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RECYCLING OF MUNICIPAL SOLID WASTE FOR ELECTRCITY GENERATION AND GREEN EARTH

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Abstract: *Waste generation is increasing everywhere. Hence improved waste management is an essential element to make the resource efficient. Municipal Solid Waste (MSW), generated if not properly managed, causes health and environmental issues. The conventional method of solid waste management is land filling and incineration. Though, these methods have proven advantages, they have drawbacks such as place occupation, smell and Green House Gases (GHG). This paper focuses on the recycling of MSW in a Bubbling Fluidized bed reactor. Furthermore, the modeling of a Far-infrared heater to heat the Bubbling Fluidized Bed Reactor is also carried out. Moreover, the composition of synthesis gas with reduced tar and char composites is also obtained and the optimum parameters for efficient energy production are identified from the available municipal solid waste.*

Keywords: Far-infrared heater, gasification, Municipal Solid Waste, Syngas.

1. Introduction

Renewable energy technologies are utilized throughout the world for "clean energy" as the concerns for the impact of non-renewable energy extraction and the use on the environment increases. Waste is a promising resource for sustainable energy generation and the potential to improve the economy of the country. Municipal Solid Waste (MSW) are generated more than 55 million tons and is estimated that the amount of generation will increase every year. The Ministry of New and Renewable Energy has predicted that there exists a power generation potential of about 1500 MW from the MSW generated in India and the Indian Government is actively promoting the waste to energy technologies. But, according to the Indian Renewable Energy Development Agency (IREDA) only 2% of the potential has been tapped in India so far. The per capita waste generation in India is 0.2-0.6 kg/day which is estimated to increase at 1.33% annually. As per the estimates, 115000 tons of solid waste is generated per day in the country. Management of MSW remains one of the most neglected areas of urban development in India. Municipal agencies spend about 5-25% of their budget on MSW management. In spite of such expenditure, the present level of service to MSW is so low that there is threat to public health and environmental quality [1].

Gasification process is a thermo chemical process where carbon based material such as paper, plastic, petroleum based waste or biomass are exposed to an environment poor in oxygen so that combustion does not occur. The feedstock materials are converted into gaseous energy carrier known as synthesis gas (syngas). This is a gas mixture that comprises of carbon monoxide, carbon dioxide and hydrogen. The produced syngas can be used for electricity generation, manufacture of chemical, hydrogen or transportation of fuel, basic chemical feedstock in petrochemical industries, syngas treatment to produce steam for use in fuel cell [2]. Among the various gasifiers, Bubbling Fluidized Bed Gasifiers (BFBR) achieves higher efficiencies. The tar formed as a result of the gasification process leads to more frequent maintenance and results in lower plant capacity factors. Hence, this leads to a decrease of revenues or to higher investments.

This paper investigates MSW as biomass feedstock. The high tar production can be avoided by improving the design of BFBR and selection of the operating parameters of the system. Moreover this study is sought to revive the use of BFBR heated by a far- infrared heater for MSW. The paper is organized as follows: Section II focuses on the various gasification processes. Section III focuses on the modeling of a far-infrared heater and the estimation of syngas composition. Section IV is about the results and discussions. Section V concludes the paper with the future scope.

2. Gasification process

The most important part of the gasification process is the gasifier. The gasifier efficiency is an important factor used in determining the technical and economic viability of using a gasifier system. There are various types of biomass gasifier technologies, each designed for specific fuel types. The efficiency and effectiveness of these gasifiers is dependent on the gasifier type/ design, the various types of biomass gasifiers are fixed bed, fluidized bed and entrained flow gasifiers. Among these gasifiers, fluidized bed gasifiers achieve higher efficiencies than other gasifier type. Tar formed in gasification is a mixture of organic components ranging from low molecular weight components like benzene to heavy poly-aromatic hydrocarbons. Tars are equivalent to a major economic penalty in biomass gasification. Tar aerosols and deposits lead to more frequent maintenance and repair of especially gas cleaning equipment and resultantly lower plant capacity factors. This leads to a decrease of revenues or to higher investments. The tar in the gas poses major operational challenges because it clogs in the engine valves resulting in high engine maintenance costs.

