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Assessment of Power Generation Potential from Municipal Solid Wastes: A Case Study of Hyderabad City, Sindh, Pakistan

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Abstract

This paper is an attempt to estimate the power generation potential through utilization of municipal solid waste (MSW) in order to overcome energy crisis, faced by country now a days. The waste-to-energy has proven itself to be an environment friendly solution for the disposal of municipal solid waste. Representative samples of the MSW were collected from the open dumping sites of solid wastes and analyzed for calorific value by using a Bomb Calorimeter in the laboratory. Net and gross calorific value of mixed MSW were obtained as 6519 & 6749 kcal/kg, respectively. Based upon its calorific value, net power generation was estimated as 1512 kWh per ton of MSW generated. This shows that MSW generated in the study area is more suitable for thermal treatment process. In this regard, different thermal treatment technologies have been compared with respect to various parameters and mass burn incinerator is found suitable for generation of power. This technology for conversion of MSW into power generation would not only be beneficial to meet the power demand but also reduce the environmental pollution to certain extent.

Keywords: Municipal solid Waste; Composition; Calorific value; Power generation

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Introduction

In light of fact, the development and growth of economy of a nation widely depends upon energy sector. In other words, energy is the driving force for development in all countries of the world. The increasing clamour for energy and satisfying it with a combination of conventional and renewable resources is a big challenge [1]. Nobody can deny the significant role of energy among all major drivers of growth in strategic planning of Pakistan Government. Instead of having huge quantity of energy resources, Pakistan is still under energy crisis and has to depend upon imports in order to overcome its needs hardly. The conventional sources of energy like fossil fuels have remained the choice of the world for centuries. But now a days, globally the over consumption of the fossil fuels due to the industrialization and growth in population at the alarming rate has raised many environmental as well as social issues. The continued concerns over energy prices, increase in population and climate change issues have led towards a need for alternative and new energy sources [2]. As it has been concluded that global warming, is mainly because of greenhouse gases releasing from energy systems based on fossil fuels. In this regard, the world opinion regarding alternatives of fossil fuels has been growing which would not only ensure eco-friendly sustainable development but also environmental pollution would be reduced to some extent. Renewable

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energy contributes strongly to the sustainable development for which waste-to-energy (WTE) conversion represents an important opportunity. WTE is a viable option for disposal of MSW and energy generation [3].

Pakistan is one of the richest countries in the region in terms of renewable energy sources but unfortunately they have not been properly exploited. As a result, Pakistan like other developing countries of the region has been facing serious challenges regarding shortage of energy since many years. As various renewable energy sources like solar energy, wind energy, energy from solid wastes etc, are available and can be exploited commercially in Pakistan. In this study, estimation of energy from municipal solid wastes (MSW) in terms of power generation is theoretically focused and treatment technology is recommended. This is due to availability of wastes, their low cost and the necessity of their collection and treatment. The industrialization and the modernization of human society have induced the waste concentration in urban areas and they are discharged in natural sites in huge quantities. This situation has caused environmental pollution which has required their specific management [4].

There are number of environmental issues like waste water generation & its treatment, air & noise pollution, soil degradation, deforestation, etc., among all these issues, one is the most challenging environmental problem is the appropriate disposal of MSW. It's accumulation for long term in the open environment is continuously increasing and being a part of causing the urban environment degradation directly or indirectly. The management of MSW is one of the important parts of the inclusive environmental management in most of the developing countries [5]. In most of the countries like in low and average revenue generation, there are various social as well as environmental sever threats due to the mismanagement of MSW [6]. While, there is a great opportunity of producing energy like gas as well as electricity. Most of developed countries generate electricity from their solid wastes. Mostly in many countries of the world, solid waste is being used for electric power generation through incineration or gasification technology, capturing of landfill methane and mostly focused by using waste to energy concept [7]. About 90% volume of solid waste may be reduced by adopting thermal treatment and by this simultaneously problems including disposal of solid waste and generation of electricity are addressed [8]. In addition, the prudent use of natural resources is one of the broadest objectives of sustainable development [9]. Electricity and gases are the most important form of energy which can lead the country for several steps to the developed one. The MSW are the important source of methane which could be harnessed as a potential energy source [10]. With proper MSW management and the right control of its polluting effects on the environment and climate change, MSW has the opportunity to become a precious resource and fuel for the urban sustainable energy development [11]. Moreover, waste could represent an attractive investment since MSW is a fuel received at a gate fee, contrary to other fuels used for energy generation [12].

