Operational Experience of Agro-residue Briquettes Based Power Generation System of 100 kW Capacity

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Abstract-A crop residue gasification based power generation system was developed at Sardar Patel Renewable Energy Research Institute (SPRERI). The performance of the gasifier alone and the whole power generation system was evaluated using selected crop residues briquettes as fuel. Short duration experiments were carried out using selected crop residues briquettes of 40, 55, 57 and 60 mm diameters. Based on experimental findings, sequential modifications were done in the system to improve its performance as well as the ability, to be operated for longer duration, continuously. Thereafter, a continuous 50 h operation of the system was also carried out to understand the effect of various operating conditions on gasification process. The gasifier performance was found most acceptable with 40 mm diameter briquettes.

Keywords-Crop residue briquettes gasification, clinker formation, producer gas cooling and cleaning, engine efficiency

1. Introduction

Recent estimates states that the total agro-residue availability in India is more than 500 million MT/ annum. Around 20-25 % of it is available for being used as energy purposes [1]. The balance is used as fodder for livestock and other social needs. Low bulk density of the agro-residues (200 to 500 kg/m^3) makes their transportation and storage very expensive. This problem can be overcome by designing a distributed energy or power generation and utilization schemes. Besides, the issue of high ash contents and lower melting point of the ash due to presence of potassium and sodium oxides makes the combustion and gasification of crop residues difficult and results the problem of ash fusion inside the gasifier reactor. It has been brought out that the ash fusion temperature measured by standard tests can only provides the indication of the clinker formation behaviour of the crop residues [2]. When there is an air flow through a rice husk combustion bed, the particles fuse when the superficial velocity exceeds about 10 cm/s even when the average bed temperature was well below the ash fusion temperature. Therefore, an experimental study for investigation of the gasification behaviour of crop residues briquettes would give more realistic data about the suitability of any crop residue for gasification. Under National Agricultural Innovation Project, sponsored by Indian Council of Agricultural Research, SPRERI has developed an open core, throat-less, downdraft gasifier of 1800 MJ/h capacity for gasification of briquettes of crop residues. Short duration performance evaluation of the gasifier using selected crop residue briquettes of various sizes has been carried out at SPRERI and the gasification efficiency up to 69 % has been reported [3]. At present the gasifier and producer gas cooling & cleaning system has been integrated with a 100% producer gas based engine gen-set of 100 kW capacity. Present paper shares the experience of long duration performance evaluation of the gasifier, producer gas cooling & cleaning system and engine gen-set using various type and size of crop residue briquettes.

2. Materials and Methods

2.1. System Description

The 100 kW capacity biomass gasification based power generation system consisted of open core, throat less down-draft gasifier, producer gas cooling & cleaning sub system, a

100 % producer gas based engine gen-set and resistive load bank. The schematic arrangement of the system is shown Fig. 1 and System description with technical details of various components of the system are given in Table 1. The air for the reaction is primarily drawn from open top of the gasifier reactor. Besides, the reactor shell has been provided with six tuyers (air nozzles) for supply of supplementary air in the combustion zone. The grate area has been designed for fuel consumption rate (FCR) as 150 kg/h and SGR as 200 kg $h^{-1}m^{-2}$.

2.2. Fuel Preparation

Briquettes of saw dust, sugarcane baggase, cotton stalk and pigeon pea stalk were produced using piston press briquetting plant of 500 kg/h production capacity. The briquetting machine had been procured from M/s High Tech Agro Processing Ltd, Faridabad (India) for production of biomass briquettes of 55 mm diameter. Briquettes of 25 mm and 35 mm diameters were also produced by incorporating minor modifications in that machine [4]. The throughput of the machine was found reduced with decrease in diameter of the briquettes. Soybean stalk briquettes of 57 mm diameter were received from CIAE, Bhopal (India) and briquettes of 40 mm diameter made using 1:1 mixture of cotton stalk and pigeon pea stalk were received from TNAU, Coimbatore (India). Sugarcane baggase briquettes of 60 mm diameter were procured from a commercial firm, M/s Shri Dwarkesh Bio-fuels, Vadodara (India).

