.30 m/sec (0.9114 /3)
4	Gas flow rate in the wet scrubber	40 m^3 /h
5	Diameter of Wet scrubber	0.217 m or 8.55 inches ≈9 inches
6	Bed Height of wet scrubber (H_{ws})	0.9144 m or 36 inches

3.4 Design of Dry Filter

Retention time and velocity of producer gas entering in the filter play a vital role in design of filter. These retention time and velocity depends on the type of material used in filters. Based upon the experience of authors, data available in the literature it was observation that optimum retention time in a dry filter should be in the range of 6 to 10 sec. Methods suggested by Punjab Agriculture University, Ludhiana during the study of filtration [17] was used for calculation of dimensions of filters. Assumptions and calculation made during designing of dry filter is tabulated in Table 5. As the designed system of 5 kWe is modular and it was made potable (fitted in the trolley), thus to make the system safe and compact, the required diameter of the filter was divided in two parts (15 inches diameter each). One filled with biomass and other one filled with sand.

Table 5.Assumption and calculation made during designing of dry filter

Sr. No.	Parameters	Values
1	Retention time (RT) of producer gas in the dry filter	10 sec
2	Bed Height of filter (H_f)	0.254 m or 10 inches
3	Velocity of producer gas in filter (V_{pgf})	0.0254 m/sec (0.254/ 10)
4	Producer gas flow rate in the dry filter	40 m^3 /h
5	Velocity of producer gas (V_{pgf})	0.0254 m/sec
6	Diameter of filter (D_f)	0.74 m or 30 inches

3.5 Producer Gas Engine and Alternator

A 12 HP 100% gas engine was fitted with the gasifier system after the cleaning and cooling of the producer gas. Fig.1 shows the schematic of designed system A 6 kW alternator will ensure the production of electric power, which will be further utilized for pumping or community lighting.

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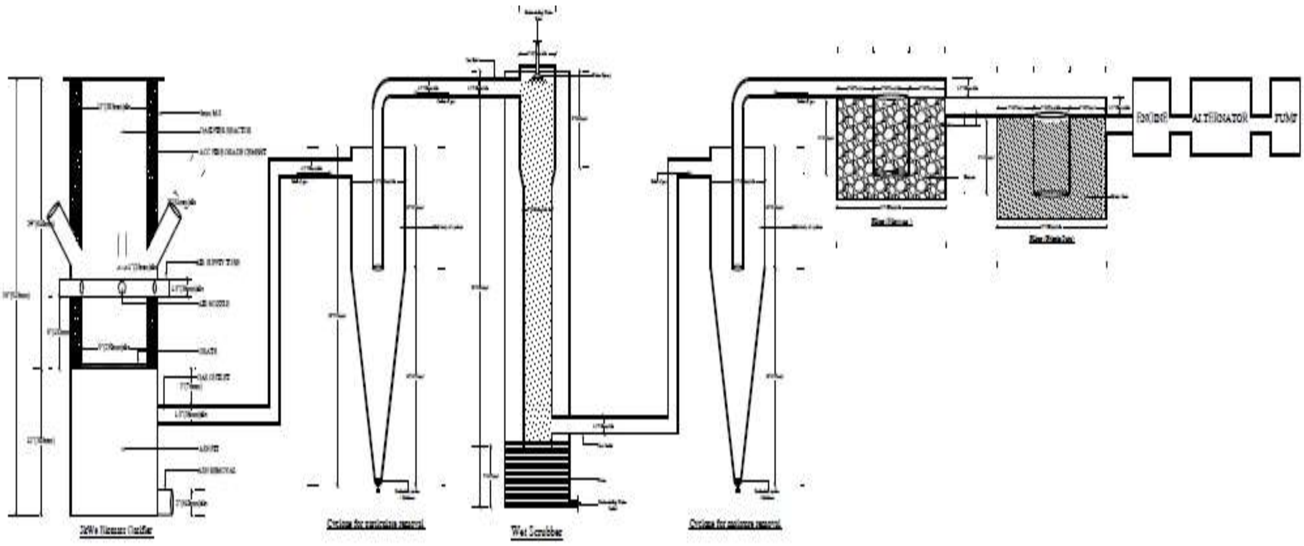

Fig.ure1. Schematics of 5kWe Biomass Based Power Generation System

Latter all the components are assembled on a trolley for easy transportation from one place to another place (Figure 2).

