Agriculture waste used on the working parameters of fluidized gasification

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ABSTRACT:

The objective of the present work was to assess the agro-industrial residuals in a fluidized bed gasification process. The experiments were performed in a pilot scale auto-thermal fluidized bed gasifier (FBR) were wheat husk, rice husk and corn stalk was used as the feed stock after analyzing phsio-chemical analysis with physical pre-treatment by using air as gasifying agent. The working parametric such as bed temperature (t), equivalence ratio (e), pressure (p), feed size (fs) and fuel consumption rate (fc) with optimum condition considered to improve producer gas efficiency, tar yield efficiency and ash content efficiency. Experiments were conducted between the 't' range of 650-900°C, using 'e' ranges 0.2 to 0.35, 'fs' between of 75 to 300 μm and 'fc' range of 5 to 20 kg/hr. In the present investigation, an empirical relationship was developed to predict the process of generating producer gas with better quality through gasification of biomass in a FBR using response surface methodology (RSM). The full potentiality of wheat husk, rice husk and saw dust for gasification was investigated via RSM. Higher fs and e resulted in more gas yield due to increases in the exothermic reactions. The developed model was made a good prediction for the experimental data as well as predicated data.

Index Terms – Fluidized gasification, Response Surface Methodology, Equivalence ratio

1. Introduction

An agro-industrial waste could be utilized for the recovery of energy. Biomass such as wheat husk, rice husk and corn stalk. Used as reasonably due to high energy content 10<18 MJ/kg [1-4]. In many countries, moist of surplus, agro wastes are disposed by direct burning in open heaps, which result in energy loss and units emission of various pollutants to the environment. The process of converting carbonaceous substance into gaseous products using a gasifying agent such as air, O2 and steam has been considered as one of the visible alternative to combustion of low density [5]. Agro-industrial residue further the gasification process is

80% thermodynamically efficient in converting the organic substance of the feed into a product gas with the mixture containing Co2, Co, H2, CH4, N2 and other minor organic compounds such as tars, ammonia, sulfur formed in case of air is used as gasifying agent beside the gasification system products a clean fuel gas can be used in a combined cycle for generation power may achieve 40% efficiency. An integrated combined cycle of gasification system offer higher efficiency than that of a convention direct combustion pulverized coal fixed process [6].

Nowadays, gasification technology that coverts solid biomass into syngas for combined integrated cycle, coal covert liquid products and chemical products [7-9]. The gasification technology has been developed for woody agriculture biomass is carbon-neutral as eco- friendly CO2 emission when solid biomass used. However, biomass has a low heating value transportation, storage cost and density and also the problem of shortages of this fuel due to seasonally and the potentially necessity to have large size gasifier [10].

The generation of energy from rice husk and wheat husk, could also generate income as a co-generation of power to the national grid system could save the fuel cast and cost of treatment however, many technologies have been developed for utilizing biomass as gasification to generate power by using Agro-biomass to drive generator to producer energy [17-20]. very few investigation have been done related to different working parameter in a fluidized bed gasifier using woody biomass, hence the present work was aimed to develop fluidized bed gasifier using air of gasifying agent by incorporating the process parameter like bed temperature, equivalent ratio, pressure, feed rate, particle size and to investigate the effect of producer gas, tar, ash efficiency [21].

2. Experimental investigation

A. Agro biomass

The feed material such as wheat husk, rice husk and corn stalk was selected to study the fluidized bed gasification process. biomass were collected from rural area from Kattumannar koil, Cuddalore district, India. The phsio-chemical properties of biomass as feed material are presented in Table 1. The test materials were dried and then sieved in a standard sieves, as particle size was distributed as 196 µm, 298 µm and 285 µm as followed by wheat husk, rice husk and saw dust [22]. The specific gravity of the selected materials was measured using bottle method; the moisture content, volatile matter, fixed carbon and ash content was determined by ASTM procedures (ASTM, E -871, 872 and 830) respectively [23]. The feed elemental composition was analyzed by PERKIN ELMAR 2400 Series II. The bed material was used as lime stone and may used particle size as selected as 0.4 mm. The fluidization velocity was determined by using U-tube manometers are used to measure the pressure drop above and below the distributor plate and at different heights of fluidized bed gasifier. The air velocity determined to the peak pressure drop gives the experimental value of minimum fluidization velocity.