Table 1. Specification of the power generation system

Component Name	Purpose/Description
Biomass gasifier system	
Reactor type	Open core, throat-less, downdraft
Grate	Area 0.75 m^2 , rotated elecrtically for ash removal
System output	Upto 1800 MJ/h (500 kWth)
Fuel feeding	By belt conveyor, upto 150 kg/h
Gas discharge	Centrifugal blower, 400 m^3/h at 800 mm WG (Suction mode)
Producer gas cooling and cleaning (C & C) system	
Cyclone - 1	Collected bulk of SPM contents of PG.
Twin spray towers	Reduce tar and SPM contents of the PG. Bothtowersconnected in series. Each tower provided with 8 nos. Spray nozzles. Second tower partially packed with SS raschig rings
Cyclone - 2	Collectedcondensedmoistureand SPM present in PG stream
Charcoal filter	Filter media waste char obtained from gasifier ash bin. Absorbed residual moisture, tars & SPM in PG
Wood shavings filter	Further reduced the tar & SPM content of PG
Organic filter	Producer gas stream first passed through a bed of fine wood shavings. Thereafter, the stream got splits into two streams and each passesed through a bed of sawdust.
Fabric filter	Installed just before engine gen-set as safety filter. Ash particle larger than 2 micron size got traped in the fabric cloth.
100% producer gas based engine gen-set	
Model, Make	Cummins , GT-855G
Capacity/speed	100 kW, 1500 for 50 Hz frequency of current
Resistive load bank	
Make	Allied Electrical Industries, Vadodara, Gujarat
Type	Rheostat type loads
Load switches	1, 2, 3, 4 and 10 kW
Panel cooling	Three exhaust fans
Display	Amp.,Volts and kWh

2.3. Operation and Experimentation

The gasifier was operated as per the procedure prescribed by Ministry of Non-conventional Energy Sources [7]. Initially charcoal pieces (25-35 mm diameter, 20-50 mm length and around 80 kg mass) were loaded in to the reactor up to the tuyer level. For quick ignition some loose biomass such as wood shavings, dry leaves etc. were loaded up to a bed height of around 15 cm. Thereafter, the fuel briquettes were loaded up to around three-forth height of the reactor. The starting blower was put-on first and the gasifier was torched by holding a flame at the air tuyers, one by one. Within 10-15 minutes, the gas flare started at starting burner. As soon as the flame at the starting burner got stabilized, the gas was transferred to the main burner. Only after ensuring that the gas flow rate was consistent and flame at main burner steady, the gas was allowed to flow into the engine gen-set. Both, starting blower and main blower lines had been provided with globe valves to control the gas flow rate. The gasifier reactor had been provided with a ladder and platform to facilitate poking of the fuel bed to break bridging of the fuel in the reactor, as and when necessary. The schematic diagram of the experimental setup is given in Fig. 1.

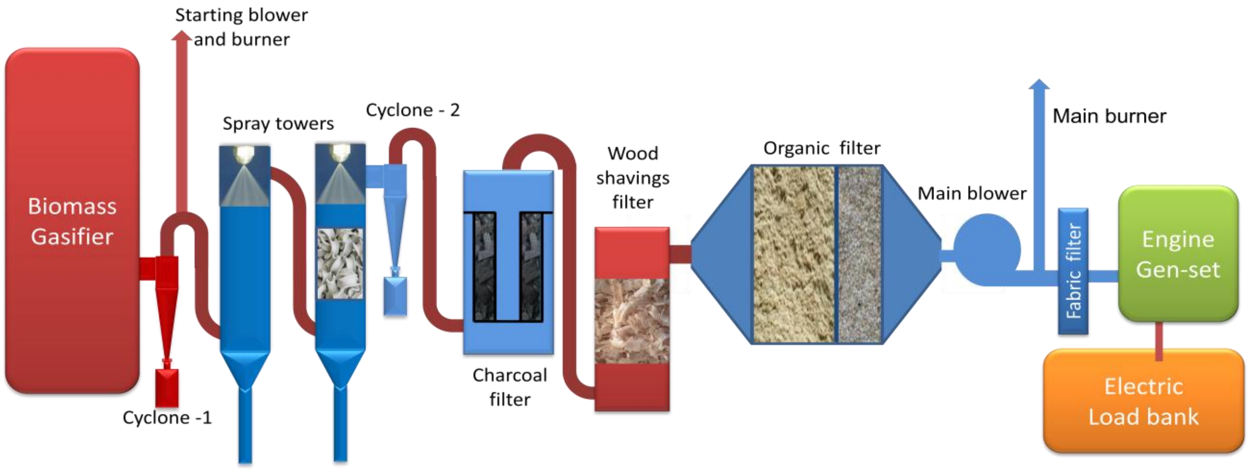

Fig. 1. Schematic diagram of experimental set-up.