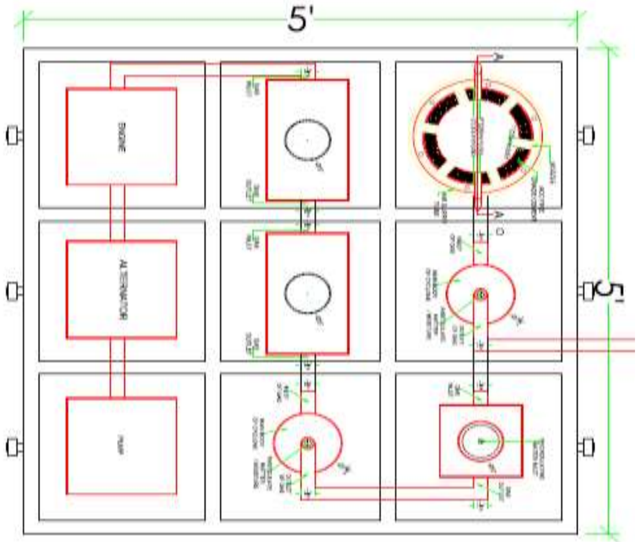

Fig.2. Top View of the experimental set up fitted in trolley

IV. CONCLUSION

A portable 5kWe gasifier system for producing electricity was designed and developed to deliver an electrical power by running 100% producer gas engine. The system consists of gasifier reactor, two cyclones (one for removal of particulate matter, other for moisture), one wet scrubber, two filters (one biomass and other jute/fabric); 12HP 100% producer gas based IC Engine with alternator capacity of 6kWe and a solar backup system for initial start of blower. Whole setup is arranged in a transportable lorry for easy transportation as per the need of farmer requirements. Functionality test of complete package was carried in the lab; however actual performance would be tested for agricultural operations like pumping and community lighting.

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REFERENCES

[1] S. Chopra and A. A. Jain, “Review of Fixed Bed Gasification Systems for Biomass”, CIGR e-journal, Invited Overview No. 5, **Vol. IX , 2007.**

[2] R. N. Singh, Shashank Jain and Ashish Kumar, “Design & Development of Combustion Com Gasification System for Solid Biomass” International Journal of Scientific Research in Multidisciplinary Studies, **Vol.6, issue, 7, pp: 72-76, 2020.**

[3] P S Pathak, T A Khan, P Sharma, “Biomass production its utilization and surplus for energy generation in India. In: Biomass management and energy purposes- Issues and strategies”, Editors B S Pathak , N S L, Srivastava, “Technical publication No. SPRERI/2005/2”, Sardar Patel Renewable Energy Research Institute, Vallabh Vidyanagar (Gujarat), **10-35, 2005.**

[4] MNRE, “Programme/Scheme wise Physical Progress in & Cumulative upto Jan, 2021” Ministry of New and Renewable Energy, Gov. of India physical-progress, **2020-21.**

[5] J. Rezaiyan and N. P. Cheremisinoff, “Gasification Technology, A Primer for Engineers and Scientist”, CRC Press, Taylor & Francis Group, Boca Raton, **2005.**

[6] Kunio Yoshikawa, “Development of portable ultra-small biomass gasification and power generation system” 5th World Bioenergy Congress and Expo held on June 29-30, 2017 at Madrid, Spain

[7] J. V. Littlejohns, J. Butler, L. Luque and Kevin Austin. “Experimental Investigation of Bioenergy Production from Small-Scale Gasification of Landfill-Diverted Wood Wastes”. Waste Biomass Valor 11, **pp: 6885–6901, 2020.**

[8] C. Pfeifer, Hofbauer H. “Development of catalytic tar decomposition downstream from a dual fluidized bed biomass steam gasifier”. Powder Technology; **108:9-1, 2008**

[9] A. K. Jain “Design Parameters for a Rice Husk Throat less Gasifier”. Agricultural Engineering International: the CIGR Ejournal, Manuscript EE 05 012. **Vol. VIII , 2006.**

[10] A. K. Jain, S. K. Sharma, and D. Singh, “Reaction kinetics of paddy husk decomposition”, Jr. of Solar Energy, Engineering, ASME, **Vol. 121, pp: 25-32, 1999.**

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[11] A Kauppa and R Goss "Small Scale Gas Producer Engine System" Published by Friedr, Vieweg & Sohn Braunschweig/ Wiesbaden, **1984.**

[12] S. A. Channiwala and P. P. Parikh, "Development of a 15 kW (Shaft Power) Downdraft Experimental Research Gasifier", Proc. 1st National Meet on Recent Advances in Biomass Gasification Technology, IIT Bombay, **1989.**

[13] S. A. Channiwala, "On Biomass Gasification Process and Technological Development Some Analytical and Experimental Investigations" Ph. D. Thesis, IIT Bombay, **1992.**

[14] S. A. Channiwala, K. B. Patel, J. K. Ratanadharia, "Design and Development of tar free gasifier", 4th international Conference on Mechanical Engineering, Dhaka, **pp: I 1-6, 2001.**

[15] S. Dasappa, U. Shrinivasa, B. N. Bagla and H.S. Mukunda, "Five kilowatt wood gasifier technology: Evolution and field experience", Sadhana, **Vol. 14, Part 3, pp 187-212, 1989.**

[16] Anon, "Tar reduction in producer gas", Biennial Report, AICRP on RES for Agriculture and Agro based Industries, School of Energy Studies for Agriculture, PAU, Ludhiana, February **13-16: 3-9, 2002.**

[17] A. K. Jain, S. K. Sharma, and D. Singh, "Development of a kinetic model for designing throat less gasifier", Indian Chemical Engr, Section A, **vol. 44, issue 4, pp: 232-240, 2002.**

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He is life member of 4 society engaged in Energy & Environment. Guided 7 Ph.D. and more than 70 PG students. 7 Ph.D. research scholars are continuing. He was also member of Executive Council of DAVV and Dean of Faculty of Engineering Science. Presently working as a Prof. & Head at Energy and Environmental Studies, Devi Ahilya Vishwa Vidyalaya, Indore. Prof. Singh has more than 28 year experience in Teaching & Research. His area of interest is Bio-fuel, Biomass, biodiesel, bio ethanol and Renewable Energy. He is chief Editor of Progress in Energy & Fuel and Editors of some journals. He published more than 100 research papers in journals of repute.

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