Table 1
Ultimate and proximate analysis of biomass

Ultimate analysis				Proximate analysis			
Components	Percent			Components	Percent		
	Wheat husk	Rice husk	Corn stalk		Wheat husk	Rice husk	Corn stalk
Carbon	40.10	50.48	31.54	Volatile matter	84.10	70.60	54.91
Hydrogen	6.40	6.51	4.07	Fixed carbon	5.68	2.97	11.51
Nitrogen	1.35	1.49	3.99	Moisture	9.92	9.45	11.43
Oxygen	51.79	41.40	25.87	Ash	1.63	17.09	22.14
Sulphur	0.36	0.20	0.96	Heating value (MJ/kg)	17.94	19.81	15.52

Wheat husk

Rice husk

Corn stalk

Photographic view of different biomass

3.Experimental setup

A 20 kg/hr fluidized bed gasifier has been developed and the experimental investigation was carried out on agro-industrial biomass such as wheat husk, rice husk and corn stalk. The schematic line diagram of experimental setup is shown in figure 1 and table 2 shows the experimental design specification and operating parameters. The gasifier is made up of carbon steel material with the inside diameter of 108 mm and height of 1400 mm having inside refractory lining of thickness 0.1 m and multiple hole distributor plate of 105 mm diameter was used for air distribution. Lime stone was used as bed material fitted with gasifier, arrangement is made to discharge the ash periodical disposal system. The screw feeder used to feed the feed material and to maintain the bed in a fluidized stage air was introduced at the bottom of gasification system using blowers. The air flow was estimated by orifice meter placed in a feed pipe to measure the pressure drop with proper controlling and regulating valves. The calibration of orifice prior to the experiment with two instruments; namely a anemometer (make: Dantec, Denmark) and micro-manometer (make: Furnace Control, England).

The pressure drop between the orifice were measured in the manometer with respect to flow rates by the anemometer. At different equivalent ratio pressure drop were noted to measure the air flow rate.

Table 2
Design and operating features of Fluidized Bed Gasifier

Parameters	***Range***
Gasifier	Fluidized Bed Gasifier
Gasifier specifications	Diameter (Inner) : 108 mm Total height : 1400 mm
Heating	Electric heating
Coolant	Water
Biomass capacity	20 kg / hr
Feeding method	Screw feeder
Gasifying agents	Air
Temperature	650-950 ºC
Operating parameters	Bed Temperature, Pressure, Feed rate, Equivalence ratio and Particle size.
Purification	Cyclone, Water scrubber, Dry filter

Pre-heating the bed material with help of electrical heaters during startup to achieve the bed temperature, feed was controlled in a screw feeder using speed drive properly into the gasifier to prevent the combustion outside the chamber. The deserved equivalent ratio was achieved by controlling the air supply to the gasification system. The cyclone separator used to separate the solid particles from the producer gas. The bag filter used to clean up the gas by removing dust and other Corse particles. The water cooling systems were used to cool the producer gas and remove the tar by condensation.

