Experimental Investigation of Updraft Gasifier Using Solid Waste as Feedstock

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***Abstract*— Even though the presence of waste to energy industry in past decade most of the solid wastes do end up in landfills. For every tonne of waste land filled, greenhouse gas emissions in the form of carbon dioxide increase by at least 1.3 tonnes. Gasification is a promising technology which would help deal with the landfill problems and would rather convert the municipal solid waste (MSW) into an energy source.**

Gasification is a process in which a solid carbonaceous fuel is transformed into combustible gas consisting of carbon monoxide, hydrogen, carbon dioxide and methane. This process is achieved by reacting the fuel at high temperatures, without combustion, with controlled amount of oxygen or steam. This gas is known as producer gas which acts much efficient than the direct combustion of the fuel. In this study an updraft gasifier is fabricated and is used to carry out the experiment. The solid non-recyclable wastes like china cardboards, clothes, wet newspapers, etc, are used for the generation of the producer gas. A gas analyzer is used to measure H_2, CH_4 and CO concentrations of the product gas. The study investigates the aspect of municipal solid waste as potential energy source in gasification technology.

***Keywords*— Gasification; Biomass; Solid Waste; Greenhouse gas; Combustion; Gas analysis**

I. INTRODUCTION

1.1 General Introduction

The demand of energy around the world has been increasing at a very fast pace especially in the developing countries. In light of global issues of sustainable energy and reduction in greenhouse gases, renewable energy is getting increased attention as a potential alternative source of energy. There are nine general sources of energy on earth. There are geothermal, nuclear, fossil, solar, biomass, wind, wave, hydro and tidal energies. Except for the first three the remaining six are generally called renewable sources of energy, as they are not depleted with time.

Biomass is the oldest source of energy and currently accounts for approximately 10% of total primary energy consumption. Many of the developing countries has growing their interest in bio fuel development and providing greater access to clean liquid fuels while helping to address the issues such as increase in fuel price, energy security and global warming concerns associated with petroleum fuels. Abundant biomass is available throughout the world which can be converted into useful energy. Biomass is considered as a better source of energy because it offers energy security, rural employability and reduced GHG emission. Biomass is traditionally available in the form of solid. Solid biomass include crops residues, forest waste, animal waste, municipal waste, food waste, plant waste and vegetable seeds.

Compared to other sources of renewable energy, biomass is seen as an interesting source of renewable energy. The significance of biomass as fuel has been amplified during the last decades driven by several reasons. Biomass technology offers a technology where the fuels needed are sustainable, resources are often locally available and conversion into secondary energy carriers is feasible without high capital investments.

Biomass technology is based on a wide range of feedstock as fuels. The main biomass sources in use for energy production varies from forest residues, agricultural residues, wood based industry waste, animal waste, landfill gas to energy crops. There are several major biomass conversion processes including thermal, chemical, biological, and oxidative methods. Similarly, there are many potential valuable products that may be produced from its conversion to including heat energy, synthetic fuels, fertilizer, hydrogen, chemicals, bio-polymers, and even bio-pharmaceuticals.

1.2 Theory of Gasification

The combustion of a product produces some products which form complete combustion of biomass, generally contain nitrogen, water vapour, carbon dioxide and surplus of oxygen. However in gasification where there is a surplus of solid fuel (incomplete combustion) the products of the combustion are combustible gases like carbon monoxide (CO), Hydrogen (H2) and some traces of methane and unwanted products like tar and dust. The chemical reaction between water vapour and carbon dioxide leads to the formation of above mentioned gases through a glowing layer of charcoal. Thus key to gasifier design is to make conditions such that a) biomass is reduced to charcoal and, b) charcoal is converted to produce CO and H2 at suitable temperature.

