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REVIEW ON WASTE-TO-ENERGY CONVERSION THROUGH THERMO-CHEMICAL PROCESSES

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Abstract: Waste disposal is an important issue that needs to be addressed, not only for health and environmental reasons but also for its social and economic impacts. Three important waste streams that contribute to the growing amount of wastes generated come from medical, industrial, and electronic residual wastes. These residual wastes are usually just being dumped or disposed of in sanitary landfills. Apart from finding solutions to these environmental waste problems, these wastes can be a possible source of energy that can support our energy sustainability. Waste to Energy (WTE) is a very broad term that covers any process that converts waste into energy, or an energy-carrying product, such as a gas or oil. Despite the existence of many different technologies, the aims of all WTE processes are essentially the same, Reduce the volume of waste and hence reduce the volume requiring disposal in landfill; Reduce the biodegradable fraction of waste to zero, and Produce a useful commodity (typically electricity and/or heat) from non-recyclable waste. This review summaries the technological approaches that have been developed, presents some of the basic principles, provides details of some specific processes.

Keywords: Thermo-chemical, Pyrolysis, Gasification, electronic waste, industrial waste, medical waste, waste disposal, waste-to-energy

1. INTRODUCTION

The World Bank estimates that 1.3 billion tonnes of waste is generated annually worldwide and, by 2025, this amount will increase to 2.2 billion tonnes per year [1]. The tremendous rise in municipal solid waste (MSW) in the fast-growing cities of developing and emerging countries have led to increasing public concerns with regards to the resultant health and environmental impacts. Apart from municipal solid wastes, other major wastes that have potential as WTE feed sources are those coming from medical facilities, hazardous wastes from industries, and different residual electronic wastes. Most of the residual wastes from these waste streams, after segregation and treatment, usually just end up in storage facilities – or worst – in landfills. For medical wastes, for example, the global wastes generated surge and increase manifolds during the COVID-19 pandemic, which adds up to our waste problems. Hazardous industrial wastes, on the other hand, such as paints and used oils and grease after treatment just end up also in storage facilities or in landfills. Moreover, for electronic wastes – after segregating and recovering the recyclable materials – the residual electronic wastes also are just being disposed of in landfills. These three different wastes streams instead of adding to environmental waste problems may have potential benefits as a WTE feed, which can help not only in managing these wastes but also to provide alternative source and energy supply support. In this era of sustainable growth, trends are moving away from conventional (non-renewable) resources towards renewable resources to satisfy the energy requirement of the general population without creating negative environmental impacts. A worldwide effort is being made to recognize the potential of every nation in the solid waste management sector and its subsequent utilization in the energy recovery sector. Solid Waste Management (SWM) is a current paradigm between developing and developed countries. In industrialized countries, technologies to utilize MSW for the production of energy, heat, solid biofuel and compost were well established [2-4]. MSW is a valuable renewable resource with capacity of biogas generation for combined heat and power (CHP) production by using the appropriate waste-to-energy technologies [5]. These technologies must be selected based on the waste composition assessment and economics [6]. Selection of the appropriate WTE-T is not an easy task due to generation of solid waste is influenced by seasonality and socioeconomic level of producers [7]. Policy instruments for sustainable waste management also have a significant impact in the selection of WTE-T [8]. Waste-to-energy technologies can be classified into biochemical and thermochemical processes while MSW can be classified as biodegradable and non-biodegradable, which are suitable for biochemical and thermochemical processes respectively [9, 10]. Biochemical processes are related to anaerobic digestion technologies to produce biogas [11] and thermochemical processes are related to pyrolysis [12], gasification [13] and incineration technologies [14]. Other authors also consider landfill gas utilization technologies [15] along with biorefineries as WTE-T [16, 17]. These technologies are potential to reduce greenhouse gas emissions in decentralized energy from waste systems [18]. this paper aims to review the suitability of waste type, based on their characteristics, and to match the exhibited characteristics against the operational parameters of the appropriate WTE technologies.