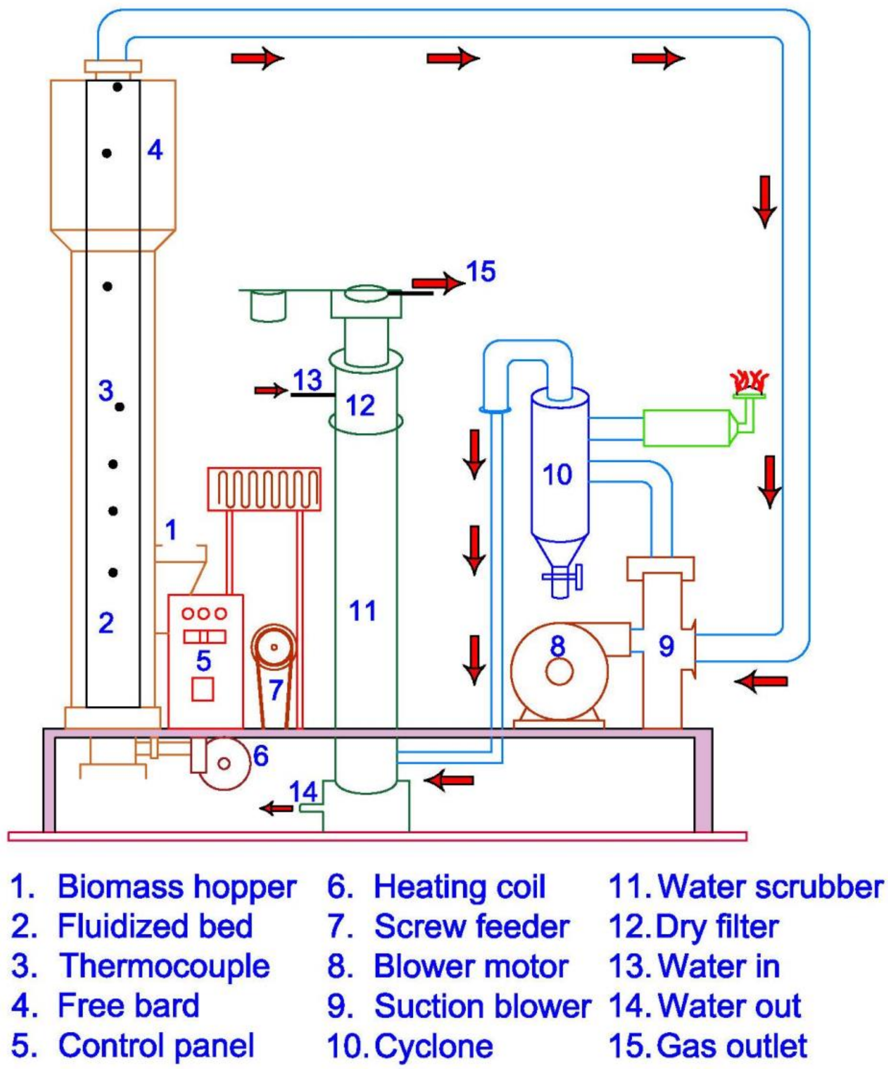


Figure 1. Layout of experimental setup

Experimental testing and operating conditions

Temperature (t)

Investigation carried out by maintain the desired bed temperatures as the selected feed material such as wheat husk, rice husk and corn stalk. One of the important features of biomass gasification is that the bed temperature can be kept as low as 650–950°C, thereby preventing sintering and agglomeration of carbon ash during the conversion process. Low temperature requires catalyst for producing hydrogen and nitrogen. The bottom part of the gasifier, temperature is stable for all the fuel around 650 °C. High temperature above 950 °C will change the gas composition.

Equivalent ratio (e)

Quantity of air required to burn a portion of the fuel to release heat by supporting the endothermic reactions, to prevent the heat losses in Solid, liquid and gaseous product by maintaining the required temperature termed as equivalence ratio as an important factor in a gasification process. Experiment were carried out with a equivalence ratio 0.2 - 0.5 with wheat husk, rice husk and saw dust by varying equivalence ratio at 0.25, 0.30 and 0.35.

Pressure (p)

The chemical cycle when the production of hydrogen may affects, if the pressure rises above 5 bar and if the pressure less than 1 bar producer gas generates with low purity.

Feed size (f_s)

The biomass less than 75 μm implied more conversions leads to lower solid temperatures in the system may affect the concentration of producer gas. Feed size above 500 μm leads to devolatilization period and may reduce the pre-treatment cost.

