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Review

Technological aspects for thermal plasma treatment of municipal solid waste—A review

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ABSTRACT

The 21st century earth is a new world, with numerous urban areas, exponentially growing population, global warming, global markets and with it, increased consumerism which has led us to amass huge amounts of municipal solid waste (MSW). This waste is difficult to manage using conventional methods and is ever increasing, blocking essential space that has become an expensive commodity in today's world. Conventional techniques such as combustion/incineration have been the conventionally preferred method of waste management for several nations in lieu of land-filling, releasing toxic emissions onto an already over polluted environment. In this paper we shall explore a novel MSW management technology in the form of plasma torches and thermal plasma treatment that enables us to reduce waste density by as much as 95%, without any toxic emissions, while producing a synthetic gas as by-product. Synthetic gas or syngas is presently being used to generate energy. Some researchers are also exploring the possibility of hydrogen extraction through this route. This paper discusses the current limitations of this technology and highlights a few researches that are being conducted around the world that may soon take this concept from technical feasibility to practical reality.

Contents

1. Introduction

Since the beginning of industrial revolution in the 18th century there has been a steady growth in urban population as more people from rural areas were migrating into cities to be part of a revolution that would provide people with jobs, food and clothing. This was the beginning of the creation of an urban consumer market. The concept of consumerism grew with the development of new technologies that gave people access to a variety of products in huge quantities with substantially consistent quality and by 1939 the concept of consumerism grew on a global scale as more countries such as Germany, France and the USA, following the example of the British Empire, had rapidly developed their industrial capabilities. The end of the Second World War and the rise of the USA as a new superpower, saw a new form of consumerism—the consumption of products in huge quantities, not just limited to those that are considered essentials to fuel economic growth [1].

The growth of consumerism meant that the supply of products must be unhindered. Industry grew and along with it the demand for labour. The World Health Organisation reports that in the beginning of

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the 20th century, 20% of the population dwelled in urban areas, by 1990 that number rose to a little less than 40% and is expected to rise to a staggering 70% by 2050. These statistics show that there is a growing trend in people migrating into urban areas for better job, lifestyle and livelihood [2]. The increase in urban population and the steady rise in consumption have adverse effects on the environment such as rapid global population increase (currently the global population stands at 7.2 billion people and rising as per United Nation's Department of Economic and Social Affairs [3]) and the generation of huge quantities of municipal solid waste (MSW) is increasing along with the increasing numbers of urban dwellers (Table. 1). While most countries do not regard population increase as an immediate threat, the excessive accumulation of MSW has led to major concerns in the developed and developing nations [4,6] as conventional methods [4,8–10] are not able to effectively dispose off the waste at rates at which they are being generated. While MSW recycling is essential it is dependent on the government's motivation to take the necessary measures to promote awareness. However the generation of waste will continue to grow making it essential for us to formulate a solution to effectively manage waste regardless of geographical or income of a country, factors that play an important role.

Accumulation of waste results in decomposition and harmful emission of gases and some methods of storage require large tracts of land which are becoming increasingly valuable with increase in population. The World Bank reports that there are presently three billion urban residents generating 1.2 kg per person per day of MSW and that number is projected to grow to 4.3 billion urban residents generating 1.42 kg per person per day of MSW by 2025 [4]. Hence an unconventional yet effective solution is required which can be found in the form of thermal plasma pyrolysis which this paper seeks to explore.

1.1. MSW

MSW has various compositions, varying from region to region, country to country and from people to people based on their income, lifestyle/culture, climate, energy sources and economic affluence. Developing countries such as India and China, with a rapidly growing urban population, produce MSW which is mostly organic in nature, such as food scraps, wood, leaves, and process residues from farms whereas developed countries with a wealthier population show higher consumptions in inorganic materials such as plastic, paper, metal, and e-wastes [4].

E-wastes are essentially discarded electronic appliances such as computers, cellular devices, televisions or components such as discarded mother boards, and processors (this may consist of carcinogenic heavy metals such as lead, mercury, chromium, which defies other forms of processing and may enter our food cycle through water and soil contamination, if not treated/neutralised effectively), due to e-waste high degree of mercury contamination can be expected in MSW [5].

The MSW composition cannot be simply categorised as organic and inorganic wastes. Industrial wastes, mostly inorganic such as plastic, tyres, metal components and medical wastes such as soiled bandages, syringes, cotton, and plastics are infectious wastes or red bag wastes which may be contagious and pose health and environmental hazards [14–16], and therefore are required to be segregated from the typical waste pile gathered from residential areas. The World Bank reports that while countries with high income have a collection rate of 98%, low income countries have a very low collection rate of a mere 48% even though a substantially large amount of their municipalities' waste management budget goes into collection; separation of various types of wastes is generator dependent, however in regions with low-income, the generators have insufficient knowledge and motivation to categorise and separate their waste and their governments lack funding and/or the inclination to prioritise sorting, post collection. So it must be assumed that the presence of industrial and medical wastes is highly probable in MSWs if sourced from regions of low income or with poor waste management policies [4]. Although medical wastes and industrial wastes may require special processing, it has been established that thermal plasma pyrolysis techniques can be used to treat both medical wastes [10,12,14,16] and industrial wastes [11,13,16–20], generating syngas without producing any toxic by-product and using it for energy generation.

There are no specific data available on the composition of MSW, making it difficult to determine a standard. However the World Bank reports in [4] that a global MSW composition estimate can be represented in the form of a pie chart, Fig. 1.

As shown in Fig. 1, MSW is pre-dominantly composed of organic wastes. As mentioned earlier organic waste can be food scraps, yard trimmings, and process residues; its composition will vary from region to region based on the income of the region, geography, etc. C. Ducharme in [6] noted that organic component of MSW can be approximated by the formula $C_6H_{10}O_4$, an observation stated by Themelis et al. in [30] on his study of New York City MSW. The formula can guide researchers when considering the organic component of the MSW sample, and determine its composition percentage.

1.2. Plasma

After solid, liquid and gas, plasma is considered to be the fourth state of matter; plasma is essentially composed of electrons, ions and neutral particles. However, plasma in its entirety is electrically neutral.

Plasma has a long history of utility in industry. It was first employed for metallurgical processes in the 19th century and later in the 20th century. It was used for acetylene extraction from natural gases in the chemical industry. The reason for using plasma was its ability to provide high temperatures. The very same reason saw NASA develop this technology extensively for simulating the high temperatures that missiles and space-crafts routinely face upon re-entry into earth's atmosphere due to the rapid ionisation. The technologies that we currently use in waste processing are derivatives of the technology initially developed by NASA [10].

Table 1
MSW Generation by country [4].

Country	Current available data		Projections for 2025	
	Total urban population	Total MSW generation (tonnes/day)	Urban population	Total MSW generation (tonnes/day)
India	321,623,271	109,589	538,055,000	376,639
China	511,722,970	520,548	822,209,000	1,397,755
USA	241,972,393	624,700	305,091,000	701,709
Russia	107,386,402	100,027	96,061,000	120,076
United Kingdom	54,411,080	97,342	59,738,000	110,515
France	47,192,398	90,493	53,659,000	107,318
Germany	60,530,216	127,816	61,772,000	126,633
Brazil	144,507,175	149,096	206,850,000	330,960
Israel	5,179,120	10,959	8,077,000	16,962
South Korea	38,895,504	48,397	41,783,000	58,496
Japan	84,330,180	144,466	86,460,000	146,982