2. METHODOLOGY

This review is based on a literature search using Science Direct and NPTEL.

3. WASTE-TO-ENERGY (WTE) TECHNOLOGY

There are several waste to energy technologies available based on the type, quantity and characteristics of raw material, the required method of the energy, economic conditions, environmental standards and specific factors [19]. The most commonly used waste to energy technologies are thermo-chemical, bio-chemical, chemical and physical conversion technologies [20]. The thermal treatment includes cineration, pyrolysis, gasification and refused derived fuel (RDF) The biological treatment includes anaerobic digestion (AD), fermentation and enzyme. The chemical conversion includes hydrolysis, solvent extraction and transesterification. The physical conversion includes mechanical extraction, briquetting of Biomass and distillation.

Thermo-chemical technologies are generally used to convert waste into heat, electricity, and other value-added products (VAP) by subjecting waste to high temperatures [21]. Thermal conversion is considered a part of integrated waste management technology [22].

3.1. Incineration

One of the most common waste treatment technology is incineration, in which waste mass is reduced by 70% and waste volume is reduced up to 90%. Incineration is suitable for high calorific value wastes. In this process, produced energy is converted in electricity generation[19, 23, 24]. The whole process carried out in three phases i.e. incineration, energy recovery and control of air pollution. The whole process is illustrated in Figure 1. In the first phase (incineration process), waste is directly burned at 700-1000^{o} C in the combustion chamber by using flue gas and preheated air. Ultra-hot steam is produced after combustion of waste and this steam is used to create heat energy. Turbine is connected to generator which produces energy, heat and bottom ash. Bottom ash primarily contains of silicon, iron, calcium, aluminum, sodium and potassium.Heat and energy are recovered in second phase of incineration process. The biggest disadvantage of incineration process is the production of greenhouse gases. Thus, it is of prime concern to install emission control equipment to the incinerator, which is the third phase of incineration process [19,25,26]. Incineration technology of Indian MSW is not convenient as it contains high organic composition, moisture content or inert content (range 30- 60% each) and low calorific value (range 800-1100 kcal/kg) [27].Usually, in India small incinerators are used for burning of hospital waste. Still, a medium sized incinerator plant was installed to dispose of 300 tonnes of day-to-day waste at Delhi, India in 1987. However, the plant remained out of order currently, because non-availability of waste having required calorific value for incineration [28]. At present, there is no large-scale incinerator working in India

