International Research Journal of Environment Sciences ISSN 2319–1414
Vol. **1(3),** 11-16, October **(2012)** *I. Res. J. Environment Sci.*

Design and Analysis of Fluidized Bed Gasifier for Chicken Litter along with Agro Wastes

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Available online at: www.isca.in
Received 11th September 2012, revised 20th September 2012, accepted 25th September 2012

Abstract

With the purpose of utilizing the energy content of chicken litter, design of fluidized bed gasifier for chicken litter was carried out. The design methodology adopted by other investigators for rice husk was used in the present case with properties of chicken litter as input data. A pilot scale gasifier was fabricated as per the design. Performance tests were conducted with the fabricated gasifier. The results showed that the design procedure adopted was adequate. The gasification test results were comparable to the same quoted in the literature.

Keywords: Fluidized bed technology, gasification, chicken litter, agro wastes.

Introduction

Currently, the need for the energy is increasing day by day and the commercial energy source alone cannot meet the requirement. The bio-mass is one of the renewable energy sources, which helps to fill the gap between the energy production and the energy demand. Chicken litter is a bio-mass which is available in plenty. Nearly 15,000 millions of chicken are available in the world, which can produce 120 tons of litter per day[1].

Research Methodology

Fuel Characteristics: Tests were conducted to evaluate the percentage of various constituents of chicken litter. The results obtained are presented in table 1.

Table-1
Percentage of Various Constituents Present in the Chicken Litter

Parameter	Chicken Litter (Dry basis)
Moisture content	7.3
Fixed Carbon	4.2
Volatile Matter	53.7
Ash	34.8
Carbon	25.2
Hydrogen	3.5
Nitrogen	6.7
Oxygen	22.25
Sulphur	0.25
Lower Calorific Value (kJ/kg)	10,256
Higher Calorific Value (kJ/kg)	10,333
Ash Deformation Temperature, °C	875

The chicken litter is found to have significant quantity of nitrogen. But, out of the total nitrogen that exists 60 -80% is typically in inorganic form, such as urea and protein. Excessive application of chicken litter in cropping system can result in nitrate contamination of good water. High levels of NO_3 contamination of good water can cause methaemoglobinaemia (blue baby syndrome), cancer and respiratory illness in humans and fetal abortions in live stock. Alternative, environmentally acceptable, disposal routes with potential financial benefits, may lie in large – scale bio-mass to energy schemes that can also provide an easier to handle fertilizer as a by-product. Three options have been considered and in some cases implemented centralized anaerobic digestion, composting and direct combustion with heat and power. The cost of transporting feed stock has, in all cases been the limiting factor[2,3]. Another method of disposal is the fluidized bed gasification, which can be utilized even for high ash content, high moisture content, low carbon and low ash fusion temperature fuels[4].

The fluidized bed gasifier has an air distribution plate and has two functions. It serves as a support to the bed material and also has nozzles or air caps that allow air to flow into the reactor. Below the air distribution plate is the plenum zone where initial combustion is performed for gasifier start-up purposes. The byproducts of combustion flow through the air distribution plate and into the gasifier, heating up the bed material and the reactor walls until a certain temperature is reached. Fuel feeding will commence once the required temperature is reached and the initial combustion process is halted.

Fluidized bed gasifier is more flexible in the selection of fuel type. It can gasify various types of biomass without much difficulty and has high carbon conversion rates as well as high heat transfer rates which enable this system to handle a larger quantity and lower quality of fuels. These gasifier handle smaller fuel particle size compared to the fixed bed gasifier.

Fluidized Bed Gasification Technique: This gasifier utilizes the minimum fluidization velocity of the bed material to achieve fluidization state. Bubbles are formed within the bed and move upwards toward its transport disengaging height. The bubbles carry along with it a small portion of bed material in a portion called ‘wake’, and when it reaches the maximum or transport disengaging height the bubbles along with the carried material burst through the surface of the bed and falls downward the gasifier by gravity. When it’s free fall gravity is balanced by the force of the minimum fluidization velocity, the bed material flow upwards again along with new bubbles formed. This is a cycle that will happen throughout the process, thus increasing the mixing efficiency of the bed material, fuel particles and gasifying agent. This will in turn increase the heat transfer mechanism. Also due to the fluidization the gasifier is in a ‘boiling’ state, the temperature would be uniform in the gasifier.

