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Optimization of waste to energy routes through biochemical and thermochemical treatment options of municipal solid waste in Hyderabad, Pakistan

Muhammad Safar Korai [a,*], Rasool Bux Mahar [b], Muhammad Aslam Uqaili [c]

[a] Institute of Environmental Engineering & Management, Mehran UET, Jamshoro, Sindh, Pakistan
[b] U.S.-Pakistan Center for Advance Studies in Water (US-PACASW), Mehran UET, Jamshoro, Sindh, Pakistan
[c] Electrical Engineering Department, Mehran UET, Jamshoro, Sindh, Pakistan

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ABSTRACT

Improper disposal of municipal solid waste (MSW) has created many environmental problems in Pakistan and the country is facing energy shortages as well. The present study evaluates the biochemical and thermochemical treatment options of MSW in order to address both the endemic environmental challenges and in part the energy shortage. According to the nature of waste components, a number of scenarios were developed to optimize the waste to energy (WTE) routes. The evaluation of treatment options has been performed by mathematical equations using the special characteristics of MSW. The power generation potential (PGP) of biochemical (anaerobic digestion) has been observed in the range of 5.9–11.3 kW/ton day under various scenarios. The PGP of Refuse Derived Fuel (RDF), Mass Burn Incinerator (MBI), Gasification/Pyrolysis (Gasi./Pyro.) and Plasma Arc Gasification (PAG) have been found to be in the range of 2.7–118.6 kW/ton day, 3.8–164.7 kW/ton day, 4.2–184.5 kW/ton day and 5.2–224 kW/ton day, respectively. The highest values of biochemical and all thermochemical technologies have been obtained through the use of scenarios including the putrescible components (PCs) of MSW such as food and yard wastes, and the non-biodegradable components (NBCs) of MSW such as plastic, rubber, leather, textile and wood respectively. Therefore, routes which include these components are the optimized WTE routes for maximum PGP by biochemical and thermochemical treatments of MSW. The findings of study lead to recommend that socio-economic and environmental feasibility of WTE conversion technologies should be performed in the context of the country.

1. Introduction

Pakistan faces both an energy crisis on one hand and difficulty in transporting wastes from generation to final disposal as a result of a rapidly increasing population. The population of Pakistan was recorded as 188.08 million in 2014 and continuously increasing with growth rate of 1.9%, making it one of the world's most populous countries and further exacerbating waste management issues [1–3]. Approximately 38.55% of the population is concentrated in urban centers, while the remaining 61.42% is in rural [1–4]. The entrances as well as exits of each city are plagued by the unsanitary burning and dumping of huge quantities of solid wastes. In monsoon seasons, the waste management issues reach an extreme level. The roads, streets, and sewers become clogged with litter. The improper handling, storage, and processing of MSW have caused many urban environmental issues in the country [5]. No one optimized collection route of MSW has been determined even in major cities of Pakistan [5,6]. As compared to other countries (i.e., Denmark, Germany, France, Italy, UK, USA, China, etc.), less than 50% of MSW is only disposed by landfill and composting in improper way in Pakistan [7,8]. The dumping of MSW disposal method is the major source of various environmental issues including water pollution, soil pollution, green house gases emissions, etc.

Municipal solid waste is the fourth largest global emissions contributor [9–11]. Approximately 550 Tg of global methane emissions are annually contributed by MSW [11,12]. The global warming potential of methane is about 21–23 times higher than carbon dioxide [9]. The third largest anthropogenic sources of CH_4 emissions are solid wastes in landfills [13]. The emissions from MSW landfills are predicted to rise up to 816MtCO_2-eq by 2020 [14] if little or no efforts are made to reduce them. Pakistan shares about 0.8% of total global green house gases (GHG) emissions by

* Corresponding author.
E-mail address: safar.korai@faculty.muet.edu.pk (M.S. Korai).

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standing on 135th position [15]. The rise in above global standing position is expected by 2030 because of the rapidly growing population rate leading to urbanization, increasing transport, energy and waste generation [12]. About 4.73MtCO_2-eq of CH_4 was contributed by waste management in Pakistan with 2832 tonnes from solid waste and others from wastewater as mentioned in the national 2008 inventory of GHG emisions [14]. Also the shortage of energy has become major point of discussion for every Pakistan government during the last two decades. Presently, power demand has increased to 19,000 MW as reported by Zofeen [16]. Like in other developing countries, the conventional energy sources like fossil fules have remained the choice of Pakistan [5,17]. Immense efforts are being made worldwide to reduce GHG emissions and to harness hidden renewable energy resources. The acknowledgment regarding to reduce GHG emissions and to convert waste into energy are universally going towards the vital role of waste sector. The increasing of cost associated with conventional energy generation and waste disposal has globally compelled developing countries to move towards the waste to energy concept [18–20]. Exploitation of energy from MSW will play a significant role in the future and has many advantages as an effective solution for reducing environmental impacts while potentially relieving the energy crisis.

