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A Review on Gasification for Municipal Solid Waste and Sewage Waste

[1]Kannan. M, [2]Anjali. T, [3]Kowshika. R, [4]Swathi. R

[1]Professor, Dept. of Civil Engineering, Parisutham Institute of Technology and Science, Thanjavur, Tamilnadu, India

[2,3,4]UG student, Dept. of Civil Engineering, Parisutham Institute of Technology and Science, Thanjavur, Tamilnadu, India

***Abstract* - A review was conducted on gasification for municipal solid waste and sewage waste. In gasification there are upstream process and downstream process are there. Upstream process consists of size reduction, drying and densification. Downstream process includes gas cleaning and gas utilization process. Gasification process is conversion process of solid and combustible fuel into gas mixtures is known as producer gas. That producer gas will go for downstream process. The main components of the producer gas were carbon monoxide and hydrogen including a small amount of methane and light hydrocarbons. The producer gas or syngas can be used as a biofuel, electricity, biogas etc. It will replace the abundant use of fossil fuels like petrol, diesel, naphtha oil, etc. In gasification process some other by products also obtained they are ash and tar. The generated tar is gravimetric tar, which is total tar. As light tars, benzene (light aromatic tar) was a major light tar. Naphthalene, anthracene, and pyrene (light polycyclic aromatic hydrocarbon tars) were also generated, but in relatively small amounts. Ammonia and hydrogen cyanide (precursor for NOx) were generated from thermal decomposition of tar containing protein and nitrogen in sewage sludge. The ash can used as food products for plants (fertilizer). Utilizing the sewage sludge as an energy source would generate large fossil fuels, neutralize sewage sludge landfills and reduce the risk of developing and spreading the disease due to the presence of harmful substances.**

Keywords: Gasification, Municipal Waste and Solid Waste.

I. INTRODUCTION

Gasification of municipal solid waste (MSW) is an attractive alternative fuel production process for the treatment of solid waste as it has several potential benefits over traditional combustion of MSW. The so-called "syngas" obtained by gasification has several applications. It can be utilized as a gas fuel being combusted in a conventional burner or in a gas engine and then connected to a boiler and a steam turbine or gas turbine to utilize the heat or produce electricity (Yong-Chil Seo et al., 2018). Gasification is a process where a substance is partially oxidized. The oxidizing agent (air, oxygen or hydrogen) is added in sub-stoichiometric amount as compared with the amount required for the complete combustion of the substance. The oxidation of substance is an exothermic (air/oxygen as oxidizing agent) or endothermic (hydrogen oxidation medium) process and the end products are syngas and char, with tar and ash as byproducts. The gasification with air produces a syngas with calorific value between 4 and 7 MJ/m^3, with pure oxygen the heating value of gas is 10 to 15 MJ/m^3 and hydrogen increasing the heating value of produced gas to 15–20 MJ/m^3. The advantage of gasification is production of heat for kilns or boilers. The major problem of gasification is the production of tar (Brown, 2011).

Globally, the volume of waste generated from urban centers of the world is around 1,300 million tons per year (1.2 kg/capita/day) which is expected to rise to 2,200 million tons per year by 2025.The waste generated from South and East Asia represents 33% of the world's total quantity. It is anticipated that the MSW generation rate in Asia will reach to 1.8 million tons /day by 2025 (Srivastava et al., 2014). For India MSW generation ranges between 0.3 kg/capita/day and 0.6 kg/capita/day, with the annual volumetric increase in MSW generation is estimated to be 1.33 % per capita. The MSW generated is rarely treated in India. 90% of waste is unscientifically dumped openly or land filled creating health and environmental issues (Sharholy et al., 2008). Landfills are rather a temporary storage place, and hence waste needs to be treated to convert it into valuable product, that is waste to product (WtP) or waste to energy (WtE). Waste to energy processes such as biological treatment or thermal treatment utilize the energy potential in waste to reduce CO_2 and other pollutants emission to atmosphere (Helsen and Bosmans et al., 2010). Thermal treatment of the solid waste reduces the mass by 70–80% and volume by 80– 90% (Lombardi et al., 2015). The time required for treating the waste thermally takes only minutes or hours, and forms a stable odor free product, free of pathogens. Environmentally, thermal treatment is better than biological or landfills. Landfills emits methane (four times more effective greenhouse gas as compared to CO_2) during the