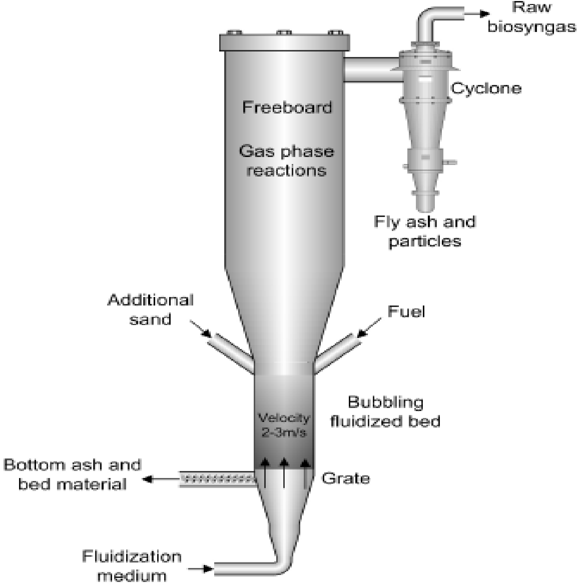

Figure-1
Typical diagram of fluidized bed gasifier

Design Methodology: The gasifier design was made according to the information available in the literature[4,5,6] and from the data’s obtained by the proximate and ultimate analysis process. The calculation was made for all the parts of the system.

Reactor Sub-system: It is made up of the reaction chamber two cylinders arranged vertically, one above the other, externally heat insulation, air distribution plate and a plenum.

Size and shape of the gasifier chamber: Circular and non-circular (rectangular and square) beds have been utilized. Uniform fluidization has been reported in cylindrical containers. But satisfactory fluidization is attainable only in the central section while using non-circular beds, it being fast or feasible along the wall of container and at all the corners. No uniformity has been observed to be more prominent in hot operating condition when using non-circular beds. Hence for fluidized beds gasification a container with a cross-section of circular or near circular is ideally suited.

Bed Material: The investigations reveal that the heat transfer from bed to the immersed tube is a strong function of particle size. The particle size influences the minimum fluidization velocity. The diameter of the bed material is given by the following equation.

$$D_p = (D_i * D_{i+1}) \qquad (1)$$

Bed Height: For the larger diameter of the gasifier chamber a larger bed height is required. Whereas, it requires more fan power to accommodate the pressure drop per unit cross-section of the bed. If this aspect is neglected then deeper beds are preferred than shallow beds from the point of providing adequate residence time for the solid particles to burn completely within the bed. This will lead to less loss of heat in the form of unburnt carbon after deeper beds become essential for accommodating heat transfer tubes which extract heat from the bed. Bed height is generally in the range of 0.3-1.5m[6].

Dust Collector: The dust collector which is concerned with the removal or collection of solid dispersions in gases for purposes of: i. Air pollution control, as in fly-ash removal from power – plant flue gases. ii. Equipment-maintenance reduction, as in filtration of engine-intake air or pyrites furnace-gas treatment prior to its entry to a contact sulfuric acid plant. The figure 2. Shows cyclone collector, one of the best types of dust collectors used in fluidized bed Gasifier.

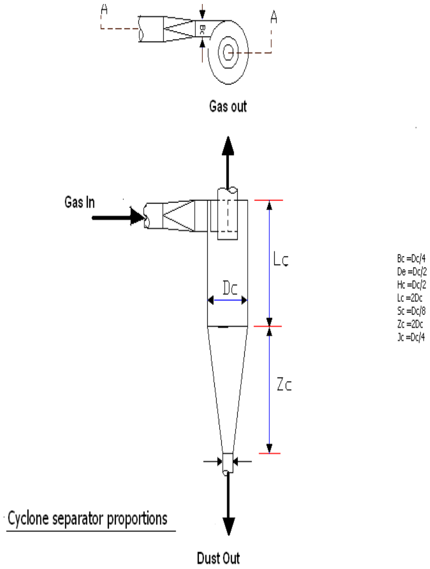

Figure-2
Cyclone Collectors

Gas Distributor: For a better performance of fluidization operation, the gas distributor becomes an important element. The function of a distributor shown in figure 3 may be summarized as follows: i. It must induce fluidization as opposed to spouting, this being of greatest importance in shallow beds. ii. Complete fluidization must be induced on start up and the bed should be maintained in constant motion above all the gas entry points during subsequent operation. iii. The distributor must be capable of operating for long periods without any appreciable increase in pressure drop due to solid deposit.