2.3.1. 3-6 h duration trials

The results of short duration trials of the gasifier reactor using 25, 35 and 55 mm diameter briquettes have been reported earlier [3], where it has been found that the gasification efficiency was highest for operation using 25 mm diameter briquettes as fuel followed by 35 and 55 mm diameter briquettes. The clinker formation was observed significantly higher in case of gasifier operation using 55 mm diameter briquettes as fuel in comparison of 25 and 35 mm diameter briquettes. The reason for the same may be sorted out by understanding the net heat flux during gasification of various sizes of biomasses. The net heat flux during the gasification or combustion of any solid fuel is higher for smaller size of fuel as compared to bigger size fuel [1]. The higher heat generation during smaller size briquettes resulted the high tarry product generation due to fast pyrolysis of biomass. When these tars passed through the combustion zone, due to endothermic reaction the temperature of the combustion zone reduced, which resulted the lower clinker formation. Additionally, in case of larger size briquettes, due to channelling, development of few higher temperature zones in combustion bed also resulted to the clinker formation. Although the performance of the system was found satisfactory during all the experiments using briquettes as fuel but, it was felt that the efficiency of the system was slightly lower than the designed value, which is 75%. After inspection, insulation of the gasifier reactor was found damaged, which has since been got repaired. Besides the grate rotation was done only when the pressure drop across the gasifier reactor was found 2-3 times than the initial value. The grate may also be rotated if there is bridging of the fuel material inside the gasifier reactor. The indication of the bridging are reduced calorific value of the gas and rise in temperatures of the combustion zone & raw producer gas. The initial 3-4 h operation data for gas calorific value and temperatures of the raw producer gas & combustion zone may be taken as base data to observe the reduction in gas calorific value and rise in the temperatures of combustion zone and raw producer gas. This practice significantly reduced the char yield at the bottom of the gasifier reactor (from 18 – 20 % to 5 – 7 %).

2.3.2. 8 h duration trials

Based on the experience/ feedback collected during the short duration trials carried out earlier [3], a few minor modifications were incorporated in the system to make it suitable for the longer duration operation. The ash bin of the cyclone-1 was removed and a water sill was provided to hold sufficient amount of SPM expected to be retained over a longer duration operation. A water discharge pipe was provided at bottom of cyclone-2 (installed after spray towers) to remove the condensate. The lower end of the discharge pipe was kept immersed in the water tank. The experiments were carried for continuous 8 h duration using SB, PS, CS+PS (1:1) and SD briquettes. The performance data were also collected for the C & C system in a few selected experiments.

2.3.3. 50 h duration trials

After the gasifier system performed satisfactorily during experiments each of 8 h continuous operation, continuous 50 h experiment was conducted during 31 March 2011 using soybean stalk briquettes received from CIAE Bhopal centre were used for the test and performance data were collected for the gasifier operation in four consecutive stages as per details given below:

- Gasifier top and all 6 tuyers kept wide open (first 24 h): During first 24 h the gasifier was receiving air from top of the reactor and the supplementary air was drawn from the six tuyers.
- Gasifier top wide open and tuyers kept closed (next 3 h): After 24 h, the tuyers of the gasifier reactor were closed and the air was allowed to enter only from the top of the reactor.
- Gasifier top partially closed and tuyers wide open (next 13 h): After 27 h, all the tuyers were opened and the top cover of the gasifier was closed partially (around 1/10th opening).
- Gasifier top closed and all tuyers wide open (next 10 h): After 40 h, the top cover of the gasifier reactor was closed completely and the entire air required for the gasification was drawn from the tuyers.

The variation in temperatures (inside the gasifier reactor at various heights, raw producer gas temperature), pressure drop across the gasifier reactor, composition and calorific value of the producer gas only were recorded hourly for all the four stages. The gasifier was operated on thermal mode for 38 h and with C & C system 12 h, which included 8 h with engine gen-set operation.