1.3 Gasification Technologies

Biomass gasification systems are either fixed or fluidized beds. Fluidized bed gasifiers are generally only cost effective in large-scale applications, those that generate over 15 MW. Fixed bed systems are more suitable for small-scale heat and

18 power applications and generally feature simple construction Characteristics of fixed bed gasification include high carbon conversion, low gas velocity and low ash carry-over. The most challenging is the tar removal, and development is being made in thermal and catalytic conversion of tar .Before use in many applications, producer gas must be cleaned and cooled, generally using a filtration system of cyclones, wet scrubbers and dry filters .Within the categorization of fixed bed gasifiers, there are several reactor designs classified according to the path of the gasifying agent through the gasifier. These include updraft, downdraft, cross draft and two stage gasification systems. Gasifying agents can be air, steam, oxygen, or a mixture of these .Further classification may be made based on the function of the producer gas: thermal applications make use of heat gasifiers, and engine applications make use of power gasifiers. Classification of the gasification method, operating conditions, and type of biomass feedstock all affect the composition and level of contamination of the producer gas Due to their relatively simple design considerations, only downdraft and updraft fixed bed systems will be feasible for this project and are examined in this review.

The power produced from non renewable sources like coal and petroleum are not going to last for a long period due to their exhaustive nature. Further, the high price of petroleum products compels to search and develop renewable energy sources like solar, wind and biomass which are available in abundance in India. Nuclear energy production being a highly costly process, deter its use in daily activities. The installation of dams for hydel energy is not always possible. Tidal energy is a much localized energy source. Biomass is eco-friendly and safe source of energy . The energy from biomass may be obtained either through biochemical reactions (biomethanation) or thermo- chemical reaction. Both the processes are practically feasible. The process of incorporating biomass to produce producer gas through thermo-chemical process is called gasification. This paper restricts presentation on biomass gasification. The term gasification absolute purpose covers the conversion of any carbonaceous fuel to a gaseous product with a useable heating value. This definition differs combustion, because the product flue gas has no residual heating value. It does include the technologies of pyrolysis, partial oxidation, and hydrogenation. The dominant process is partial oxidation, which produces the fuel producer gas (otherwise known as synthesis gas or syngas) consisting of carbon monoxide and hydrogen in varying ratios, whereby the oxidant may be pure oxygen, air, and/or steam.

1.4 History of Gasification Technology

The use of gasification technology to produce combustible gases is not a new concept. Gasifiers were used as far back as 1861 to fire furnaces in the iron working industry .Between the years 1879-1881, J. E. Dawson, in England, developed a cooling and cleaning process, and showed that gas engines could be powered by a gasifier . Most of these early gasifiers were of the updraft variety. However, a downdraft gasifier was described as far back as 1843 in Sweden by Gustaf Ekman . Also, most of the early gasifiers used coal or coke as a fuel. It was not until the early 1920's that gasifier technology had grown sufficiently to include the many different forms of cellulosic fuels. The development of gasifiers in Sweden is an interesting case study. The following material was taken from the text edited by SERI. In 1918, Axel Swedlund of Sweden designed an updraft charcoal generator, which was followed in 1924 by the first of his downdraft designs. During 1923 and 1924, several experiments were conducted using updraft gasifiers on trucks, buses, and rail cars. One experiment consisted of driving a truck 624 kilometres. However, due to the high tar content of the gas, the engine had to be removed and cleaned after 320 kilometres. The results of these experiments showed that, although the use of gasifiers to power internal combustion engines was possible, it was not convenient at that time.

In general, start-up was very difficult when the gasifier was the only fuel available. Also, during that period, the engines had relatively little power even when an intensive gasifier research program during the war. During the last years of the war, gasifier technology had advanced to the point where it was considered an adequate substitute for liquid fuel. When the war ended, however, liquid fuels once again became plentiful, and it was not economically feasible to continue gasifier research. The project briefly describes the small scale updraft gasifier that uses wood fuel. The design, performance, and the fabrication of the gasifier are illustrated in detail in the succeeding chapters to provide interested individuals and organisations a comprehensive guide in designing, fabricating and operating the gasifier.