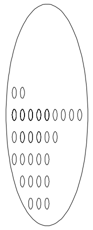

Figure-3

Gas Distributor

Minimum Fluidization Velocity: Fluidization velocity or superficial velocity shown in figure 4, is the condition in which the velocity of fuel increases to a state in which it is reached when all the particles are just suspended in the upward flowing gas or liquid. At this point frictional forces between particles and fluids counter balances the weight of particles. The vertical component of compressive force between adjacent particles disappears and the pressure drop through any section of the bed equals the weight of the fluids and particles in that section.

The Fluidization characteristics of agro waste are very important for the modeling and design of the reactors. Agro waste cannot be easily fluidized due to their peculiar shapes, sizes and densities. For proper fluidization and processing in the reactor, a second solid, usually an inert material like silica sand, alumina, calcite etc., is used to facilitate fluidization of agro waste. It also acts as a heat transfer medium in the reactor. The fluidization of sand and agro waste mixtures is characterized by particles of different shapes, sizes, densities and compositions.

The lower limit of the superficial velocity or minimum fluidized velocity of the gas that will flow through the particle bed is calculated separately for sand, chicken litter, Rice Husk and saw dust using the following expression[5]:

$$U_{mf} = \frac{\{dp^2(\rho p-\rho f)g\epsilon^3\phi^2\}}{\{150\mu(1-\epsilon)\}} \qquad (2)$$

Terminal Velocity of the particle: The maximum value of the superficial velocity of the gas was determined for all the materials of the bed depending on the Reynolds number (for 0.4 < Re < 50) of the particle using the following expression[5].

$$U_t = dp\left\{\frac{4(\rho_p-\rho_f)^2 g^2}{225\rho_f\mu}\right\}^{1/3} \qquad (3)$$

Fluidization Velocity during Gasification: The superficial velocity of the gas to be used during the Gasifier operation was established considering the relation between the expanded and the minimum heights of the fluidized bed.

$$\frac{H}{H_{mf}} = 1 + \left\{\frac{\left[10.978\,(U_f - U_{mf})^{0.738}\ \rho_p^{0.376}\ d_p^{1.006}\right]}{U_{mf}^{0.937}\ \rho_f^{0.126}}\right\} \qquad (4)$$

For the fluidized bed, suggested in equation (4) was used.

$$1.2 < \frac{H}{H_{mf}} < 1.4 \qquad (5)$$

For the design, a value of 1.3 was selected for equation (5) and equation (4) was solved to determine the value of U_f [9].

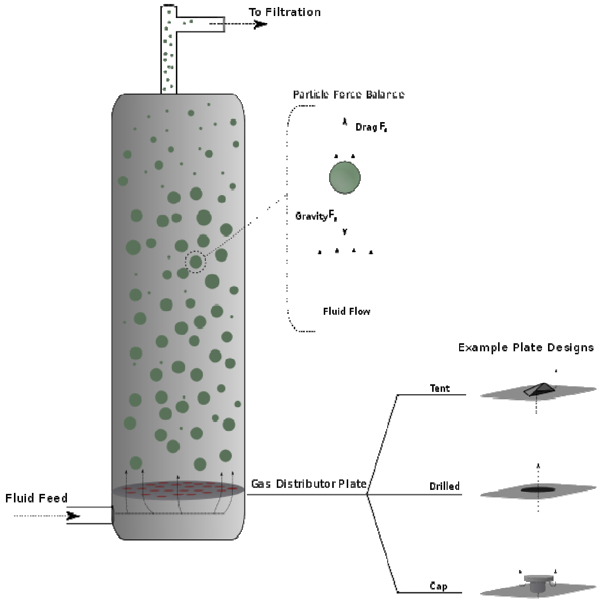

Figure-4
Fluidization Velocity Condition

Overall Height of the Gasifier chamber: The gasification involves only partial oxidation of the fuel, the heat released inside a gasifier is only a fraction of the heating value of the fuel. Also, a part of the heat released is absorbed by endothermic reactions taking place inside the gasifier. It is, therefore uncommon to recover heat from the main gasifier column. Both gas and solid residence time is influenced by the gasifier height. The overall height of the reaction chamber was determined by the expression shown in equation (6)