Fuel consumption rate (f_c)

Biomass gathers on the bottom forming a solid bed with a feed rate was less than 5 kg/hr,

If the fuel consumption rate was less than 20 kg/hr, may decrease the residence time of the feed inside the gasifier and thus decrease its exposure to melting inside. Hence, the gasifier used for the present work designed with the maximum feed rate of 20 kg/hr.

3. Design matrix on experimentation

From the investigation the agro-industrial biomass as a predominant factor may have the greater influence on the quality of the solid (ash), liquid (tar) and gaseous (producer gas) have been identified [24-29]. The biomasses such as wheat husk, rice husk and corn stalk, are used in the present investigation. Owing to a wide range of factors such as temperature, pressure, equivalence ratio, feed size and fuel consumption rate. The use of five factors and central composite rotatable design matrix was chosen to minimize number of experiments. The number of tests required for the CCRD includes the standard 2k factorial with its origin at the center, 2k points fixed axially at a distance, say α, from the center to generate the quadratic terms, and replicate the experiment tests at the center point; where number of variables represent by k. The axial points are chosen such that they allow rotatability, which ensures that the variance of the model prediction is constant at all points equidistant from the design center. By adding axial points which extend, the design will provide protection against the curvature from twisting. Hence, the design was extended up to ± α. The value of α is chosen to maintain rotatability and depend upon the number of experimental runs in the factorial portion of the CCD, as shown in Equation (3.1)

$$\alpha \;=\; [\text{number of factorial points}]1/4 \qquad (3.1)$$

If full factorial for α is evaluated using

$$\alpha \;=\; [23]1/4 = \pm 1.682 \qquad (3.2)$$

When □ > 1, each factor is run at five levels (–□, –1, 0, +1, + □) instead of the three levels of –1, 0, and +1. The reason for running the CCD with □ > 1 is to have a rotatable design. However, the factorial portion can also be a fractional factorial design of resolution. The center values for the variables were carried out at least six times for the estimation of error, and single runs for each of the other combinations. For full replication of the test at the center an independent and more uniform estimate of the prediction variance over the entire design as shown in Table 3 the ranges of factors are considered. For the convenience of recording and processing the experimental data, the upper and lower levels of the factors are coded as +1.682 and -1.682 respectively. The coded values of any intermediate value can be calculated by using the Equation (3.3).

$$X\mathit{i} \;=\; 1.682\,[2X - (Xmax - Xmin)] / (Xmax - Xmin) \qquad (3.3)$$

Where, Xi is the required coded value of a variable X, and X is any value of the variable from Xmin to Xmax

Xmin is the lower level of the variable.

Xmax is the upper level of the variable.

Xmax is the upper level of the variable.

Design matrix consisting of 20 sets of coded conditions 8 factorial points, 6 corner points and six center points was chosen in this study [30-34]. Table 4 shows the experimental results and actual results for 20 sets of coded and actual values.

Table 3
Important factors and their levels

Factors	*Units*	*Notation*	*Factors levels*				
			–1.682	–1	0	+1	+1.682
Wheat husk	%	W	0	6	15	24	30
Rice husk		R	0	12	30	48	60
Corn stalk		C	0	5	12.5	20	25

The experimental data and those were compared with the predicted values of the developed model. The producer gas energy is assessed with the variable ACE (Ash conversion efficiency). This variable represents the ratio between the energy content of the producer gas (HHVgas) and the energy content of the initial agro-biomass. (HHVbiomass) without taking into account the heat input in the reactor:

ACE = 100 (Carbon content in the gas x Gas yield) /

(Ash content in biomass material x Total feed) (1)