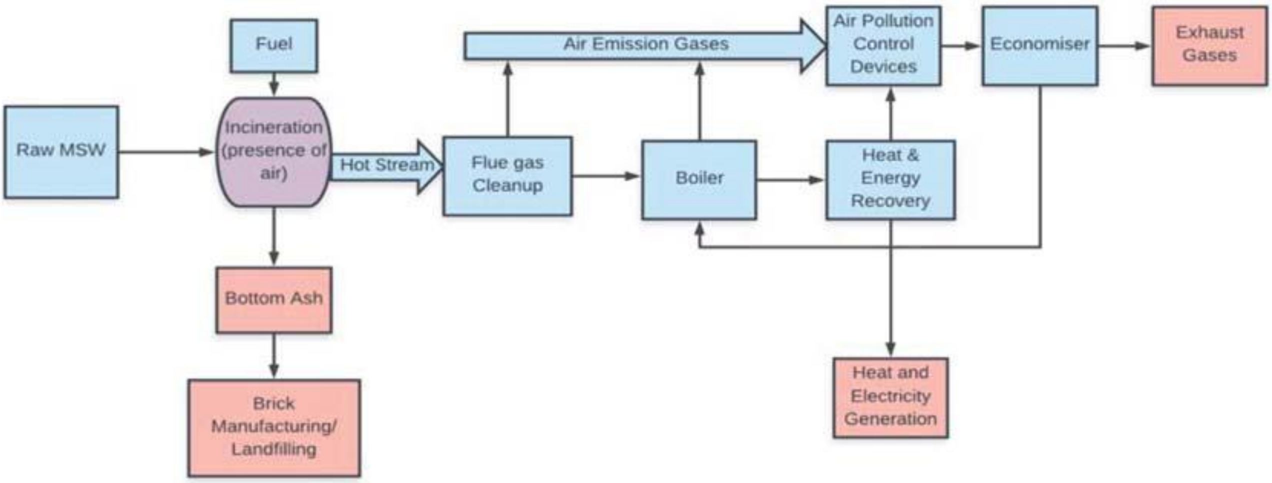

Figure 1. Incineration process to produce electricity and heat

3.2. Gasification

Gasification is a partial oxidation of organic substances at elevated temperature (500°C - 1800°C) to produce a synthesis gas (often called syngas) that can be used as a feedstock (through some reforming processes), or as a fuel [29]. The synthesis gas contains CO, CO_2, H_2, H_2O, CH_4, trace amounts of higher hydrocarbons such as ethane and ethane, inert gases originating from the gasification agent and various contaminants such as small particles [30]. The partial oxidation can be carried out using air, oxygen, steam, carbon dioxide or a mixture of these. Air gasification produces a low heating value (LHV) gas (4-7 MJ/Nm3 higher heating value), while oxygen gasification produces a medium heating value (MHV) gas (10-18 MJ/Nm3 higher heating value). [31]. This synthesis gas can be used for efficient production of electricity and/or heat, or second generation liquid biofuels. Several different gasification processes are available or being developed which are in principle suited for the treatment of MSW, certain hazardous wastes and dried sewage sludge. Good operation of the gasification reactor and minimisation of tar formation requires that the nature (size, consistency) of the waste input remains within certain predefined limits. This often requires special pretreatment of MSW, thereby increasing the cost. Figure 2. illustrates the gasification process.

Special features of gasification processes are:

• smaller gas volume compared to incineration (up to a factor of 10 by using pure O_2),

• smaller waste water flows from synthesis gas cleaning,

• predominant formation of CO rather than CO_2,

• capturing of inorganic residues, *e.g.* within slag in high temperature slagging gasifiers,

• high operating pressures (in some processes), leading to small and compact aggregates,

• material and energetic utilisation of the synthesis gas.

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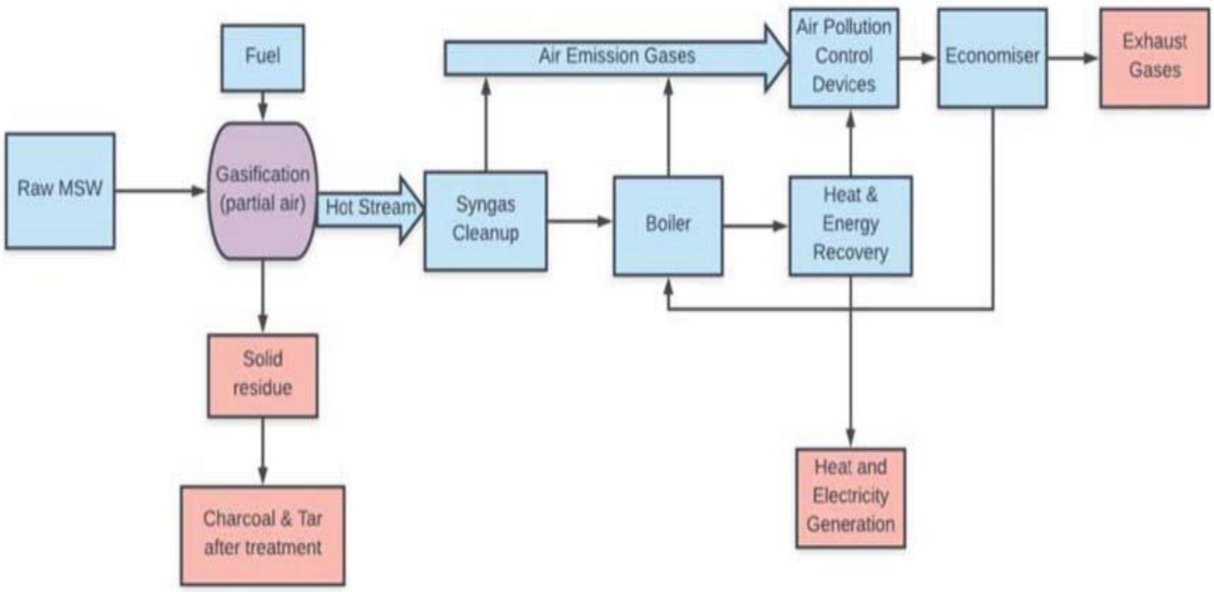