$$H_t = TDH + H \qquad (6)$$

In some cases, the total gasifier height should be sufficiently high to accommodate the dense bed and a transport or threshold disengagement section, which would avoid excessive loss of bed materials. Another consideration that imposes a minimum limit on gasifier height is the poor carbon conversion resulting from low residence time for the char particles. The threshold disengaging height was calculated using the equation (6a) based on the internal diameter and the fluidization velocity.

$$Log\left(\frac{TDH}{dt}\right) = m\log dt + \log b \qquad (6a)$$

$$where\ m = -0.115U_f - 0.587, and\ b = 4.46V_0$$

The maximum expanded height of the bed was assumed as 12cm (0.12m), being twice the internal diameter of the reactor[6].

Pressure Drop in the Fixed Bed: The pressure drop in the fixed bed was calculated using the following relation[7].

$$\Delta p = \frac{\{150H_t(1-\epsilon_m)^2 \mu\, U_0\}}{\{g\, \epsilon_m^2\, \emptyset_{s\, dp}\}} \qquad (7)$$

Mass Balance: For the development of the mass balance, the energetic components obtained from the typical concentration of the producer gas obtained in the analyzer, i.e. concentrations of carbon monoxide (CO), hydrogen gas (H_2), and methane (CH_4) were used.

The fuel gas will contain typical products of combustion, with the exception of Oxygen which will be present in insignificant amounts. The CO_2, H_2O and N_2 proportions in the fuel gas will depend on the fuel chemical composition and the amount of air in the reaction. According to this, the global reaction of the gasification process was raised and is being presented in the following equation:

$$X_1\,(3.05\,C + 5.83H + 2.29O + 0.24\,N) + X_2(O_2 + 3.76N_2 + a\,H_2O + bH_2O)$$
$$X_7\,(12CO + 4\,H_2 + 3CH_4 + X_3H_2O + X_4CO_2 + X_5N_2) + X_6C \qquad (8)$$

The water contents in the poultry litter saw dust and rice husk were obtained by means of proximate analysis.

Air Mass Flow: From the fluidization parameters previously established, the air mass flow necessary for the process was determined through the expression:

$$m_a^{\cdot} = 3600\left(U_f\, A\, \rho_f\right) + 0.648\, b \qquad (9)$$

Global Gasification Reaction Co-efficient: From the molar balances for each element in equation (8), the global gasification reaction co-efficient were obtained.

Mass Flow: A manual feeding of the chicken litter saw dust and rice husk was developed for the required flow rate of the gasification process.

Solid wastes Mass Flow: For the calculation of the total amount of solid waste resulting from the gasification process, a value of 20 % of residual carbon not converted was added to the ash content. The amount of solid waste mass flow can be determined by the following expression:

$$m_w^{\cdot} = 0.22m^{\cdot} \qquad (10)$$

Producer Gas Mass Flow: The producer gas mass flow was calculated using the following relation:

$$m_g^{\cdot} = m^{\cdot} + m_a^{\cdot} + m_w^{\cdot} \qquad (11)$$

Equivalence Ratio (Φ): The equivalence ratio of the gasification process is one of the most important parameter for the adjustment of operating conditions. Its value is defined as:

$$\emptyset = \frac{(Air-fuel\ Ratio)_{act}}{(Air-fuel\ Ratio)_{stoichiometric}} \qquad (12)$$

Where the Stoichiometric Air-Fuel Ratio is taken to be 1.947 and the actual Air-Fuel Ratio is determined by balancing O_2 in the following equation.

$$C_aH_bN_cO_d + x(O_2 + 3.76\,N_2) \rightarrow CO_2 + yH_2O + zN_2 \qquad (13)$$

Energy Balance: The energy balance of the gasification process was established using the relation in equation (14)

$$E + E_a = E_g + E_l \qquad (14)$$

From the lower heating value (LHV) of chicken litter, rice husk and saw dust and the mass flow, the energy available in them was calculated using the following relation.

$$E = m^{\cdot}\,(LHV)/3600 \qquad (15)$$

Since the atmospheric air entering the reaction chamber is at the same reference temperature of 25°C, the fluidization-gasification air energy (E_a) is nil.