2.4. Measurements

The proximate analysis of all the crop residues before and after briquetting was carried out using the methods suggested by ASTM and SPRERI [5, 6]. Moisture content of the powdery crop residues used for preparation of the briquettes was measured for five samples each of approximately 100 g and the average values have been reported. A bomb calorimeter, make Advance Research Instruments Company, was used to measure gross heating value of all the crop residues. Gas temperature was continuously recorded at the gasifier outlet. An orifice based digital gas flow meter, which displayed the flow rate of producer gas in Nm^3/h, was installed at outlet of the main blower. During each experiment temperatures in different zones of the gasifier, gas temperature at the gasifier outlet, flame temperature and pressure drop across the gasifier were recorded. The producer gas samples were collected for each trial and gas composition and gross calorific value were determined. K-type thermocouples and a 16 channel data logger (Make: Data-taker, Model: DT-85) were used for measurements of temperature at various locations inside the gasifier as well as gas C & C system. Water-filled manometers were used to measure pressure drop across the gasifier reactor. Composition and calorific value of the producer gas were measured using ACE Make online producer gas analyzer. Producer gas samples were also collected in rubber balloons on hourly basis at blower discharge end and analyzed by gas chromatography using TCD detector (Netel Chromatographs, Baroda, Gujarat, India) to verify the results obtained from the online producer gas analyzer. The chromatograph consisted of two columns-Molecular sieve and Porapack-N as stationary media and Argon as carrier gas. The amount of char and ash coming out from bottom of the gasifier (in ash pit) was measured after drying in a few selected experiments. The combined tar and SPM contents of the producer gas were measured using portable tar and SPM sampling system designed by IIT Bombay. The tar and SPM were also measured separately be gravimetric analysis using anisol as solvent. The mass of briquettes fed per hour in to the gasifier to top-up the fuel level up to three-forth of the height of the gasifier reactor was recorded. Specific gasification rate (SGR) was calculated for the average fuel consumption rate for entire period of operation and taking grate area as 0.75 m^2. The gasification efficiency was computed using average fuel (dry mass) consumption rate, flow rate of the producer gas, calorific values of the producer gas and the fuel. The efficiency of the engine gen-set was computed using the gas flow rate and CV, were measured at various loads.

3. Results and Discussion

Results of proximate analysis of powdered crop residues used for briquette preparation at SPRERI are given in Table 2. Proximate analysis of crop residue briquettes measured after crushing and grinding the briquettes, is given in Table 3. It may be seen that after briquetting a slight reduction in calorific value was found mainly due to loss of some volatile content during briquetting process.

Table 2. Properties of powdery biomass used for briquette preparation

Biomass	Volatile matter, (%db)	Ash content (%db)	Fixed carbon (%db)	Gross calorific value (kcal/kg)
Sugarcane baggase	83.17	4.13	12.30	3984
Cotton stalk	83.89	8.97	7.14	3884
Pigeon pea stalk	79.96	2.86	17.18	3897
Sawdust	75.86	2.81	21.33	4071

Table 3. Proximate analysis of the powdered biomass briquettes

Biomass	Volatile matter (%db)	Ash content (%db)	Fixed carbon (%db)	Gross calorific value (kcal/kg)
Sugarcane baggase[a]	78.34	7.41	14.25	3887
Sugarcane baggase[b]	71.96	12.03	16.01	3796
Cotton stalk	72.61	9.96	17.13	3785
Pigeon pea stalk	76.73	5.49	17.78	3811
Sawdust	71.81	3.79	24.40	3971
Cotton stalk + Pigeon pea stalk (1:1)	72.67	4.89	18	3798
Soybean stalk	78.25	6.82	14.93	3826

a=Briquettes prepared at SPRERI
b=Briquettes procured from M/S Shri Dwarkesh bio-fuels, Vadodara

3.1. Short duration performance evaluation of the gasifier system on thermal mode - Gasifier operations for Eight hours

Short duration performance evaluation of the gasifier was carried out using briquettes prepared from sugarcane baggase, soybean stalk and mixture of cotton stalk and saw dust. The performance of the gasifier system has been summarized in Table 4. It may be seen that for during operation using 40 mm diameter briquettes as fuel, the average gasification efficiency was almost steady and highest (around 76%). It may also be seen that the variation in gasification efficiency from the average value increased with increase in diameter of the briquettes and was the highest of the ± 3% for 60 mm diameter briquettes.

Table 4. Average performance of gasifier for 8 hours operation with different briquettes

Parameters	Briquetting material					
	Sugarcane baggasse		**Pigeon pea stalk**	**Soybean stalk briquettes**	**Cotton stalk + pigeon pea stalk (1:1)**	**Saw dust**
Briquettes dia. (mm)	55[c]	60[d]	55	57	40	55
Moisture content (% wet basis)	5.1-5.7[e]	5.2-5.4[f]	6.2	5.9	7.2	5.7
FCR (kg/h)	141.5	139.2	141	136	137.3	140.5
SGR (kg/h-m^2)	188.7	185.3	188	181.3	182.6	187.3
Gas flow rate (m^3/h)	332-345	317-356	330-345	334-348	311-317	334-341
Gas CV (kcal/Nm^3)	1100 ± 60	1060 ± 75	1100 ± 50	1100 ± 50	1175 ± 25	1100 ± 50
Gasification efficiency (%)	71 ± 2[e]	70 ± 3[d]	71 ± 0.75	71 ± 0.75	76 ± 0.5	72 ± 1

c= Briquettes prepared at SPRERI
d= Briquettes procured from M/S Shri Dwarkesh bio-fuels, Vadodara
e= Average of 4 experiments of 8 h duration each
f= Average of 3 experiments of 8 h duration each