1.5 Objectives

- Test the gas concentration of producer gas produced by the gasifier using combustible non recyclable solid waste as a feedstock.
- The main goal of this project is to examine the feasibility of gasification of non recyclable combustible solid waste.

II. PROXIMATE ANALYSIS

Proximate analysis is the means of determining distribution of products when the solid waste is heated at a particular temperature. Proximate analysis separates the products into four groups: (1) moisture, (2) volatile matter, consisting of gases and vapours driven off during pyrolysis, (3) fixed carbon, the non-volatile waste, and (4) ash, the inorganic residue remaining after combustion. Proximate analysis is the widely used process for determining characteristic of coals in connection with their utilization.

2.1 Moisture Content

Moisture content of the sample determines the heating value, if the moisture is high the corresponding heating value of the gas will be low. Moisture content is to be determined on a dry basis as well as on a wet basis. One gram of the solid waste fuel sample was measured and dried in a muffle furnace at a temperature of 105 C for one hour. The following data was obtained from the test

Weight of the solid waste before drying in the oven = 1g

Weight of the solid waste after drying in the oven = 0.89g

The moisture content of the solid waste on the wet basis is defined as

MCwet = $\frac{wet\ weight - dry\ weight}{wet\ weight} \times 100\%$

MCwet = $\frac{1 - 0.89}{1} \times 100$ = 11%

The moisture content of the solid waste on the dry basis is defined as

MCdry = $\frac{100 \times MC\ (wet)}{100 + MC\ (wet)}$

MCdry = $\frac{100 \times 11}{100 + 11} \times 100 = 9.9\%$

High moisture contents reduce the thermal efficiency as the heat is used to vaporise the water and consequently this energy is not available for the reduction reactions and for converting thermal energy into chemical bound energy in the gas. Therefore high moisture contents result in low gas heating values. When the gas is used as a thermal source, low heating values can be tolerated and the use of feed stocks with moisture contents (dry basis) of up to 40 - 50 percent is feasible, especially when using updraft gasifiers.

2.2 Volatile Matter Content of the Fuels

Accurately measured 1g of the fuel samples was measured and dried in an muffle furnace at a temperature of 950 ℃ for 7 minutes. This indicates that all volatile matter has been driven off. After this, the weight of the heated samples was taken.

Weight of the solid waste before placing on hot plate = 1g

Weight of the solid waste after heating on the hot plate = 0.12g

VM = $\frac{weight\ initial - weight\ final}{weight\ initial} \times 100\%$

VM = $\frac{1 - 0.12}{1} \times 100 = 88\%$

2.3 Ash Content

1g of the solid waste fuel sample was measured accurately and dried in a muffle furnace at a temperature of 500-600 ℃ for two hours, the weight of the samples was taken, and given as follows:

Initial weight of the solid waste before placing on hot plate = 1g

Final weight of the solid waste after heating on the hot plate = 0.09g

Ash = $100 - \frac{initial\ weight - final\ weight}{initial\ weight} \times 100\%$

Ash =100 - $\frac{1 - 0.09}{1} \times 100 = 9\%$

Ashes are harmful for the gasification process particularly in up or downdraught gasifiers. Slagging formation in the reactor, caused by melting and agglomeration of ashes, at the best will greatly add to the amount of labour required to using liquid fuel.

The increase in the car fleet continued into the early 1940's but for the outbreak of World War II, which was accompanied by a commercial blockade. At this time, the opportunity to buy liquid fuel was severely restricted. These circumstances led to operate the gasifier. If counter measures are not taken, slagging can lead to excessive tar formation and/or complete blocking of the reactor. A worst case is the possibility of air-channelling which can lead to a risk of explosion, especially in updraft gasifiers.