Producer Gas Energy: The energy contained in the producer gas produced during the process was obtained by means of the following expression.

$$E_g = E_u + E_s \qquad (16)$$

The useful energy of the producer gas corresponds to its chemical energy which is given by the following relation.

$$E_u = m_g^{\cdot}(LHV)/3.6\rho_s \qquad (17)$$

Where, $LHV_g = 0.1263(\%CO) + 0.358(\%CH_4) + 0.1079(\%H_2)$ (18)

The sensible energy of the produced gas incorporates the synthesis gas, at its exit temperature taken to be 750°C. The following expression is used to calculate the sensible energy.

$$E_s = m_g^{\cdot} \sum(y_ih_i)\,/3600 \sum(y_iMw_i) \qquad (19)$$

Energy Losses: The energy losses in the solid wastes and to the atmosphere the energy balance.

$$E_l = E_{wall} + E_w \qquad (20)$$

The energy contained in the wastes is given by the expression:

$$E_w = E_{cw} + E_{ash} \qquad (21)$$

The energy due to residual carbon in the waste is determined by the following relation.

$$E_{cw} = 0.2\, m_w^{\cdot}\,(LHV_{cw} + h_{cw})/3600 \qquad (22)$$

On the other hand, the energy loss by sensible heat in the ashes was calculated from the following expression.

$$E_{ash} = (0.8m_w^{\cdot})\big(820 + 1.67(T_{ash} - 273)\big)/3600 \qquad (23)$$

Finally, The Table 2 shows the properties of different materials used in the design of fluidized bed gasifier. In this table, the properties of saw dust and rice husk are also considered because the saw dust and rice husk are used as the droppings over the chicken litter in the farm sheds

Results and Discussion

The results obtained from the calculations of the design of the fluidized bed gasifier is summoned in the table 3

The results obtained from the gasification of the developed fluidized bed gasifier were tested for chicken litter, saw dust and rice husk. The results of the gasification of these were compared with the results of the other authors and it is tabulated in the table- 4.

The results show that the mathematical model developed for the equivalence ratio of 0.20 – 0.35 can be considered working satisfactory. There are differences with the other values, but these differences can be considered acceptable, taking into account the simplicity of the proposed design and the complexity of the real process.

The comparison of different gases obtained from the developed gasifier is made with the results of the other authors to validate the proposed design are presented in the table-4. Regarding the heating value produced, the hydrogen and carbon monoxide concentrations for the experiments developed with the chicken litter, rice husk and saw dust were relatively agreed with the data reported in the literature, while the methane composition was underneath. This deficiency can be explained due to the low carbon combustion efficiency.

Table-2
Shows the Physical Properties of the Different Materials used for the Design of the Fluidized Bed Gasifier.

Parameter	***Sand[9]***	***Chicken Litter[7]***	***Saw dust[8]***	***Rice husk[4]***
n Particle Size (µm)	385	850	316	856
Apparent Density ($kg.m^{-3}$)	2650	422	242	389
Porosity	0.46	0.65	0.8	0.64
Sphericity	0.78	0.98	0.95	0.49