3.2. Long duration performance evaluation - Continuous 50 h operation of the gasifier system

During first 24 h when the gasifier top cover and all the tuyers were opened, the calorific value of the producer gas was maintained at 1175 ± 50 kcal/Nm^3 with CO and H_2 ranging between 15±5 % (by volume). During most of the 24 h period the CH_4 content was below 3 % (by volume) and the temperature of the combustion zone was below 1000 ^oC and no excessive pressure due to clinker formation was observed. The power output of the gasifier was below 350 kWth up to first 4 h of operation and was maintained in the range of 450.6 to 494 kWth after 5th h.

The performance of the system was steady up to 24th h. To see the effect of closing tuyers (i.e. air intake only from top) on gasification process, the tuyers of the reactor were closed after 24th h. In this case the reactor was operated in a mode similar to what was reported by Reed & Markson [8,9]. In this case, the combustion and pyrolysis zones inside the gasifier reactor started to move on upward direction, which can be observed from the gasifier temperature profile in Fig.2. From this condition onwards, the air flow is received only from top of the reactor. The particles in the combustion zone radiated the heat to subsequent layers in all directions. When the temperature of the fresh layer of fuel reached up to a point, where fresh biomass released volatiles, the volatile mixed with incoming air and the air-volatile mixture got ignited in high temperature environment. This kind of sub-stoichiometric combustion is termed as flaming pyrolysis [8]. In this case the flame propagation remained upward as in and this process is called stratification process. The flame traveled upward until the top layer is reached and the entire bed becomes a charcoal bed as similar to the case explained by Mukunda [1].

At 26th h of operation the methane content of the producer gas increased and reached up to 12% also the tar content of the raw producer gas was above 600 mg/m^3. The main reason for this was the increased length of pyrolysis zone. Under this condition the entire length of gasifier reactor was above 600 ^oC and the top fuel layer inside the reactor was burning. At this stage more amounts of carbon and hydrogen contents of the biomass were coming in the form of CO_2 and CH_4, therefore, CO and H_2 contents of the PG were found reduced. The pressure drop across the gasifier reactor was also found increased from 19 to 43 mm WG.

After 27th h all the tuyers were opened and the top cover of the gasifier reactor was closed partially (around 1/10th opening). The system reached at the initial condition within 3 h, except drying zone where, due to the burning fuel bed the temperature was remained high until the fresh fuel material was fed. The temperature of the combustion zone in this stage was found increased up to 1127 ^oC but no significant change was observed in the gas calorific value, gas flow rate, thermal power output and pressure drop across the gasifier reactor (as compared to open top condition).

After 40th h, the top cover of the system was closed completely to evaluate the performance of the gasifier in closed top mode. The temperature of the combustor zone started to increase and reached above 1200 ^oC within 1 h. After 40 h, the pressure drop across the gasifier reactor was found increased from 24 (at 37th h) to 85 mm WG. After inspection, the tuyers were found choked due to clinker formation inside the reactor at the tuyers end. All the six tuyers were cleaned using the metallic rod and grate was operated which slightly reduced the pressure drop across the gasifier reactor (75 mm WG). The temperature of the combustion zone was still above 1150 ^oC and the pressure drop was increasing continuously mainly due to clinker formation which was observed from the tuyers. This resulted reduction in gas calorific value and flow rate. The pressure drop across the gasifier reactor reached up to 246 mm at 50th and no significant reduction was found after grate rotation. At this stage the gas calorific value and flow rate were reduced and reached 123 Nm^3/h and 758.2 $kcal/Nm^3$ (thermal power output = 108.3 kWth). At this stage it was decided to shut down the system. Overall the gasifier was operated on thermal mode for 38 h and with cooling and cleaning system 12 h, in which 8 h with engine gen-set.