Adoption of WTE technologies is an effective way to harness energy from MSW and to reduce GHG emisions from burning/dumping. There are various WTE technologies including biochemical (i.e., composting, anaerobic diegsestion process, etc.) and thermochemical (i.e., incineration, pyrolysis, gasification, etc.). Biomethanation is an anaerobic digestion (AD) process during which complex organic substances are decomposed in by microorganisms in the absence of oxygen to generate biogas containing 50–60% methane [21,22]. About 0.075 kW can be produced from one cubic meter of biogas during biomethanation process in Indian MSW [22,23]. Current usage of biogas from AD plants is increasing in combined heat and power generation systems and may also serve as vehicle or other fuel in many countries [21,24]. Almost 244 AD plants with a capacity of 8 million tons of organic wastes are operating in Europe [21,25]. More than 6000 domestic AD plants are operating in Pakistan by using cattle manure as substrate [26]. There is potential to produce biogas of 9 million m^3 per day from animal dung by installing AD plant of size 70 m^3 in the rural areas of Pakistan [27,28]. Whereas the disposal of organic fractions of MSW in Pakistan is either burning or dumping with other wastes in open air and very little amount of organic waste is used for informal composting [5,6]. According to the findings of study [27], the methane production potential of different biomass such as buffalo dung, cotton straw, rice husk, wheat straw, maize and MSW is about 50, 2, 14, 200, 250 and 100 m^3/ton respectively in pakistan. The fully utilization of livestock and bagasse for power generation can share up to 40% in the present scenarios of Pakistan [29]. In Pakistan, biogas energy sources such as livestock, bagasse, agriculture wastes and MSW can be significantly utilized for energy production [30,31]. The huge quantity of rice husk, wood wastes and other crop residues in Pakistan can be used for the gasification process [27]. The RDF pellets can be used an efficient fuel having advantages over using coal because of its high calorific value (0.145 kW/kg) [32]. In Malaysia, 1 MW electricity is being produced from 100 tons of MSW per day by incineration technology [33,34]. The net PGP of Gasi./Pyro. is about 20–26 kW/ton of MSW [22,35,36]. The PGP of MBI, Gasification, Pyrolysis and PAG has been observed to be in the range of 0.75–0.85 MW h/ton year, 0.4–0.8 MW h/ton year, 0.3–0.6 MW h/ton year and 0.5–0.8 MW h/ton year of MSW [37,38]. Presently about 130 million tons of MSW are annually being treated in more than 600 WTE facilities around the world to produce electricity [37]. The same study reports that 88 and 7 WTE plants are functioning in the USA and Canada, respectively, by using 27 million tons of MSW annually. Approximately 750,000 tons of MSW per year are treated using MBI in over 90% of the WTE treatment facilities in Europe [39,40]. Mainly three technologies (i.e., RDF, Incineration and Biomethanation) are functional in India [22]. Whereas, neither biochemical treatment plant for organic fractions of MSW nor any well designed WTE treatment facility has been observed in Pakistan and even major cities of the country are facing problems associated with conventional disposal of MSW [5]. In this regard the present study has been formulated by considering main two objectives. The first is to determine the PGP of biochemical and thermochemical treatment options for MSW under various scenarios and the second is to evaluate various technologies (AD, RDF, MBI, Gasi./Pyro. and PAG) in order to optimize the potential WTE routes of MSW in Hyderabad, Sindh, Pakistan.

2. Methodology

2.1. MSW quantification and composition analysis

For quantification and composition of MSW, various samples of waste were collected randomly from residential as well as commercial areas and recycling shops. Then, separation and weighing of different waste components such as food wastes, yard waste, wood, plastic, paper, cardboard, rubber, cloth waste, glass, metals including ferrous as well as non-ferrous, were carried out manually and by using physical balance. On the basis of composition, further quantities of MSW along with potential components were estimated using the Eq. (i) [41] by considering the 2.4% growth rate of MSW [10,42].

$$Eq_{(MSW)} = Gr_{(MSW)} \times Pq_{(MSW)} \times n + Pq_{(MSW)} \qquad (i)$$

where $Eq_{(MSW)}$, $Gr_{(MSW)}$, and $Pq_{(MSW)}$ are estimated quantity, growth rate, and present quantity of MSW, respectively, during n years.

2.2. MSW characterization

After collection, MSW samples for analysis were prepared according to the quartering method [39,41,43]. Various MSW characteristics including moisture content (MC), total solids (TS), volatile matter (VM), fixed carbon (FC), ash content (AC), calorific value (CV), and element analysis were determined by adopting standard methodologies as given in Table 1.

Theoretical biogas potential (TB_P) of waste samples was also estimated. Molar concentrations of elements were first estimated

Table 1
Various MSW characteristics along with standard methods and equipment.

Characteristics	Method	Equipment
Moisture content	ASTMD3173	Oven Dry
Volatile matter and fixed carbon	ASTMD3175	Muffle Furnace
Ash content	ASTMD3174	Muffle Furnace
Element analysis	BBOT23122013	FlashEA® 1112 Organic Elemental Analyzer
Calorific value	–	Gallenkamp Ballistic Bomb Calorimeter