Design and modelling of MSW (RDF) gasifier

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Abstract. Increase in population and technology advancement leads to higher generation Municipal Solid Waste (MSW). The current method of disposing solid waste of by incineration process, which operates at high capital, Operation and maintenance cost and emission of toxic gases. This paper discusses the process design to model the MSW gasifier to minimize heating requirement when compare with conventional incineration process for a waste disposal. The modelling aims to gasify the MSW to produce heating value syngas in 10 kW downdraft gasifier. The gasifier is configured in with equivalence ratio, gasification agent, feedstock flexibility, thermo-chemical process (auto-gasification) control, low tar formation and other parameters. The designed modelled yields biomass feed rate, gas flow rate, gas heating value, energy efficiency, specific gasification rate. An impressive option on reduction of landfill disposal from above designed gasifier model is feasible.

Keyword: Landfill; MSW gasifier; auto-gasification; incineration

1. Introduction

Due to high accumulation of solid waste on the domestic places together with the aggravation of environment problems caused by an increased number of Land fill sites, there is an increased interest in the research and development of techniques used in solid waste management. These process represent a solution for the future in sustainable environment friendly, taking into consideration the interest in reducing greenhouse gas emissions, as well as air and soil pollution [1].

According to [2], Land fill sites represents one of the main pollutant factors of groundwater contamination, more than 90% of the Municipal Solid Waste (MSW) generated in India is directly dumped on land in an unsatisfactory manner. From the 2012-13 Central Pollution Control Board (CPCB) Report, only 19 percent of the total waste generated is treated. The un tapped waste has a potential of generating 439 MW of power from 32,890 tonnes per day of combustible waste including Refused Derived Fuel (RDF).

In order to sustain this energy, an optimization in the waste utilization of the Municipal Solid Waste is mandatory until it reaches maximum level closer to that of the waste-to-value processing. Nowadays, the most expensive technology of a waste processing is the incineration, which represents main factors affecting capital and operating cost.

As presented by [3], an increase of waste-to-value is anticipated by 2025, reaching a zero level sustainable waste processing, which will determine a significant decrease in the environmental effects of the MSW, helping them reach by reduce in the carbon footprint.

Composition of municipal solid waste. The municipal solid waste consists of combustible substance, non-combustible substance, and material with high moisture. The combustible substance comprises up to 80% of plastic and paper, while the remaining 20% represents wood, organic, and textile waste. Due to the high organic contents of these combustible substance, it could be a promising feedstock as refuse-derived fuel (RDF) for further processing into gaseous fuel.

Conversion procedure of municipal solid waste into refuse-derived fuel starting from collection of waste followed by pretreatment of the mixed composting with spraying of chemicals and enzymes. Next, the mixed composting is dried under hot sun. The bulk item is separated manually followed by screening of mixture according to desire mesh size. After the mixture was separated, it will then undergo further size reduction mechanically followed by magnetic and air separation to remove metals and light materials. Finally, refuse-
derived fuel is produced in the form of brick, fluff, and pellets [11].

Municipal Solid Waste (MSW) [4] is being used in energy-to-waste plants and as fuel substitutes in different industrial processes. Particularly Refuse Derived Fuel (RDF) selected fractions from MSW has distinct possibilities for the future waste-to-energy technologies. This paper aims at conducting a feasibility study of energy recovery of RDF from MSW generated. Downdraft gasifier is selected because the low the tar content produced at least 0.04 g/Nm3, while the gas produced is relatively high and clean [5].

2. Materials
In this article a MSW Gasifier, based on the reviewed parameters of the Refuse-derived fuel (RDF) was designed in order to emphasize combustible components from waste to material and to evaluate the lower heating value for specific gasification rate. On this design model, a 10 kW downdraft gasifier parameters will be computed and then details regarding method of processing will be studied through process design to model.

2.1. Refuse Derived Fuel (RDF)
The potential RDF of the MSW shows it is a suitable fuel source for energy production and power generation. The combustibles in RDF resource consist (i.e. plastics, paper, textile, mixed organic waste, wood, and rubber) in an evaluation of energy recovery and benefits in terms of heating value and homogeneity obtained. The following Table 1[4] shows the values of the proximate analysis and ultimate analysis for the RDF material for Moisture, ash content and volatile matter (wt%).

| Proximate analysis (%wt) | Ultimate analysis (%wt) |
|--------------------------|--------------------------|
| Moisture | 4.00  |
| Volatile matter | 81.47  |
| Fixed carbon | 9.73  |
| Ash | 4.80  |
| High heating value (kJ/kg dry basis) | 29,410  |
| Density (kg/m³) | 930  |

3. Methodology
The steps used to calculate the expression of the design to model process are presented in figure 1. First the assumptions of the design process were considered and to obtain moisture content (MC), volatile matter (VM), and ash content from proximate analysis and the weight percentage (%) of carbon (C), hydrogen (H), sulfur (S) and nitrogen (N) from ultimate analysis. In thermochemical calculations, Stage (I), gasifier efficiency is calculated by Lower heating values of biomass and product gas of the RDF fuel. Then Stage (II), the mass flow rate obtained and in Stage (I-II) volume of the gasifier is obtained. The height and diameter of the gasifier is calculated during Stage (IV) by using the specification gas rate. MSW gasifier is a design model which has the possibility to calculate the diameter and height of thermo-chemical gasification systems, in order to evaluate the optimize size of the gasifier, starting from lower heating value to specific gasification rate are computed. The reviewed parameters are is used to enter initial and input data for stoichiometric thermochemical expressions of the process model. After the calculation of the lower heating value, the gas yield and energy efficiency calculated, with the help of all thermo-chemical equations the specific gasification rate is derived [6].