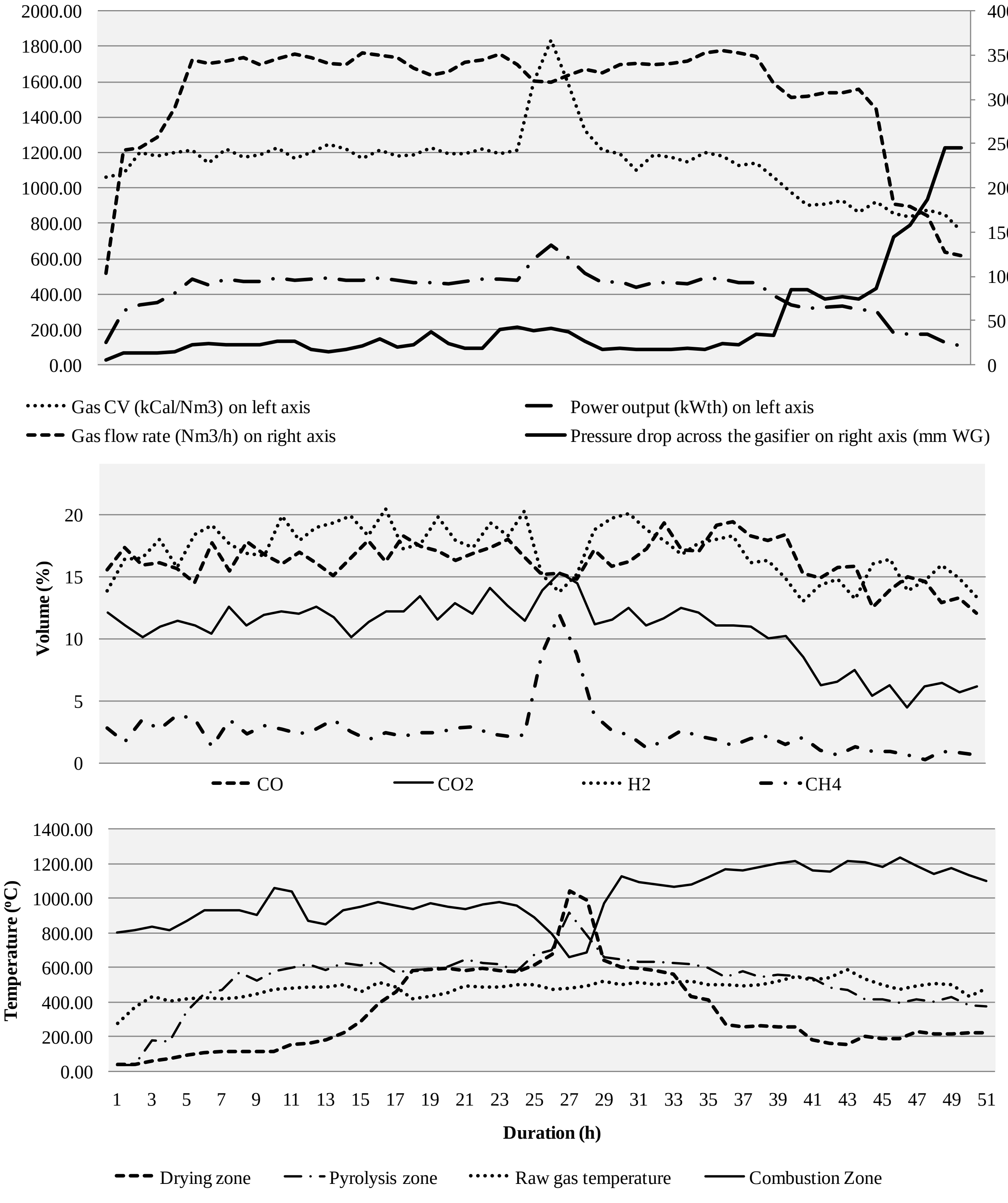

Fig. 2. Overall performance of the gasifier during continuous 50 h operation

3.3. Performance evaluation of producer gas cooling & cleaning system

Component wise summarized performance data for producer gas cooling and cleaning system are given in Table 5 and 6. It can be seen that after passing through fabric filter, tar and SPM contents of the producer gas were below 50 mg/Nm^3 and the temperature of the producer gas was below 45 ^{o}C.

It has also been observed that the tar content in case of smaller sized briquettes was higher as compared to 40 and 55 mm diameter briquettes as shown in Table 7. As discussed in earlier section the clinker formation was higher in case of gasifier operation with larger sized briquettes. It is, therefore advisable to operate the system on briquettes of 35-40 mm diameter.

The results of SPRERI design gravimetric tar and SPM measurement system were compared with the IIT Bombay design portable tar and SPM sampling device. Total difference in both the system was below 3 mg/Nm^3.