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anaerobic digestion of waste, while thermal treatment releases only CO_2 and other gases such as CO, methane having high calorific value is extracted for energy recovery (Shah et al., 2011). As stated by (Sharholy et al., 2008) all waste to energy thermo-chemical techniques have been tried and tested in developed countries with positive results. These are yet to get off the ground in India largely because the financial viability and sustainability is still being tested. The available technologies for thermo-chemical treatment of waste are pyrolysis, gasification, plasma gasification and incineration. According to behind the population in the urban areas is likely to double by 2010, while the quantity of Municipal Solid Wastes (MSWs) generated is expected to triple. The number of Class I cities with population exceeding 1,00,000 has increased from 212 to 300 during 1981– 1991. Due to limited land availability in some countries and various environmental problems associated, such as gas emissions and leachate production, the technology of land filling needs to be improved. There is an urgent need to work towards a sustainable solid waste management system, which is environmentally, economically and socially sustainable. Waste to energy generation option can be an alternative for sustainable management of this waste and will be helpful in tackling this huge quantity of waste (R.P Singh et al., 2011).

Residual Municipal Solid Waste (MSW) is waste that is household or household like. It comprises household waste collected by local authorities some commercial and industrial wastes eg. From offices, schools, shops etc that may be collected by the local authority or a commercial company. The aim of this guide is to provide impartial information about the range of technologies referred to as Advanced Thermal Treatment (ATT) – the principle ones being gasification and pyrolysis. These technologies are designed to recover energy (in the form of heat, electricity or fuel) and can contribute to the diversion of Biodegradable Municipal Waste (BMW) from landfill. There are many examples of ATT processes that are established, viable and bankable on various waste streams (e.g. biomass, industrial wastes, tyres etc.) but a lesser number proven on municipal wastes (Department of Environmental Food and Rural affairs, 2013). Waste materials such as municipal solid waste (MSW) include organic components such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint, and batteries. This comes from our homes, schools, hospitals, and businesses. In 2013, Americans generated about 254 million tons of trash and recycled and composted about 87 million tons of this material, equivalent to a 34.3 percent recycling rate. On average, we recycled and composted 1.51 pounds of our individual waste generation of 4.40 pounds per person per day. In 2013, newspapers/mechanical papers recovery was about 67 percent (5.4million tons), and about 60 percent of yard trimmings were recovered. Organic materials continue to be the largest component of MSW. Paper and paperboard account for 27 percent and yard trimmings and food account for another 28 percent. Plastics comprise about 13 percent; metals make up 9 percent; and rubber, leather, and textiles account for 9 percent. Wood follows at around 6 percent and glass at 5 percent. Other miscellaneous wastes make up approximately 3 percent of the MSW generated in 2013 (U.S Environmental Protection Agency, 2016). Municipal solid waste, also generally termed trash or garbage, represents a non-hazardous unwanted item that is constantly supplied by human. Since the past few decades until present, the disposal of municipal solid waste has always been a demanding challenge due to ever-expanding human population. In addition, due to the outbreak of the novel corona virus disease 2019 followed by the emergency lockdown and stay at home policy enforced in most of the countries, the unprecedented increase in municipal solid waste generated such as increasing use of plastic packaging with approximately more than 6000 tons per day in the Southeast Asian countries (Haque et al. 2020) could be even more challenging especially to those countries with unsatisfactory municipal solid waste management (Sarkodie and Owusu 2020). In China 220 million metric tons, India has 168.4 million metric tons & In U.S 258 million metric tons municipal solid waste will be produced. It was forecasted that the production of municipal solid waste will achieve 1.42 kg/capita/day by the year 2025 (Hoornweg and Bhada-Tata 2012) and will likely hit 2.6 billion metric tons in 2030 (Statista 2020). Municipal solid waste can be segregated into combustible substance, non-combustible substance, and material with high moisture according to Caputo and (Pelagagge 2002). The plastic and paper consist of 50–80% are the major fractions composed in refuse-derived fuel, while the remaining fractions are contributed by organics, wood, and textile (Casado et al. 2016; Fyffe et al. 2016). Among these, gasification is getting increasing attention due to its capability in producing higher yield of cleaner gaseous fuel such as hydrogen and syngas than combustion and pyrolysis (Jiang et al. 2019). Other than developed countries, the interest on recovery of refuse-derived fuel from municipal solid waste has also been extended to a few developing countries such as Indonesia, India, and Thailand. Indonesia is identified as one of the countries in the world with the highest growth of population, estimated to hit 270 million people that would produce 150,000 ton/day of municipal solid waste by 2025 (Kubota and Ishigaki 2018). Sewage sludge is the by-product from the treatment of waste water and has the potential to be used for generating heat and power. There is interest in the development of alternative routes to treat and dispose of sewage sludge driven by socio-economic and environmental concerns. Sewage sludge poses major issues for its usage in many applications as it contains a