Figure 2. Gasification process to produce energy and heat

3.3. Pyrolysis

The recent consciousness of the need for abatement of air pollution leads to worldwide interest in and investigation of pyrolysis as a major process for waste treatment. Pyrolysis is thermal degradation either in the complete absence of an oxidising agent, or with such a limited supply that gasification does not occur to an appreciable extent; the latter may be described as partial gasification and is used to provide the thermal energy required for pyrolysis at the expense of product yields. Relatively low temperatures (400-900°C, but usually lower than 700°C) are employed compared to gasification. Three products are obtained: pyrolysis gas, pyrolysis liquid and solid coke, the relative proportions of which depend very much on the pyrolysis method and reactor process parameters. The heating value of pyrolysis gas typically lies between 5 and 15 MJ/m³ based on MSW and between 15 and 30 MJ/m³ based on RDF.

Pyrolysis plants for waste treatment usually include the following basic process stages:

1. Preparation and grinding: the grinder improves and standardises the quality of the waste presented for processing, and as such promotes heat transfer.

2. Drying (depends on process): a separate drying step improves the LHV of the raw process gases and increases efficiency of gas-solid reactions within the reactor.

3. Pyrolysis of wastes: besides the pyrolysis gas, a solid carbon-containing residue is generated which contains mineral and metallic compounds.

4. Secondary treatment of pyrolysis gas and pyrolysis coke: condensation of the gases for the extraction of energetically usable oil mixtures and/or incineration of gas and coke for the destruction of the organic compounds and simultaneous utilisation of energy.