Because of the carbon dioxide emitted during conversion of biomass to electricity is matched by that sequestered during biomass growth, life-cycle CO_2 emissions from bioelectricity are very low, with net emissions resulting from use of fossil fuels for cultivation, harvesting, transport and pre-treatment and processing of the biomass fuel. CO_2 emissions from procurement of biomass fuels are also generally lower than from procurement of fossil fuels. Replacement of fossil-fuel-based electricity with bioelectricity therefore results in significant reductions in greenhouse gas emissions. The levels of emissions of other gases and particulates from biomass power plants depend on the fuel, conversion technology, plant operational characteristics and the use of emission reduction measures. Because of the generally low level of sulphur in biomass, SO_x emissions are usually substantially reduced in bioelectricity production compared with coal or oil-based electricity. With good planning, design and management of the entire bioelectricity production chain, it is usually possible to limit any negative environmental impacts to satisfactory levels.

Various thermo chemical processes take place in a limited supply (26-33%) of the oxidizer (air or oxygen) in a specially designed reactor commonly referred to asbiomass gasifier. In this reactor, the biomass particles undergo drying, pyrolysis, oxidation and char reduction reactions to generate a gaseous mixture of combustibles namely carbon-monoxide, hydrogen and methane, and diluents namely carbon dioxide and nitrogen. In the drying zone biomass materials are dried at temperature above 100°C, carbonization takes place above the heath/combustion zone at temperature between 600°C-800°C converting biomass materials into charcoal giving off nitrogen, methane and some tar. In the oxidation zone/heath combustion of biomass takes place resulting in carbon dioxide and water vapour. Various high temperature chemical reactions take place in the reduction zone below the oxidation zone; the carbon dioxide from combustion reacts with carbon and is reduced to carbon monoxide. The water vapour also reacts with carbon and forms carbon monoxide and hydrogen; then the hydrogen reacts with carbon dioxide and form carbon monoxide and water vapour. The hydrogen also reacts with carbon to form methane. It is in this zone where a large proportion of syngas is formed.

3. Methodology

3.1 Modeling of far-infrared heater

The filament used is a Nickel Chromium alloy coil element (Nikrothal 80) from Kanthal Industry. It has a good workability and can operate at high temperatures up to 1200 °C. It has a spiral form with dimension of 0.3mm diameter and 4m long respectively; it is flexible and can be embedded into ceramic clay. The filament wire is characterised with a high resistivity, a good oxidation resistance and stability. Due to the passage of an electrical current *(I)*, the filament initially in thermal equilibrium will oppose a resistance. The variation of the filament temperature is equal to the power lost by the filament through convection and radiation. Steady state is reached when the current passing through that filament has become constant. The variation of the filament temperature during the passage of current is given by equation (1)

$$m_f C_{pf} dT/dt = P - Q_{conv} - Q_{rad} \quad (1)$$

where,

$$m_f = \rho V \quad (2)$$

$$P = U^2 / R_{ef} \quad (3)$$

$$Q_{conv} = h_{conv} A (T-T_\infty) \quad (4)$$

$$Q_{rad} = \epsilon \sigma A (T^4-T^4_{surr}) \; A_f = \pi D L \quad (5)$$

The rate of temperature change is shown in equation 6:

$$dT/dt = 1/ \rho V C_p [U^2 / R_{ef} - h_{conv} A (T-T_\infty) - \epsilon \sigma A (T^4-T^4_{surr})] \quad (6)$$

3.2 Evaluating syngas estimation

The product gas (synthesis gas or syngas) from the biomass gasification is a mixture of carbon dioxide (CO_2), carbon monoxide (CO), hydrogen (H_2), methane (CH_4), water (H_2O) and nitrogen (N_2) if air is used as a gasifying agent. Syngas has been mostly accepted for power generation and is considered to be more mature technology compared to other biomass conversion processes. In this paper, the main features and assumption are summarized as follows:

All carbon content in biomass is converted into gaseous form and the residence time is high enough to achieve thermodynamic equilibrium. This might not be true in an actual gasification process. The products taken into account are CO, CO_2, H_2, CH_4, N_2 and water. These are the major gaseous compounds formed during the gasification process. Hydrocarbons other than CH_4 were assumed negligible in syngas and were not taken into account.