At the end of the experiment the tar were weighed and stored in a sealed recipient for further characterization. The tar yield is expressed as the ratio of the residual tar to the initial mass of biomass

$$YTar\% = [(MTar) / (Mbiomass)] \times 100 \quad (2)$$

Applying design matrix on experimentation

In the present work, to correlate the working parameters and the quality of the producer gas, a second order quadratic model was developed. In this study, the Response Surface Methodology provides a quantitative form of relationship between the desired response (Quality of the Producer gas) and the independent input variables (Biomass ratio), Wheat husk (W), Rice husk (R), and Saw dust (S), and can be expressed as a function, as in Equation (3)

Quality of the Producer gas (Q) = f (W, R, S)..... (3)

The mathematical relationship must include the main and interaction effects of all factors by selecting polynomial expressed as follows:

Y = bo + □bi xi + □ bii xi2 + □ bij xi xj (4)

For three factors, the selected polynomial could be expressed as

Quality of the Producer gas (Q) = {b0 + b1 (W) + b2 (R) + b3 (S) + b11 (W) + b22 (R)

+ b33 (S) + b12 (WR) + b13(WS) + b23 (RS)} (5)

where b0 is the average of responses () and b1, b2, b3… b11, b12, b13… b22, b23, b33, are the coefficients that depend on their respective main and interaction factors, which can calculated using the expression given below,

Bi = (□ (Xi,Yi))/n (6)

Where ‘i’ varies from 1 to n, in which Xi the corresponding coded value of a factor and Yi is is the corresponding response output value obtained from the experiment and ‘n’ is the total number of biomass feed considered. All the coefficients were obtained applying CCRD matrix including the Design Expert statistical software package. By determining the significant coefficients (at higher confidence level), the final relationship was developed including only these coefficients. The final empirical relationship obtained by the above procedure to estimate producer gas generation, tar yield and ash content of various biomass feed under fluidized bed gasification is given below;

Producer Gas Efficiency

$$\begin{aligned} \text{Producer Gas} = {} & + 72.555 - 2.546*(W) - 0.528*(R) - 0.397 (S) - 4.305 \times 10\text{-}3 *(WR) \\ & + 9.277\times 10^{-3}* (WS) + 9.446\times 10^{-3}* (RS) \\ & + 0.072* (W^2) + 3.208\times 10^{-3} (R^2) + 0.053*(S^2) \end{aligned}$$

Tar yield efficiency

Producer Gas = + 14.537 –0.499 *(W) –0.138 *(R) –0.163 (S)
–5.342 x 10-4 *(WR) –1.236x10-3 (WS) + 8.975x 10–4 * (RS)
+ 0.014* (W^2) + 1.384x 10–3 (R^2) + 0.015* (S^2)

Ash Content Efficiency

Producer Gas = + 90.192 –2.759*(W) –0.557*(R) –0.539(S) –5.185x 10-3 *(WR)
+ 0.0126*(WS) + 0.013*(RS) + 0.078*(W^2)
+ 2.882x 103 (R^2) + 0.052*(S^2)

To find the main significant and interaction factors by using Analysis of Variance technique. The results of second order response surface model fitting as Analysis of Variance (ANOVA) are given in the Table 4. The determination coefficient (r2) indicated the goodness of fit for the model. The Model F-value of (ACE = 5.76, PGE = 5.88, TYE = 4.66) implies the model is significant. There is only a 0.01% chance that a “Model F-Value” this large could occur due to noise.

Table 4
ANOVA Test results

Source	Ash Content Efficiency		Producer Gas Efficiency		Tar Yield	
	F value	p-value Prob>F	F value	p-value Prob>F	F value	p-value Prob>F
Model	5.76	0.0057	6.24	0.0042	4.27	0.0101
A-Wheat husk	3.23	0.1025	3.39	0.0952	2.11	0.1587
B-Rice husk	7.05	0.0241	7.77	0.0192	3.00	0.1008
C-corn stalk	28.25	0.0003	31.79	0.0002	19.24	0.0009
AB	0.11	0.7515	0.084	0.7775	0.030	0.8601
AC	0.11	0.7471	0.068	0.7997	0.024	0.7844
BC	0.53	0.4833	0.28	0.6071	0.060	0.8044
A2	11.04	0.0077	10.87	0.0080	10.01	0.0077
B^2	0.24	0.6376	0.34	0.5743	1.32	0.2358
C^2	2.38	0.1537	2.86	0.1218	4.98	0.0228