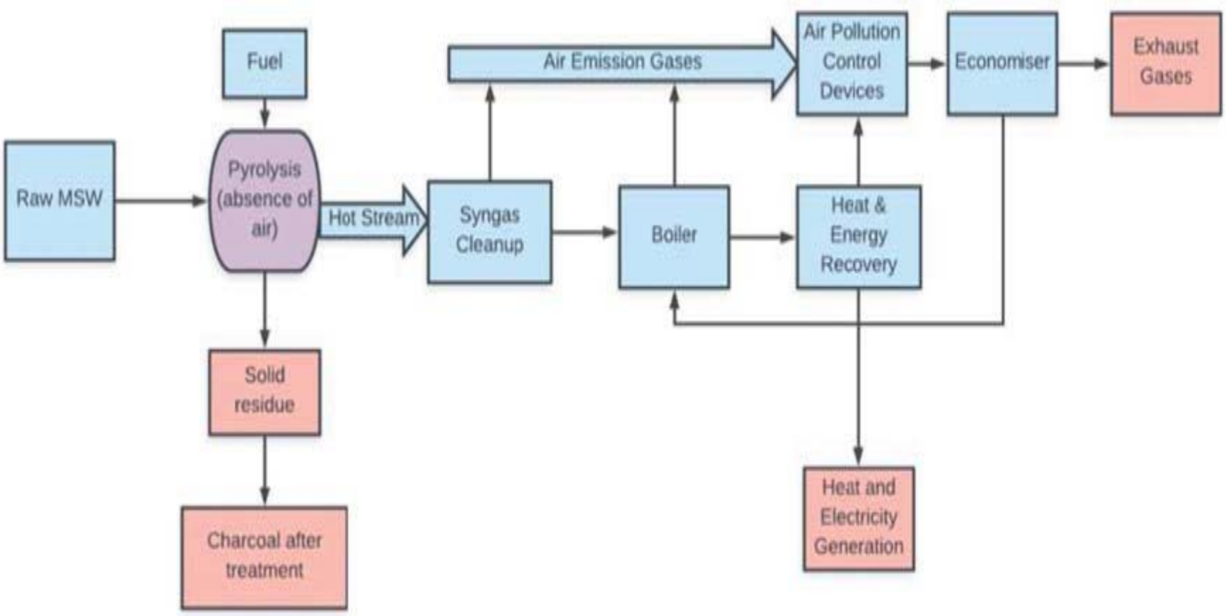

Figure 3. Pyrolysis process to produce energy and heat

3.4. **Refuse-derived Fuel (RDF)**

RDF technology stipulates safe and eco-friendly disposal of MSW. It is an alternating fuel which can be used in boilers in place of fossil fuels. The process of RDF generation is described in Figure 4. A few RDF plants were setup in India [27,32], RDF pellets is frequently used for pulp, paper industry, wood industry waste and saw-mill industry [25].

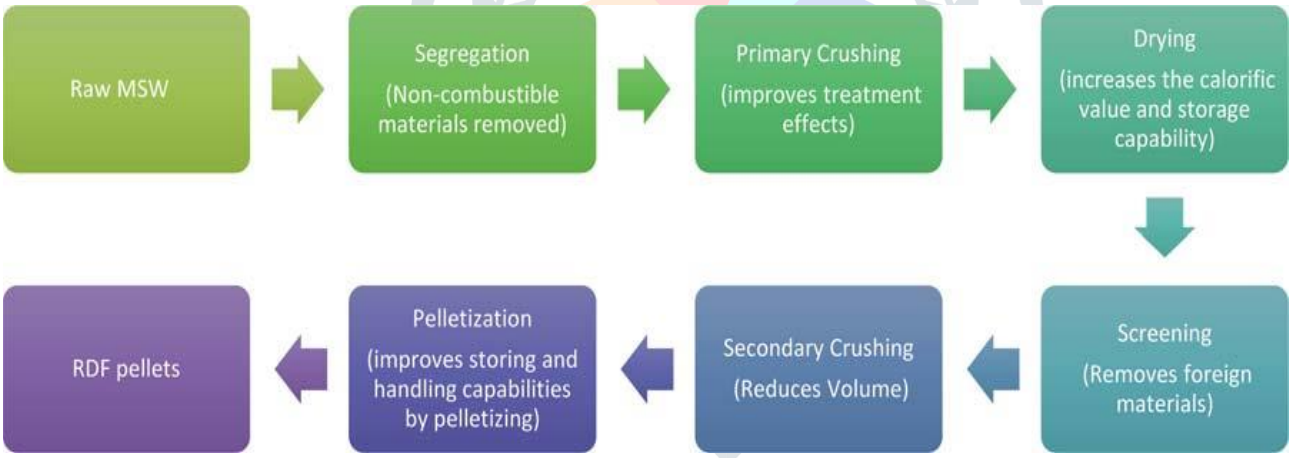

Figure 4. Refuse derived fuel process

4. CONCLUSION

With the ever-increasing demand for energy in a rapidly growing economy like India, cheap and sustainable energy is the need of the hour. Waste to Energy conversion remains a major untapped energy resource in the Indian context. Several efforts have been made by the government of India to improve our waste energy potential (biomass, MSW). A significant improvement in biomass energy generation capacity (10 GW) has been attained in the past decade, however, the MSW-based energy potential is yet to be realized. It is to be mentioned that less than 5% of the overall energy generation potential from MSW is currently utilized in India. The types of waste (MSW) plays an important role on the efficiency of WTE technologies and the yields of production. The thermal treatment required waste that have low moisture content and high calorific value for good performances.

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