Ash in the feedstock was assumed inert in all gasification reactions although it holds true typically only for reaction temperatures less than 700°C. Herbaceous biofuels contain silicon and potassium as the major mineral content which lowers ash fusion temperature below 700°C whereas gasification generally occurs at temperatures higher than 700°C. Therefore, the relations derived in this study cannot be used effectively for biomass with high mineral content.

All the gaseous products are assumed to behave as ideal gases. This will lead to insignificant errors because the gasification in fluidized bed gasifiers is conducted at high temperature. The process is completely adiabatic so that no heat losses occur from the gasifier. The amount of air is varied to achieve the desired reaction temperature in the gasifier.

Output from the gasification is assumed only to be permanent gases free of oxygen which is true because the oxygen supplied is far less than that needed for combustion in a gasification process. Sulfur and chlorine content in biomass were also neglected since they are less than 0.6% in most biomass feed stocks.

The chemical composition of biomass is taken to be in the form CH_XO_Y and the global reaction can be written as follows:

$$CH_x O\, y + a\,(O_2+3.76N_2) \rightarrow CO_2 + H_2O+3.76 * a * N_2 \quad (7)$$

where,

a = stoichiometric value of air required for gasification

$$CH_X O_Y + m_wH_2O + X\, g\,(O_2 + 3.76\, N_2) \rightarrow X_1H_2 + X_2CO + X_3 CO_2 + X_4H_2O + X_5CH_4 + 3.76XgN_2 \quad (8)$$

where,

Xg = the actual fuel to air ratio and mw is the amount of water per k mol of biomass

3.3 Composition of tar and char

The major challenge of biomass gasification is related to the formation of tar, a highly variable mixture of condensable aromatic hydrocarbons in the syngas which condense inside the gasifier or in the equipment used for handling the product stream to its end use.

The composition of tar for gasification of MSW in a bubbling fluidized bed gasifier is described below:

$$Y_{tar} = -2.8025*1/\{1-1112.345* \ln[-912*0.0889*(T-273.15)] +45.698 \ln Z \quad (9)$$

where,

Z =(T-833)/160

The amount of char formed during gasification seems to decrease exponentially when the surrounding temperature increases.

$$Y_{char} = 5/\{1-1.25*\exp[-5*0.002*(T-273.15)]\} \quad (10)$$

From the molar balances for each element in eqn. the global gasification reaction coefficients were obtained:

$$8.1\,(3.96\,C+ 6.05\,H + 2.84\,O) + 13(O_2+ 3.76N_2) + 1.54\,H_2O +0.72H_2O \rightarrow 0.696 \text{ x } (22\,CO + 23\,H_2 + 2.75\,CH_4 + 10\,H_2O + 21\,CO_2 + 49\,N_2) \quad (11)$$

The solid waste mass flow is calculated using the equation:

$$m_{sw} = 3 \text{ x } R+ 0.648 \text{ x } a \quad (12)$$

where,

R = Reynolds's number

a = area

For the calculation of the total amount of solid wastes resulting from the gasification process, a value of 20% of residual carbon not converted was added to the ash content, obtaining the following relation:

$$m_w = 0.22 * m_{sw} \quad (13)$$

where,

m_{sw} is the mass of solid waste

Therefore, the fuel gas mass flow produced was determined from the mass balance.

$$m_g = m_{sw} + m_a - m_w \quad (14)$$

where,

$m_a = 62.254$

The energy contained in the synthesis gas is obtained by

$$E_g = E_u + E_s \quad (15)$$

where,

the useful energy corresponds to the chemical energy of the energetic gaseous mixture is:

$$E_u = (m_g \text{ x } LHV_g) / (8.6 \text{ x } 1.171) \quad (16)$$

where,

$LHV_g = 0.1263*(\%\ CO)+0.358*(\%\ CH_4) +0.107*(\ \%\ H_2)$

The other term, the sensible energy of the produced gas, incorporates the enthalpy of each component of the synthesis gas at its exit temperature.

$$E_s = m_g \text{ x } \Sigma (y_i h_i) / 3600\, \Sigma (y_i Mw_i) \quad (17)$$

Therefore,

$$E_g = E_u + E_s \quad (18)$$

4. Results and Discussions

From the equations used for modeling, the solid mass flow rate was found to be 25.3kg/hr. The fuel gas mass flow was estimated as 81.984 kg / hr. The equations was modeled using MATLAB/SIMULINK and the obtained results were found to be equal.