Producer Gas Efficiency

Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case R, S, W are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. The "Lack of Fit F-value" of 4.22 implies there is a 7.00% chance that a "Lack of Fit F- value" this large could occur due to noise. Lack of fi t is bad -- we want the model to fit. This relatively low probability (<10%) is troubling. The "Pred R-Squared" of 0.0275 is not as close to the "Adj R-Squared" of 0.7128 as one might normally expect; i.e. the difference is more than 0.2 [37]. This may indicate a large block effect or a possible problem with your model and/or data. Things to consider are model reduction, response transformation, outliers, etc. All empirical models should be tested by doing confirmation runs."Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. The present ratio of 7.858 indicates an adequate signal.

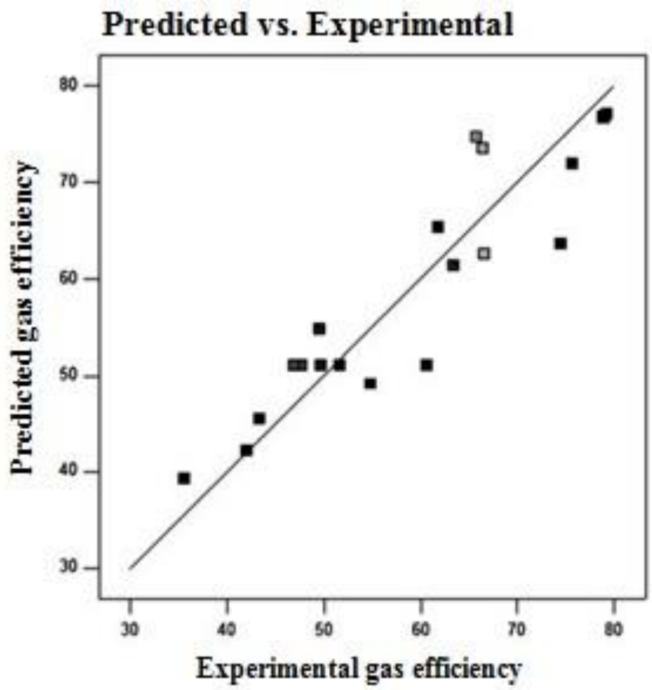
Tar yield

Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case W, R, S are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many in significant model terms (not counting those required to support hierarchy), model reduction may improve your model. The "Lack of Fit F-value" of 2.62 implies the Lack of Fit is not significant relative to the pure error. There is a 15.66% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good -- we want the model to fit. A negative "Pred R-Squared" implies that the overall mean may be a better predictor of you response than the current model "Adeq Precision" measures the signal to noise ratio [35]. A ratio greater than 4 is desirable. The present ratio of 6.072 indicates an adequate signal.