Table 5. Effect of producer gas cooling and cleaning system on cleaning of producer gas[g]

Raw gas Tar+SPM (mg/Nm^3)	Tar + SPM (mg/Nm^3) after							
	Cyclone - 1	Spray towers	Cyclone - 2	Charcoal filter	Wood shavings filter	Organic filter	Fabric filter	Operation duration
982.6	356.7	140.3	72	69.3	58.9	45.3	43.2	Up to 6 h
924.1	437.9	152.6	71.6	68.4	57.2	42.5	41.7	Up to 8 h
883.2	339.2	94.8	67.1	53.5	48.3	34.9	24.2	Two exp. of 8 h each (total 16 h)
1013.5	413.4	139.3	71	67.7	57.2	41.3	44.8	Three exp. of 8 h each (total 24 h)

g= Measurement were taken using portable tar and SPM sampling device of IIT Bombay design

Table 6. Effect of producer gas cooling and cleaning system on cooling of producer gas[h]

RawgasTemperature (^{o}C)	Temperature (^{o}C) after						
	Cyclone -1	Spray towers	Cyclone -2	Charcoal filter	Woodshavings filter	Organic filter	Fabric filter[i]
396	342	35	35	34	33	32	38
453	394	36	35	35	34	33	43
567	447	38	38	37	36	36	44 (40[j])

h = Results are reported from the recorded data of the data logger and K-type thermocouples (± 1^{o}C readability)
i = Temperature after blower increases due to contact of gas with hot casing of blower
j = Temperature of the gas after providing the cold water jacket (24 ^{o}C) on the blower casing

Table 7. Average values of Tar and SPM measured by gravimetric Tar and SPM sampling unit

Size of briquettes	Raw gas		Refined gas	
	Tar (mg/Nm^3)	SPM (mg/Nm^3)	Tar (mg/Nm^3)	SPM (mg/Nm^3)
25	296.75	496.20	16.13	21.95
40	225.73	577.85	14.30	23.74
55	180.30	578.87	10.76	23.15

3.4. Preliminary performance evaluation of engine gen-set at various loading

After detail performance evaluation of the gasifier and the C & C system, were integrated with the engine gen-set. Producer gas flow rate and calorific value were measured. Fig 3 shows the variation in engine efficiency with different loading. During all the experiments the efficiency v/s loading curve was almost similar. The engine gen-set efficiency was found higher for the smaller sized briquettes probably due to comparably higher calorific value of the producer gas. Efficiency of the engine using 40 mm dia. briquettes supplied by TNAU was found 27.3 - 27.65 % and using CIAE briquettes it was 25 - 25.45 %. In earlier experiments using 25 mm diameter briquettes [3] the efficiency of engine genset was found in the range of 27- 28.2 %. At presents the emissions from the engine gen-set could not be measured due to non-availability of suitable system.

Fig. 4 shows the fluctuation in frequency of the engine gen-set power output with a step loading (instant loading). The fluctuation is acceptable up to 30 kW step loading where; frequency fluctuation is in the range of 48.2 to 51.3 Hz and it is getting stabilized at 50 Hz in less than 75 seconds. For step loading of 50 kW the engine gen-set takes more than 5 minutes to regain and maintain the frequency at 50 Hz. Therefore, the system may be connected to any combination of load (total 100 kW) where; loading of any single device is less than 30 kW. If there is any connected inductive load of more than 30 kW capacity, it is recommended to operate the load using variable frequency drive, so that an instant loading or step loading does not exceed the 30 kW limit.