2.4 Fixed Carbon

The value of the fixed carbon is calculated as follows:

FC = 100 – (%moisture + %volatile matter + %ash)

FC = 100 – (11 + 88 + 9) = 8%

TABLE 1: The Laboratory Proximate Analysis of 1g of Each of the Fuel Samples

Analysis	Initial weight (gm)	Temperature (℃)	Duration (min)	Final weight (gm)	Percent of content
Moisture	1	105	60	0.89	11
Volatile matter	1	950	7	0.12	88
Ash	1	550	120	0.09	9
Fixed carbon					8

The results of the proximate analysis carried out on the properties of the feed stock are presented in Table 1. This analysis gives the suitability of the feedstock for use in a particular application, this includes moisture content, volatile content, the fixed carbon and ash content in the solid waste. The feed stocks considered have very low moisture content and ash content. The significant of low ash content helps to decrease problem related to residual disposal, equipment cleaning and various other operational aspects .The moisture content of the feedstock was reduced by sun drying to obtain a high gasification temperature which results in the high energy values obtained.

III. EXPERIMENTAL SET-UP

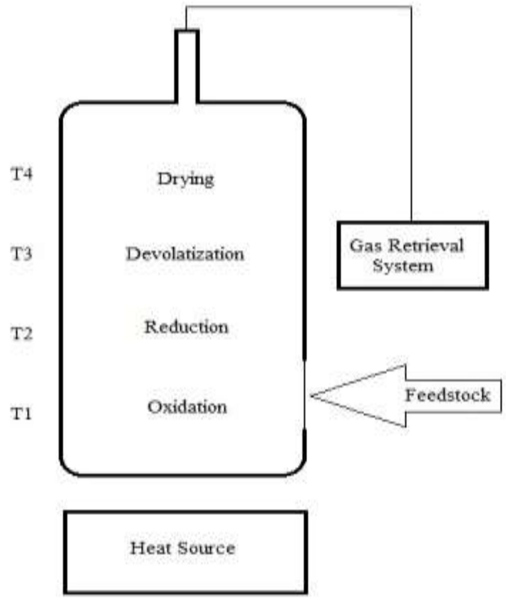

Fig. 1 Schematic diagram of experimental set-up.

3.1Factors Considered

There were several factors considered in designing the updraft gasifier. Proper consideration of these different factors helped in a great deal to achieve the desired design and performance. As given below, the different factors considered in designing the updraft gasifier are:

- Type of Reactor – The operating performance of the gasifier basically depends on the type of reactor used, the type under consideration is Updraft reactor.
- Cross-sectional Area of the Reactor – This is the area in which the fuels are burned and this is where the fuel is gasified. The wider the cross-sectional area of the reactor, the stronger the power output of the gasifier. Uniform gasification was achieved with the reactor designed in circular rather than in square or rectangular cross-section.
- Height of the Reactor – The height of the reactor determined the continuous operation time and the amount of gas produced for a fixed column reactor. Usually the combustion zone is present down the entire height of the gasifier reactor. The higher the reactor, however, the more pressure draft is needed to overcome the resistance exerted by the air compressor.
- Fuel Bed Thickness – The thicker the layer of fuel in the reactor, the greater is the seal and the resistance required for the air to pass through the fuel column. The only advantage in using a thicker column of the gasifier is that it slows downward movement of the combustion zone in the reactor, which can help in minimizing the erratic production of flammable gas during gasification.
- Insulation for the Reactor – The gasifier reactor was properly insulated for two reasons: first, this provides better conversion of the feedstock into gas.
- Fuel firing location – For Updraft gasifier, firing the fuel from the top is the best and easier way. Firing the fuel in this manner minimizes smoke emission. However reloading of the fuel in between operation might not be possible. On the other hand, the advantage of firing from the bottom is that the total start-up for the same height of the reactor can be extended, which cannot be done when firing the fuel from the top of the reactor.
- Size and Location of the ash Chamber – The size of the chamber for carbonized fuel determines the frequency of unloading the ash. Bigger chamber can accommodate larger amount of char and can allow longer time before the char is removed. In addition, designing a shorter chamber will give sufficient height for the gasifier and the burner. To properly discharge the ash or the char, a shelled cuboid is welded to the base of the hopper, the box is provided with a doorway.
- Safety consideration – Opening the reactor requires safety.