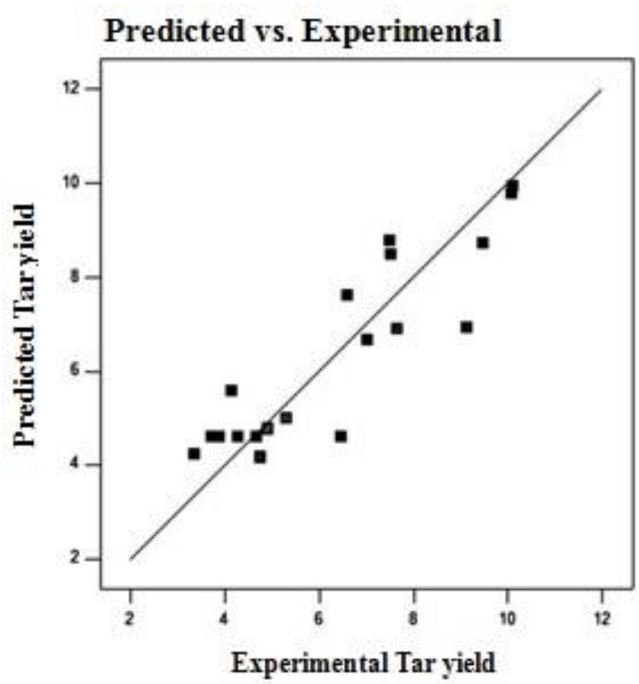
Ash Content Efficiency

Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case R, S, W are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. The "Lack of Fit F-value" of 3.12 implies the Lack of Fit is not significant relative to the pure error. There is 11.89% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good -- we want the model to fit. The "Pred R-Squared" of 0.0121 is not as close to the "Adj R-Squared" of 0.6926 as one might normally expect; i.e. the difference is more than 0.2. This may indicate a large block effect or a possible problem with your model and/or data. Things to consider are model reduction, response transformation, outliers, etc. All empirical models should be tested by doing confirmation runs.

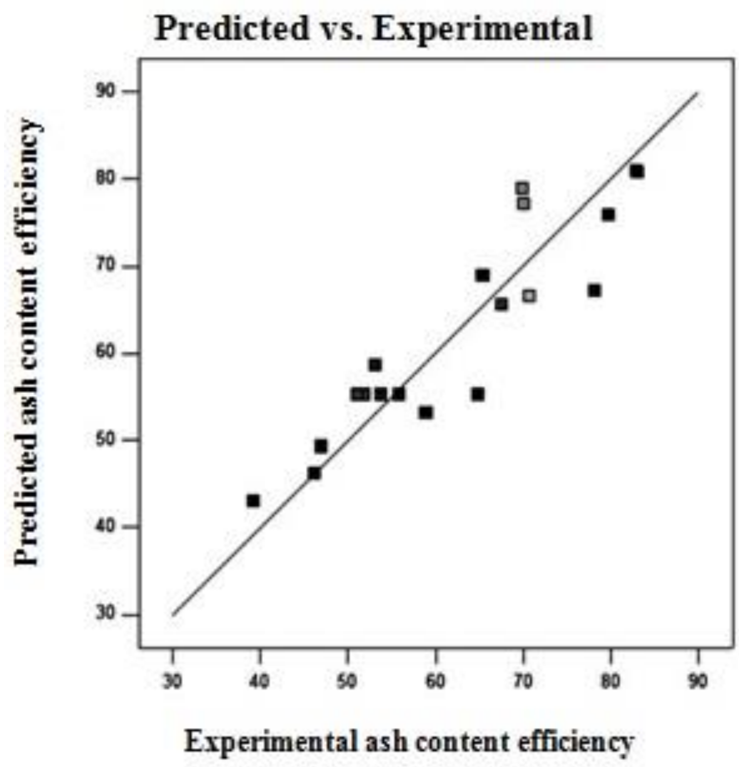
"Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable [36]. The present ratio of 7.484 indicates an adequate signal.



Producer Gas Efficiency



Tar yield



Ash content efficiency
Figure 2. Predicted Vs Experimental

Result and discussions

Agro industrial waste is a predominant biomass used for the gasification. The influences of addition of rice husk clearly demonstrated that, because of the thermal instability of carbon, a higher percentage heating value in a lesser degree of carbon conversion. Generally, increasing the gas efficiency since the heating value of the produced gas will increase with pressure and temperature [38-42]. It is reported that higher conversion of fuel during gasification of wheat husk causes an increases in tar yield. However, higher gas yield is reported with an increase in feed rate in the fuel as a consequence of higher concentration of hydrocarbons. The wheat husk as a biomass plays a key role in the production of more tar during gasification in comparison with other feedstock components. In the case of corn stalk due to the low heating value ash carbon conversion efficiency reported more.