3.1. The following are the assumptions made while modelling and designing the RDF gasifier

❖ Gasification process occurs at steady-state.
❖ Heat loss during gasification is not considered in the model.
❖ The speed of chemical reaction is high and residence time is sufficient to reach equilibrium.
❖ Considering the material MSW as the dry RDF Equivalence ratio (ER)=.35
❖ H₂, CO, CO₂, CH₄, N₂ and H₂O are the product gases.
❖ Tar content is not considered in the model.
❖ Char contains carbon only.
❖ Fuel composition is taken on dry and ash free basis.
3.2. Method of data processing

The following simplified chemical formulas are used for the gasification model to process. At first [7], the Lower heating value, gas yield and energy efficiency and next phase [8], power input, gas flow rate, volume of the gasifier and specific gasification rate are calculated.

❖ **Energy Efficiency**

\[ \eta = \frac{\text{LHV}_{\text{gas}}}{\text{LHV}_{\text{biomass}}} \times Y \times 100 \% \]  

(1)

❖ **Gas Heating Value**

\[ \text{HHV}_{\text{gas}} = ((H_\% \times 30.52 + CO\% \times 30.18 + CH_4\% \times 95) \times 4.1868) \text{ kJ/Nm}^3 \]  

(2)

\[ \text{LHV}_{\text{gas}} = (CO\% \times 126.36 + H_2\% \times 107.98 + CH_4\% \times 358.18) \text{ kJ/Nm}^3 \]  

(3)

❖ **Biomass Heating Value**

\[ \text{LHV}_{\text{biomass}} = (34835 \text{ C} + 93870 \text{ H} - 10800 \text{ O} + 6280 \text{ N} + 10465 \text{ S}) \text{ kJ/kg} \]  

(4)

❖ **Gas Yield**

\[ Y = \frac{\text{Volume}_{\text{gas}}}{\text{Mass}_{\text{biomass}}} \text{Nm}^3/\text{kg} \]  

(5)

Power input = power output/gasification efficiency (kW)

Gas flow rate = [power input/LHV\(_{\text{gas}}\)] * 3600 (m\(^3\)/h)

Bio mass flow rate = Gas flow rate/gas yield (kg/h)

Air flow rate = (Stoichiometric air-fuel ratio * Equivalence ratio * Biomass flow rate) (kg/h)

Stoichiometric air-fuel ratio = (100/23) *[((8/3)xC) + 8H-O + S]

Volume of the gasifier = (Biomass flow rate * Gasifier operation time) / Biomass density (m\(^3\))

Specific gasification rate = (Height of the gasifier * Biomass density) / Gasifier operation time (kg/ m\(^3\)/h)

4. Results and discussions

The primary purpose of this research methodology is to address the gasifier dimensions based on parameters from the theoretical model of the feasibility of gasifying a RDF in the downdraft gasifier. The characteristics calculation of the proximate analysis (wt %) of the sample was conducted according to ASTM standard D1542 [4] and encompassed the calculation of moisture content (MC), volatile matter (VM), and ash content. The elemental analysis reported Table [4] were used in calculations as the percentage (%) of carbon (C), hydrogen (H), sulfur (S) and nitrogen (N).
The thermochemical calculations for the design were stage (I) to obtain the gasification efficiency of the RDF fuel, equation (4) is used to determine \( LHV_{\text{biomass}} \) of the RDF = 32,548 KJ/kg, and \( LHV_{\text{gas}} = 5.87 \) MJ/Nm\(^3\) and product gas yield rate = 4.05 Nm\(^3\)/kg % from [11] using GAS 3100. The gasifier efficiency using equation (1), from the above calculations is \( \eta = 73.04\% \).

The mass flow rate stage (II) using equation (8) is obtained by power output and the gas flow rate for 10kW gasifier is 10 Kg/hr. And then stage (III), using equation (11) the volume of the gasifier is obtained is 0.85 m\(^3\).

The diameter and height in Figure 2, of the gasifier is calculated using the gasification specific rate and volume of the gasifier.

5. Conclusion

Design of MSW gasifier was carried out based on the requirement of thermal power output for maximize energy efficiency and minimize the environmental impacts. At first, the heating values of RDF waste components were calculated and then gasifier volume was determined by finding the input and output flow details. The dimensions of the gasifier were determined by the specific gasification rate were reactor diameter 0.5 m and length 1.7 m.

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