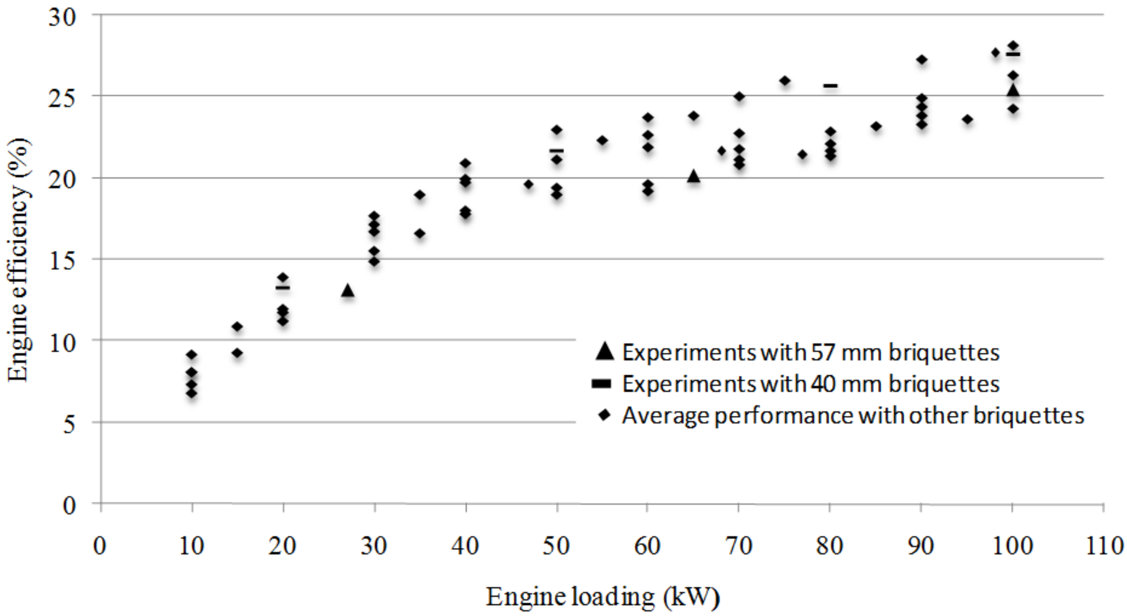

Fig. 3. Efficiency of producer gas based engine gen-set at various loadings

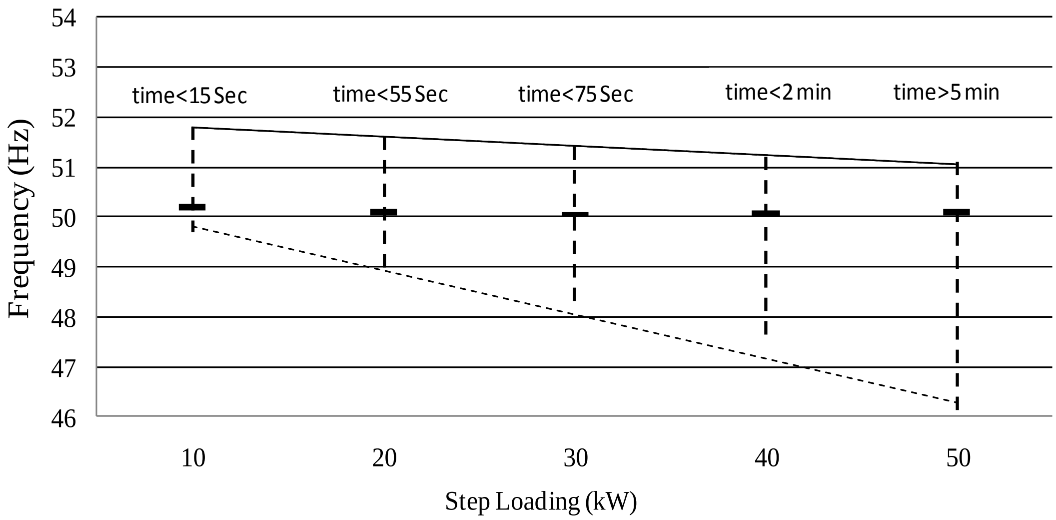

Fig. 4. Fluctuation in frequency of engine gen-set power output by single step loading

4. Conclusion

The performance of open core down draft gasifier of 1800 MJ/h thermal capacity was found satisfactory with briquettes of selected crop residues. The CV and volatile contents of loose crop residues were found slightly reduced after briquetting. The calorific value of the producer gas was found above 1050 kcal/Nm3 for all the briquettes used for gasification. The gasification efficiency during various experiments was found in the range of 71 to 76 %. The higher gasification efficiency was corresponding to the lower sized briquettes mainly due to less channelling and higher availability of surface area for the reaction. In addition the tar contents were found higher in case of small size briquettes. The efficiency of the engine gen-set was found in the range of 24.28 to 28.20 %. The higher engine efficiency is corresponding to the higher calorific value of the gas. Experimental results revealed that the optimum diameter of the fuel for the used system was found 35-40 mm diameter and 50-70 mm in length.

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Abbreviations

C & C System: Producer gas cooling and cleaning system
SB: Sugarcane baggase
kWth: kW thermal
CS: Cotton stalk
PS: Pigeon pea stalk
SS: Soybean stalk
SD: Saw dust
SPM: Solid particulate matters
MNES: Ministry of New and Renewable Energy Sources
SPRERI: Sardar Patel Renewable Energy Research Institute
FCR: Fuel consumption rate
SGR: Specific gasification rate
CV: Gross calorific value
PG: Producer gas
Nm: Normal meter
db: Dry basis
wb: Wet basis
dia: Diameter