All of this, result indicates a perfect suitability of the regression model. Each of the predicated values compared with the experimental values shown in the Fig.2. A scatter points of the two variables indicates a straight line provides a suitable fit to the experimental data. The differences between two responses are termed as residuals, this shows the measure of the closeness of agreement of the experimental value and the predicted responses; hence, they provide a measure of the adequacy of the fitted model [43, 44]. The difference in the experimental and the predicted responses, with dark points, is the residuals. The linear fit approximates the experimental data points very well; the sum of squares of residual is all very close as shown in the Table 5. Some residuals are one important indicator of the adequacy of a regression fit.

Table 5

Experimental Results

S. NO	Wheat Husk			Rice Husk			Corn stalk		
	Ash content efficiency (%)	Producer gas efficiency (%)	Tar Yield(%)	Ash content efficiency (%)	Producer gas efficiency (%)	Tar Yield (%)	Ash content efficiency (%)	Producer gas efficiency (%)	Tar Yield (%)
1.	35.89	60.61	3.50	31.29	64.11	4.60	38.99	55.77	5.24
2.	35.60	61.00	3.40	31.00	64.50	4.50	38.76	56.11	5.13
3.	35.30	61.15	3.55	30.70	64.65	4.65	38.46	56.24	5.30
4.	35.46	61.62	2.92	30.86	65.12	4.02	38.77	56.65	4.58
5.	36.62	60.49	2.89	32.02	63.99	3.99	39.79	55.67	4.54
6.	34.78	61.41	3.81	30.18	64.91	4.91	37.94	56.47	5.59
7.	34.88	61.36	3.76	30.28	64.86	4.86	38.04	56.42	5.54
8.	34.70	62.45	2.85	30.10	65.95	3.95	38.13	57.37	4.50
9.	35.72	60.94	3.34	31.12	64.44	4.44	38.88	56.06	5.06
10.	36.98	60.31	2.71	32.38	63.81	3.81	40.15	55.51	4.34
11.	36.30	60.65	3.05	31.70	64.15	4.15	39.46	55.81	4.73
12.	36.38	60.61	3.01	31.78	64.11	4.11	39.55	55.77	4.68
13.	35.54	61.03	3.43	30.94	64.53	4.53	38.70	56.14	5.16
14.	36.10	60.75	3.15	31.50	64.25	4.25	39.27	55.89	4.84
15.	35.70	60.95	3.35	31.10	64.45	4.45	38.86	56.07	5.07
16.	35.04	61.28	3.68	30.44	64.78	4.78	38.21	56.35	5.44
17.	37.58	59.01	3.41	32.98	62.51	4.51	40.48	54.38	5.14
18.	36.24	61.63	2.13	31.64	65.13	3.23	39.66	56.66	3.68
19.	36.22	60.69	3.09	31.62	64.19	4.19	39.39	55.84	4.77
20.	37.28	60.76	1.96	32.68	64.26	3.06	40.62	55.90	3.48

Conclusions

1. The present investigation was focused on the agro industrial biomass such as Wheat husk, Rice husk and Corn stalk in a pilot scale fluidized bed reactor. To examine the producer gas efficiency, tar yield efficiency and ash content efficiency.
2. The gasifier was operated at bed temperatures ranging from 650 °C to 950 °C with varying equivalence ratios of 0.2 – 0.5 , pressure 1 to 5 bar, feed rate 5 -20 kg/hr and particle size 70 -500 μm to investigate the efficiencies.
3. The empirical relation was developed in order to quantify the gas efficiency of producer gas.

4. This model gave results with high accuracy showing similar trends in predicting the variation of gas species concentrations in line with experimental data.
5. It was noticed that the producer gas efficiency more in rice husk.
6. However, ash content efficiency more in the case of corn stalk
7. Tar yield reported high in wheat husk.
8. On comparing the efficiency of the producer gas shows better performance in the rice husk when comparing the other feed.

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