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very high moisture content at almost 98 wt. %. Generally, moisture content lower than 60% is desired before disposing through landfill, agriculture applications etc. but for thermal processing, below 15% is required. The collective generation of sewage sludge in China had a growth rate of 13% from 2007-2013, with 6.25 MT of dry solids in 2013 of which only 25% was appropriately treated. In 2017, the global sewage sludge production rate was recorded as 45 dry MT per year. In 2015, five EU countries (Germany, United Kingdom, France, Spain and Italy) were reported to produce 75% of the total sewage sludge in Europe. In the same year, annual sewage sludge production in China and Taiwan was recorded as 30-40 MT and 77,000 T, respectively. Figure 5 illustrates the total production of sewage sludge in different countries. The second most important characteristic of sewage sludge is its high heavy metal content. The trace elements in sewage sludge in different regions are shown in Figure 6. Based upon the moisture level, contaminant level and socio-economic factors, U.S., China, Japan and EU countries have identified potential usage of sewage sludge in land applications, building materials, anaerobic digestion and incineration. Thermo-chemical conversion technologies such as pyrolysis and gasification have been suggested as replacements for sewage sludge energy recovery. Although thermo-chemical conversion involves complex equipment or processes, compared to other treatment processes, they may exhibit better economic performance, higher efficiency and greater volume reduction (Kamran.K et al., 2020).

Gasification converts the materials into a gas by creating a chemical reaction. This reaction combines those carbon-based materials (known as the feedstock) with small amounts of air or oxygen, breaking them down into simple molecules, primarily a mixture of carbon monoxide and hydrogen, and removing pollutants and impurities. What's left is a clean "synthesis gas" (syngas) that can be converted into electricity and other valuable products. It can be combusted or co-combusted in power boilers, industrial furnaces, combustion engines and gas turbines. The fact that gasification occurs at a much smaller oxygen level than is the case of combustion processes should be first and foremost taken into account (Sebastian Werle, 2015). Therefore, the quantity of gaseous products (particularly oxides) is smaller, and the gas cleaning system may be much less extensive. Previous studies have shown that the gasification of sewage sludge in fixed bed reactors (and the downdraft version of these reactors) produces a gas with relatively low tar content because of the decomposition and oxidation of the tar products that pass through the high- temperature combustion zone during gasification. Encouraging studies on sewage sludge gasification in a pilot- scale updraft fixed-bed gasifier have been reported (Seggiani et al.).

II. MECHANISM

Gasification

The gasification process is the thermo chemical conversion of a carbonaceous solid or liquid to a gas in presence of a gasifying agent: air, oxygen or steam. Compared to this definition, the combustion process could be associated as a gasification one, however, by definition, gasification requires that oxygen supply is lower than the amount required for complete combustion to carbon dioxide and water (the stoichiometric amount) (Andrea Milioni, 2021). Use of advanced technologies such as gas turbines and fuel cells with the syngas generated from gasification results in increased efficiency (Radwan AM et al., 2015). The gasification agent allows the feedstock to be quickly converted into gas by means of different heterogeneous reactions (Di Blasi, 2000; Hauserman et al., 1997; Barducci, 1992; Baykara and Bilgen, 1981). The combustible gas contains CO_2, CO, H_2, CH_4, H_2O, trace amounts of higher hydrocarbons, inert gases present in the gasification agent, various contaminants such as small char particles, ash and tars (Bridgwater, 1994a).

The main steps of the gasification process are:

- Oxidation (exothermic stage)
- Drying (endothermic stage)
- Pyrolysis (endothermic stage)
- Reduction (endothermic stage)

Gasifiers

The gasifier is the reactor in which the conversion of a feedstock into fuel gas takes place. There are three fundamental types of gasifier (1) fixed bed, (2) fluidized bed and (3) indirect gasifier. (V. Belgiorno et al., 2013).