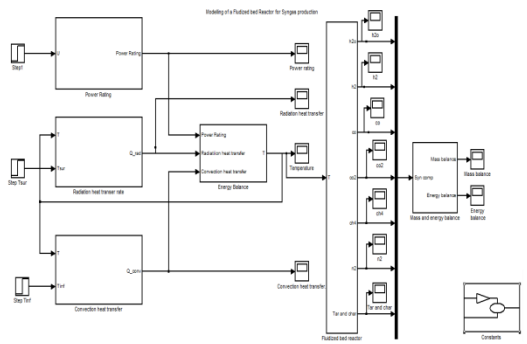

Figure 1 : MATLAB/SIMULINK diagram

The results obtained represent validation of the FIR model analysis with a constant ambient temperature and surrounding of T=298.15 K.

The rising of temperature in the heating rate simulation as expected and it reaches its maximum temperature as mentioned by the manufacturer. Steady state is reached quickly as the dynamic is very fast within 30 seconds. The maximum temperature expected for the FIR-heater is 1200°C for a power rating of P=0.78 kW, which confirms the simulation. However above the required voltage, the ceramic may crack as the stability of filament is no longer supported. Oscillations have been observed when the input voltage is greater than 120V.

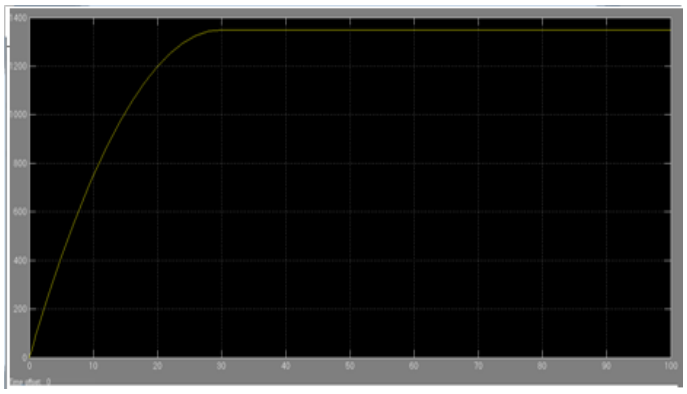

Figure 2 : Heating rate of filament

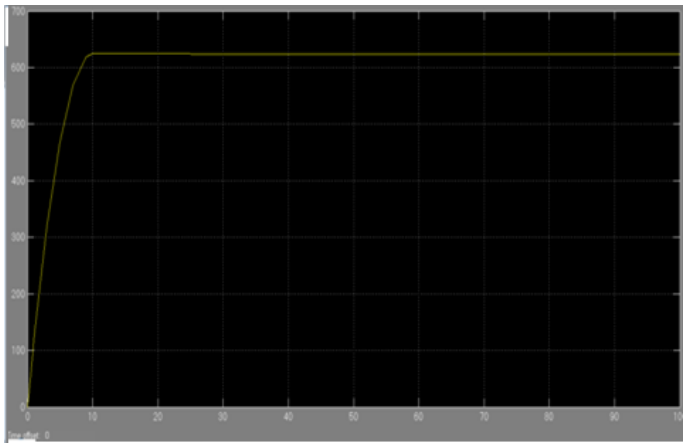

Figure 3: Radiation heat transfer rate

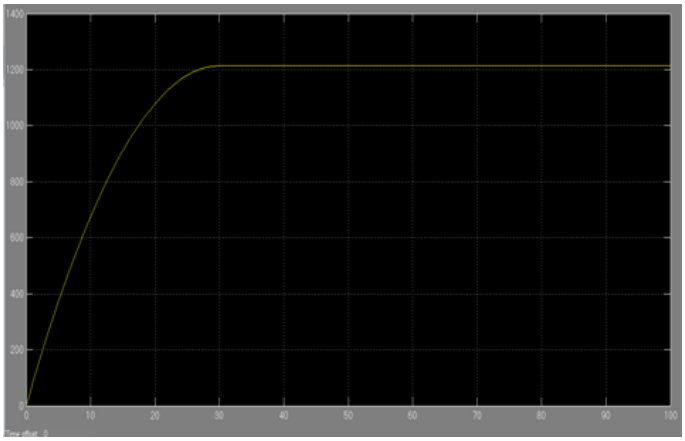

Figure 4 : Temperature

The temperature from the heater helps to produce optimum syngas from the Bubbling Fluidized bed reactor. The percentage syngas are obtained by simulation done using MATLAB / SIMULINK and the results are tabulated as follows:

Table 1: Percentage syngas composition

Gas components	*Variables*	*Predicted values*	*Mole fraction*	*Percentage (%)*
H_2	X_1	0.7344	0.1956	19.56
CO	X_2	0.6474	0.1724	17.24