The generation rate of MSW is globally increasing at the alarming rate because of different reasons, for example one of them is the rapid urbanization. MSW generation rates are influenced by economic development, the degree of industrialization, public habits and local climate. As a general trend, the higher the economic development, the higher the amount of MSW generated. Nowadays more than 50% of the entire world's population lives in urban areas. The high rate of population growth, the rapid pace of the global urbanization and the economic expansion of developing countries are leading to increased and accelerating rates of MSW generation [13-16]. Population, urbanization growth and the rise in the standards of living has all dramatically accelerated the MSW generation in developing countries [14, 17 & 18]. Worth to mention that global averages are broad estimates only, as the rates varies considerably by region, country, city, and even within cities. For example MSW generation ranges from 0.9 to 1.6 kg/day in European Union and Asia and 0.7 to 1.5 kg/day. These results in millions of tons of MSW produced globally every day [13-14]. A recent study by anonymous [16] estimates that the global MSW generation is approximately 1.3 billion tons per year or an average of 1.2 kg/capita/day. It is to be noted however that the per capita waste generation rates would differ across countries and cities depending on the level of urbanization and economic wealth. The amount of municipal solid waste generated is expected to grow faster than urbanization rates in the coming decades, reaching 2.2 billion tons/year by 2025 and 4.2 billion by 2050 [16, 19].

The average generation rate of MSW ranges from 1.9 kg/house/day to 4.3 kg/house/day in major cities of Pakistan [20]. The population of Pakistan is currently represented as about 185 million and continuously increasing without any control mechanism, from which about 35% people are living in urban areas [21]. Due to increasing population of Pakistan, the amount of MSW is estimated approximately 64,000 tons per day in urban areas of the country [20]. From the literature survey it has been observed that more than 90% from collected waste is either openly dumped at natural low laying areas and also along with road sides or placed into open surface water carrying channels as well as in sewers [22]. Instead of huge quantity of MSW generation in Pakistan, there is no any practice of using the MSW for power generation in the country. Therefore there is an urgent need to fulfill the energy requirements and to manage the waste that had been produced. Simultaneous solution to both the problems is Waste-to-Energy Technology [1 & 14]. Additionally, at present MSW is one of the feasible solutions, to meet the increasing power generation demand of country. Also it is seriously facing shortage of electricity and environmental pollution because of open burning of solid waste. In order to fulfil the power generation demand and to overcome environmental pollution to some extent, the use of MSW for power generation is very much necessary.

Materials and Methods

Study area

Hyderabad city is not having separate features in the light of fate and destiny from other various historical cities of the world and in other words it is matchless city of country in so many ways. According to the population, it is considered as the 2nd largest city in Sindh province of Pakistan and is the 3rd largest city in the country. On the globe, its position is between 25° 22′ 45″ North & 68° 22′ 6″ East and about two million is its population [23]. It is approximately 150 km away from capital of the province which is Karachi and it is above the sea level as positioned at about thirteen meters elevation [24]. Geographically, it's map is shown in Fig.1.