Fixed Bed

Vertical fixed bed reactors (VFB) are the most competitive fixed bed gasifiers. The fixed bed gasifiers are generally used for small-medium size plants (no more than 10-15 tons/hours of biomass) (Andrea Milioni, 2021). They are subdivided into updraft and downdraft gasifiers. Updraft is a counter- current gasifier, where the feedstock is loaded from the top while air is introduced from the bottom of the reactor. In the reactor the solid material is converted into combustible gas during its downward path. In a downdraft reactor, co-current, the carbonaceous material is fed in from the top, the air is introduced at the sides above the grate while the combustible gas is withdrawn under the grate (Quaak et al., 1999; Bridgwater, 1994a).

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Fluidized Bed

Fluidization is the term applied to the process hereby a fixed bed of fine solids, typically silica sand, is transformed into a liquid-like state by contact with an upward flowing gas (gasification agent). Fluidized bed gasification was originally developed to solve the operational problems of fixed bed gasification related to feed stocks with a high ash content and, principally, to increase the efficiency (Quaak et al., 1999). The efficiency of a fluidized bed gasifier is about five times that of a fixed bed, with a value around 2000 kg/(m^2 h) (Quaak et al., 1999; Bingyan et al., 1994). In a bubbling fluidized bed (BFB), the flow of gaseous oxidant (air, oxygen or oxygen-enriched air) is blown upwards through a distributor plate and permeates a bed of inert material (typically, silica sand or olivine) located at the gasifier bottom, which contains the waste to be treated (Arena and Mastellone, 2005).

Indirect Gasifier

Indirect gasifiers are the reactors used for the steam indirect gasification and are grouped as char indirect gasifiers and gas indirect gasifiers depending on the type of internal energy source. (V. Belgiorno et al., 2013). Gas indirect gasifiers use a steam fluidized bed gasifier within bed heat exchange tubes (Hauserman et al., 1997; Niessen et al., 1996).

Major Process in Gasification Drying

The Drying is what removes the moisture in the biomass before it enters Pyrolysis. All the moisture needs to be (or will be) removed from the fuel before any above 100°C processes happen. All of the water in the biomass will get vaporized out of the fuel at some point in the higher temperature. The conversion occurs owing to heat transfer between hot gases from the oxidation and biomass in the drying Purnomo zone (et al., 2017). The greater the moisture amount, the higher the energy needed for drying, with a lower produced gases enthalpy (Andrea Milioni, 2021).

Pyrolysis

Pyrolysis is the application of heat to raw biomass, in an absence of air, so as to break it down into charcoal and various tar gasses and liquids. Biomass begins to rapidly decompose with heat once its temperature rises above around 240°C (Kuki Y et al., 2016). Gases: H2, CO, CH4, CO2 and some other light hydrocarbons (Andrea Milioni, 2021). The biomass breaks down into a combination of solids, liquids and gasses. The solids that remain we commonly call charcoal (A.V. Bridgwater, 2003). The gasses and liquids that are released we collectively call tars. The process of pyrolysis at high temperatures, low heating rates, and long periods of gas phase in the reactor achieves a high yield of pyrolytic gas (S. Sadaka, 2008; E. Gollu, 1999; All power labs, 2022).

Combustion

In the combustion zone the outputs from the above zone, react with the remaining char in the absence of oxygen at a temperature of around 800- 900°C (Purnomo et al., 2017). Some sludge and biomass could start pyrolysis at low temperature (~150°C) typical for the fuel drying (Chirone R et al., 2012; all power labs, 2022).

$$C+1/2O_2 \longrightarrow CO$$

$$CO+1/2O_2 \longrightarrow CO_2$$

$$H_2+1/2O_2 \longrightarrow H_2O$$

Cracking

Cracking is the process of breaking down large complex molecules such as tar into lighter gases by exposure to heat. This process is crucial for the production of clean gas that is compatible with an internal combustion engine because tar gases condense into sticky tar that will rapidly foul the valves of an engine. Cracking is done up to a temperature of 1200°C (All power labs, 2022).