CO_2	X_3	0.6170	0.1642	16.42
H_2O	X_4	0.3199	0.0852	8.52
CH_4	X_5	0.0835	0.0224	2.24
N_2	$3.76*X_6$	1.3525	0.3602	36.02
Total		3.7547	1.0000	100.00

The composition of tar should be below 10 mg/Nm^3 for normal function of the fluidized bed gasifiers. Here, the tar composition below 2mg/Nm^3 for the equivalence ratio greater than 0.2 is obtained.

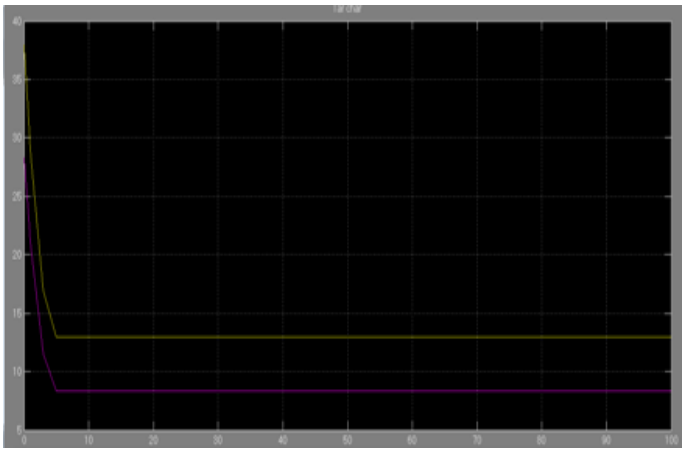

Figure 5 : Reduced tar and char

The energy produced from the synthesis gas is found to be 55.525 KW.

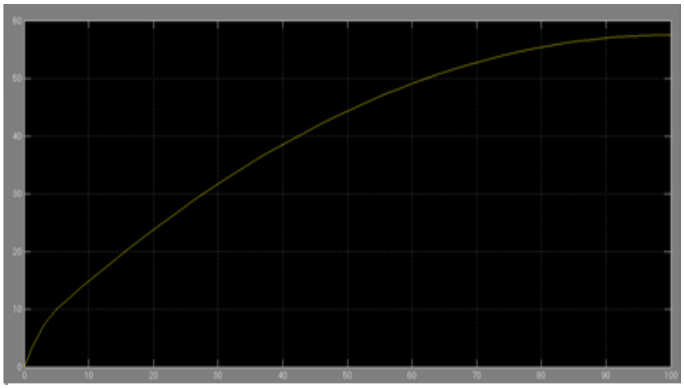

Figure 6 : Produced energy from syngas

The produced syngas can be used for electricity generation, manufacture of chemical, hydrogen or, transportation of fuel, basic chemical feedstock in petrochemical industries and for syngas treatment to produce steam for use in fuel cell. The gasifier efficiency is expected to be 76 %, and complete gasification of solid waste fed is pre-dried to a value below 10 % wt moisture on a wet basis, to allow proper gasification.

5. Conclusion

A far-infrared ceramic heater was modeled using MATLAB/SIMULINK, to heat the BFBR. The BFBR utilized the MSW as feedstock and produced gas energy for various applications. Moreover, the major drawback of biomass gasification which is the high tar and char content is reduced with the effect of infrared heater on the reactor.

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