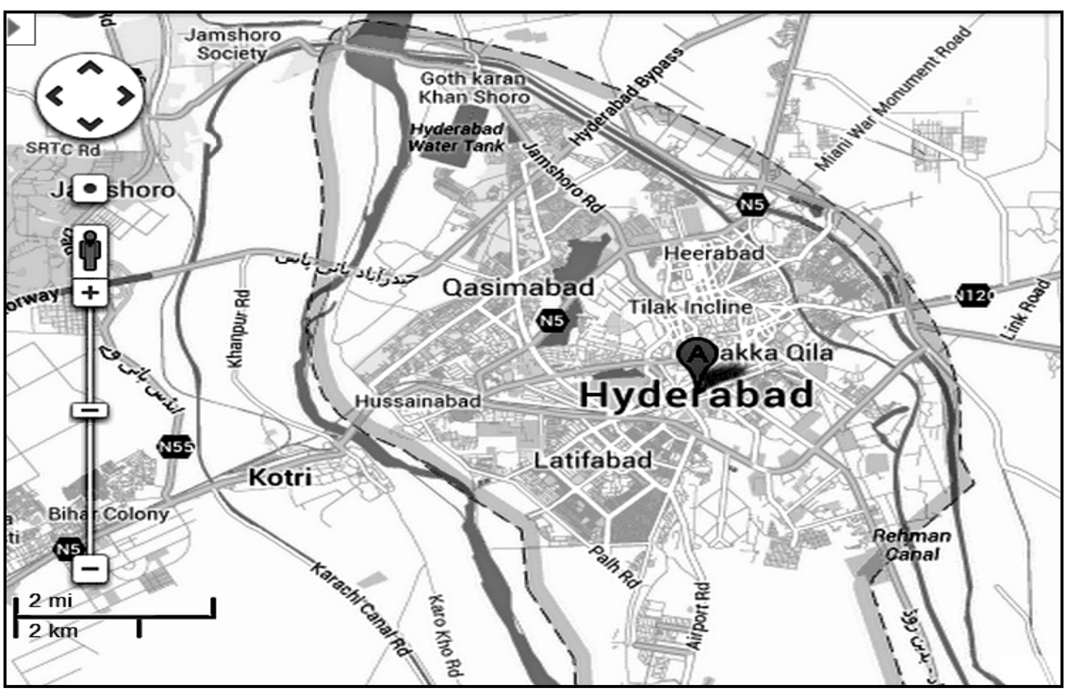

Figure 1. **Geographical map of Hyderabad city**

MSW availability

About 1600 tons of MSW is being generated every day in the Hyderabad city with generation rate ranges from 0.6 to 0.8kg/capita/day [25]. The moisture content and percent by weight of MSW components generated in Hyderabad city are given Table 1.

***Table 1*. Moisture content and percent by weight of MSW [25].**

Waste component	MC in each waste component (%)	Physical composition by weight (%)
Ash, bricks, dust	8.00	18.13
Cardboard	5.00	6.70
Food waste	76.44	30.82
Glass	2.00	6.08
Leather	10.00	1.11
Metals	8.00	3.66
Paper	6.00	5.89
Plastic	2.00	8.75
Rubber	2.00	1.10
Textile	10.00	2.07
Wood	20.00	1.84
Yard waste	51.73	13.85
Cumulative for MSW		100.00

Preparation of samples for analysis

About 50 kg of MSW was collected from dumping sites of city. After that, separation of organic and inorganic components of MSW sample was carried out manually. Percentage by weight of each organic waste component for calorific value was determined (Table 2) where as inorganic components (i.e glass, metals, ash, dirt, bricks etc) were discarded.

Then, according to Quartering method [26] mixing & cutting of large pieces of organic components of MSW were performed manually and was divided into six sections (i.e., 1, 2,3,4,5 and 6). These were separated into odd sections (i.e. 1, 3 and 5) and even sections (i.e. 2, 4 and 6). Odd sections were mixed and again separated into two sections (i.e. A and B). Similarly even sections were mixed and separated into two sections (i.e. C and D). These four sections were diagonally again mixed and separated into two sections (i.e. AD into X and BC into Y). Then X and Y sections were finally mixed together in order to get sample for analyzing (Fig. 2). Mixing, cutting and separation were performed several times, until weight of sample for analyzing became 20kg.

***Table 2.* Composition of waste samples for calorific value.**

Waste Components	%age by weight	
	Vegetable wastes (64%) including	Fruit wastes (36%) including
Food Wastes	Bitter gourds (19.16%), Tomatoes (10%), Potatoes (12.81%), Onions (10.09%), Lemons (3.5%), Eggs shells (4.75%), Green Beans (4.06%), Garlic (1.25%), Coriander leaves (6.56%), Chili greens (7.81%), Lady fingers (11.25%) and Ridge gourd (8.75%)	Mango peels & seeds (26.12%), Banana peels (18.33%), Sapodillas peels & seeds (16.67%), Peach peels & seeds (13.89%),Victoria plum seeds (9.44%),Apricot peels & seeds (8.34%) and Jammues (7.22%).
Yard Wastes	Mixed	
Paper wastes	Newspaper (60%) and Copy paper (40%)	
Cardboard wastes	Mixed	
Plastic wastes	Shopper bags (75%) and Bottles (25%)	
Leather wastes	Mixed	
Rubber wastes	Mixed	
Wood wastes	Mixed	
Textile wastes	Mixed	