Reduction

Reduction is the process of stripping oxygen atoms off combustion products of hydrocarbon (HC) molecules, so as to return the molecules to forms that can burn again. Reduction is the removal of oxygen from these waste products at high temperature to produce combustible gases.

$$CO+H_2O \longleftrightarrow CO_2+H_2 \text{ ("Water-Gas Shift Reaction")}$$

Energy Recovery Systems (ERS)

The maximum net electrical efficiency of a gasification–steam cycle plant is about 23%, which is comparable with the efficiency of a typical solid waste incinerator (Consonni, 2000; V. Belgiorno et al., 2013). Spark ignition engines, normally used with petrol or kerosene, can be run on gas alone. Diesel engines can be converted to full gas operation by lowering the compression ratio and by installing a spark ignition system (Quaak et al., 1999). The power plants based on advanced combined cycle gas turbine could allow an efficiency-rate of around60% (Najjar, 1999). The effective net electrical output is lower than 40% because of the consumption for gas pre-treatment (De Lange and Barducci, 2000). In fact gas turbines are very sensitive to the quality of gas, only extremely low levels of contaminants, principally

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tar, alkali metals, Sulphur and chlorine compounds, can be tolerated (Bridgwater, 1994). The demand for refuse-derived fuel is estimated to significantly increase to, for instance, approximately 115 million tons if it is intended to substitute 5% of the coal usage for electricity generation (Gershma, 2010).

Drawbacks/Problems in Biomass Gasification

The parameters with the greatest impact on the gasification process are the temperature of gasification reaction and the equivalent ratio, both are inter-related. To control of these parameters ensures that (i) a syngas with atolerable content of tars and particles is formed and (ii) there are no redundant ash sintering effects caused by high temperatures in the reactor. More energy is using in drying process if moisture contented biomass is higher; it will decrease the gasification efficiency. Additionally, moisture substances higher than 15% will enhance to discrepancies in the attentiveness of the syngas engendered, and consequently in its calorific value, in this manner the process turns unstable. Prior biomass preparation procedures, like pyrolysis or torrefaction, may help to provide the fuel with energy regularity and stabilizes gasification (Ruiz JA, 2013). reactive with oxygen; it has such a high oxygen affinity that it strips oxygen off water vapor and carbon dioxide, and redistributes it to as many single bond sites as possible. Through this process, CO_2 is reduced by carbon to produce two CO molecules, and H_2O is reduced by carbon to produce H2 and CO. Both H2 and CO are combustibles fuel gases, and those fuel gasses can then be piped do desired work elsewhere. Reduction treated at a temperature of off 650-900°C. Synthesis gasor syngas is a mixture of carbon dioxide charcoal (C). The carbon in the hot charcoal is highly them to (CO_2) and hydrogen (H_2) (All power labs, 2022).

III. CONCLUSION

Gasification processes and technologies have been done to strengthen the waste to energy recovery system. The environmental benefits of MSW gasification has been also reported in this book chapter. Finally, a case study on pilot-scale MSW gasification to generate electricity has been presented to discuss one of the most efficient pathways to utilize it. Based on the above discussion, it is quite clear that gasification process offers considerable energy recovery and reduces the amount of potential pollutants emission. Moreover, gasification may be proposed as a viable alternative solution for waste treatment by converting waste into a gaseous energy form, syngas for further potential uses to energy production or chemicals. MSW gasification has some drawbacks due to the heterogeneous characteristics of MSW. However, a possible solution to address this issue could be production of solid refuse fuel (SRF) with homogeneous and controlled characteristics. The strongest point for gasifying MSW is its environmental performance. Several MSW gasification emission test results indicate that the gasification of MSW is able to meet the emission standard and can effectively reduce the environmental impacts, which can be considered as a sound response to the increasingly restrictive regulations applied around the world & Overall, this analysis has shown that a decentralized urban wastewater treatment plant can cost-effectively apply air blown gasification technology to produce on-site electrical power and stabilize a hazardous waste stream. Wastewater treatment plants with raw sewage flows of 2.2 MGD or greater can realize a 20year profit of about $1,000,000 with a net electrical power output of about 60 kW. Moreover, the technology proves to be economically viable at small scale. The conclusions reached herein have added to the knowledge base of small biomass cogeneration system design and simulation. This systems-level analysis has proven the applicability of restricted equilibrium gasifier chemistry models to predicting power output of a cogeneration system, provided experimental work to calibrate the model exists. This is an important result for analysis of biomass waste. Essentially, the feasibility of gasification-cogeneration on any fuel which can be described by approximate and ultimate analysis can be estimated without detailed knowledge of chemical processes occurring in reactor. Application of this technology promises to reduce operating costs of wastewater treatment plants, carbon emissions from fossil-_red electricity, and the quantity of sludge requiring land disposal.

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