3.2 Gasifier Start-up and Operation

The significance of testing a new gasifier design is to determine the appropriate operating procedures for the new gasification system and a given feedstock. After preliminary testing, the following standard system start up and operation procedures were adopted for testing solid waste feedstock in this gasifier:

- Bottom port was sealed after the biomass is filled into the gasifier
- The thermo couple and temperature indicator was initialized and temperature recording began.
- After 3-5 minutes until the two lowest thermocouples read Temperatures of about 40°C and smoke began to come out of the chamber.
- When the heating source was obviously lit, the torch was removed.
- Throughout operation, a constant source for heating was provided down the gasifier.
- The flame was reignited when possible.
- Gas samples were taken when the bed temperature stabilized and the flare appeared largest and most consistent.
- When all samples for a day had been collected, the gasifier was allowed to cool before being cleaned or moved.

When collecting samples, the test pattern consisted of achieving a steady temperature profile then collecting gas samples.

3.3Temperature Level

Different temperature level in the gasifier is shown in the Table 2.Every 10 minutes of interval the temperature are noted by using the temperature indicator.

TABLE 2: Temperature in Different Zone

Time (mins)	Combustion (℃)	Reduction (℃)	Pyrolysis (℃)	Drying (℃)
0	33	33	33	33
10	229	163	183	117
20	237	180	211	124
30	268	229	243	140
40	297	290	236	153
50	325	300	239	180
60	370	328	230	197
70	400	345	225	192
80	369	340	219	185
90	365	360	210	179
100	304	290	200	151
110	293	279	193	147
120	278	215	180	138
130	215	191	150	117
140	197	169	141	100

Fixed bed gasifier, is a vertical cylindrical reactor, which consists of two sections: the feedstock section, and a section where mainly gas reactions take place and the ash is ducted out of the gasifier. The updraft gasifier has been designed with an insulation thickness of 110 mm and with the reactor height of about 0.65 m and the reactor diameter is about 0.35m. The temperature profile is followed by a set of four K type thermocouples situated at different heights in the gasifier. The biomass that is used in the experiment is solid waste.

In the biomass gasifier, the experimental observations are taken for every 10 minutes as the gasification process. The transition could only be denoted by means of varying temperature at various zones of the reactor. The range at which the conversion of charcoal takes place is where the gas production is high and comparatively the producer gas production gets lowered after the reaction.

IV. RESULT AND DISCUSSION

At the beginning of the test the heat source was turned on which provided the required enthalpy to heat the gasifier , white smoke was observed to be emitted, the gasifier started to produce a brown smoke which in the indication of the combustible gases been formed. At this instant the smoke was ignited; the gas was identified to be as the combustion gas as by the formation of yellow flame at the outlet of the gasifier and continued until the experiment lasted. The colour of the produced flame indicating the production of producer gases and the energy content in solid waste correspond to the tests that were carried. Table 2 illustrate temperature distribution during the gasifier's performance test operation. The highest temperatures obtained during the operation of the gasifier were found to be closer to the designed temperature. These values were obtained from the four different thermocouples inserted at the oxidation, reduction, pyrolysis, drying zones in the gasifier.

TABLE 3: Gas Concentration

S.no	Gas concentration	Name
1	1.78	CH_4
2	16.09	CO
3	42.3	H_2

Table 3 illustrates the gas concentration of the producer gas. After conducting the gasification test the gas was collected and analysed to get the above tabulated data's.

V. CONCLUSION

Instead of just land filling the solid wastes it can be used as feedstock in a gasifier to generate producer gas which can be used as an energy source.

Renewable biomass has also been considered as potential feed stocks for gasification to produce the producer gas. The gasification of biomass is the thermal treatment process which results in formation of high proportion of gaseous products and small quantities of char and ash. Different process parameters should be considered for the gasification process for proper production of gas. The parameters has affecting on the gasification of biomass such as Temperature, gasifying agent/biomass ratio, materials, type of biomass, type of gasifier on the performance of the gasification system.

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