Table-3
Shows the Results Obtained Considering the Designed Parameters

Parameter	***Sand***	***Poultry Litter***	***Saw Dust***	***Rice husk***
Reaction Chamber				
Min. Fluidization Velocity (m/s)	0.07	*0.3554*	*0.086*	0.077
Terminal Velocity of the particle (m/s)	*3.61*	*2.34*	*0.6*	2.233
Fluidization Velocity during gasification (m/s)	*0.246*	*1.558*	*1.1013*	0.26
Overall Height of the reaction chamber (m)	*nil*	*2.4*	*3.6*	2
Pressure drop (kPa)	*nil*	*10.58*	*7.4664*	4.148
Mass Balance				
Mass Flow (kg/hr)	*nil*	0.4	0.4	0.4
Air Mass Flow (kg/hr)	*nil*	1.8	1.27	1.883
Solid waste Mass Flow (kg/hr)	*nil*	0.0168	0.0024	0.088
Producer Gas Mass Flow (kg/hr)	*nil*	2.18	1.7	2.195
Equivalence Ratio	*nil*	0.256	0.35	0.27
Energy Balance				
Energy Available (kW)	*nil*	*1.22*	*2.17*	1.83
Gasification Air Energy (kW)	*nil*	*0*	*0*	0
Producer Gas Energy (kW)	Useful energy	1	1.827	1.271
	Sensible energy	$2.27x10^{-3}$	$1.87x10^{-3}$	$2.38x10^{-3}$
	Total	1.00227	1.83	1.27338
Energy Loses (kW)	To the wall	0.2074	0.37	0.3144
	As waste	0.0397	0.00465	0.2355
	In ash	0.00774	0.00214	0.0405
	total	0.25484	0.37679	0.5499

Table-4
Shows the Comparison of Results Obtained from the Present Work and the Work from Several Authors

Parameters		**Chicken Litter**	**Saw Dust**	**Rice Husk**	**Chicken Litter[7]**	**Saw Dust[8]**	**Rice Husk [9]**
Producer Gas Composition %	Equivalence Ratio	0.21	0.25	0.21	0.34	0.3	0.32
	CO_2	7.0	9.9	9.0	18.2	14.10	nil
	CO	13.5	15	9.4	9.6	18.69	11.1
	CH_4	0.4	0.1	0.45	9.7	3.41	3.45
	H_2	3.2	6.1	2.0	2.8	10.63	4.56

Conclusions

The chicken litter can be used as alternative fuel which can fill the gap between the demand and the generation of energy.

Through a simple and practical mathematical model, the design and basic sizing of a fluidized bed gasifier on a pilot scale was carried out.

The comparison of results obtained from experimental tests showed that the proposed model can be a useful tool with the preliminary prediction of the performance variable values of fluidized bed gasifier.

The results indicates that the research on the development of this clean technology for the utilization of the chicken litter can be successful through fluidized bed gasification technology.

Nomenclature

dp	mean diameter particle in m
E_a	Fluidization –gasification air energy in kW
E_{cl}	Chicken litter energy in kW
E_{cw}	nonburned carbon energy loss in kW
E_l	energy losses in kW
E_g	produced energy in kW
E_{wall}	wall energy losses in kW
E_w	energy contained in the wastes in kW
E_s	sensible energy in the produced gas in kW
E_u	useful energy in the produced gas in kW
E_{ash}	loss of energy by sensible heat in the wastes
g	gravity acceleration in m.s^{-2}
h_{cw}	carbon enthalpy (to 750^0 C) I kj.kg^{-1}
H	Complete fluidization height in m
H_{mf}	minimum fluidization height in m
H_t	overall container height in m
$\dot{m}_a$	dry air mass flow in kg.h^{-1}
$\dot{m}_w$	solid wastes mass flow in kg.h^{-1}
$\dot{m}_g$	produced gas mass flow I kg.h^{-1}
LHV_{cw}	carbon low heating value in kg.h^{-1}
Re	Reynolds number
TDH	Threshold disengagement height of fuel particles in m
U_f	fluidization velocity during the gasification in m.s^{-1}
U_t	terminal particle velocity in m.s^{-1}
U_{mf}	minimum fluidization velocity in m.s^{-1}
%C	carbon in the chicken litter
%CO	monoxide carbon volumetric concentration
$\%CH_4$	methane volumetric concentration
%H	hydrogen in the chicken litter
$\%H_2$	hydrogen volumetric concentration
%O	oxygen in the chicken litter
%S	sulfur in the chicken litter

Greek Letters:

ε	particle porosity
φ	sphericity
ψ	load factor
μ	air viscosity to the temperature and pressure operation conditions of the gasifier of the gasifier
ρ_{cl}	chicken litter density in kg.m^{-3}
ρ_f	air density to the temperature and pressure conditions of the gasifier
ρ_g	produced gas density under normal conditions of temperature and pressure
ρ_p	particle density in kg.m^{-3}
ξ	equivalence ratio.

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