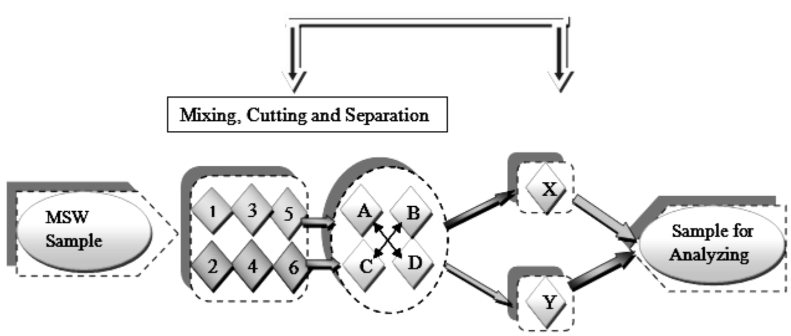

***Figure 2.* General flow chart of quartering method**

Determination of calorific value of MSW

The calorific value of each organic components (i.e paper, cardboard, wood, plastic, rubber, textile, leather, yard wastes and food wastes) of MSW was determined by using Gallen kamp Ballistic Bomb Calorimeter in the laboratory. The value regarding calorific of other inorganic components (i.e glass, metal, ash, bricks and dirt) of MSW was taken from literature [27]. To obtain the representative sample, samples were sun dried [10]. After that some of organic components (ie, wood, yard and food) of MSW were grinded into the powder form whereas the size of other components were reduced by means of scissors because of their nature and then all of them were sieved through a 250 µm sieve [10 and 28]. The powdered samples were converted in to pellets and subjected to Bomb Calorimeter [10]. For higher calorific value, about 1gm of each organic components of sample was taken according to the requirement of Bomb Calorimeter. Lower and higher calorific value of mixed MSW was determined by using Eq. 1 & 2 respectively. Lower calorific values of each components of MSW were calculated by using Eq. 3 [26].

$$LCV = \frac{\sum Xi\,(LCV)i}{Xt} \quad (1)$$

$$HCV = \frac{\sum Xi\,(HCV)i}{Xt} \quad (2)$$

$$(LCV)i = (HCV)i + 9 \times (H\%)i \times LHS \quad (3)$$

Where (LCV)i means the lower calorific value of each component in kcal/kg, Xi is the proportion of that component in the total amount of MSW in kg, Xt means total amount of MSW in kg, (HCV)i means the higher calorific value of each component in kg, LHS means latent heat of steam which is 587 kcal/kg and (H%)i means hydrogen percentage of each component of sample.

Theoretical energy recovery potential of MSW

Energy recovery potential of each component of MSW was determined by Eq. 4 [26].

$$ERPi = (LCV)i \times Wi \times 1.16 \quad (4)$$

Where ERPi means energy recovery potential of each components of MSW in kWh, (LCV)i means lower calorific value of each component in kcal/kg and Wi means weight of each components of MSW in kg.

Results and Discussion

Energy recovery potential of MSW

Lower calorific as well as higher calorific value of each component of MSW is shown in (Fig. 3). It represents that the calorific value of plastic & rubber is highest than all of other waste components. Whereas, glass & metals possess lowest calorific value than all of other waste components. Net and Gross calorific value of mixed MSW was also calculated as 6519 & 6749 kcal/kg respectively. These both values regarding net and gross calorific value of MSW generated in the study area are higher than the average calorific value of MSW generated in the Eluru, A. P, India, Jordan, Malaysia and Zengcheng, China as 1027.75 - 1687.74 kcal/kg [26], 2747 kcal/kg [29], 1500 - 2600 kcal/kg [30] and 1990.66 – 2092.43 kcal/kg [31] respectively (Fig. 4). Higher calorific value of MSW represents that the MSW was taken from dumping sites and some water in MSW had been lost before sampling. Also another reason is that the study area (i.e. Hyderabad) has a hot and dry climate throughout the year and calorific value of the MSW components was calculated by considering the dry solid waste without moisture content [32].

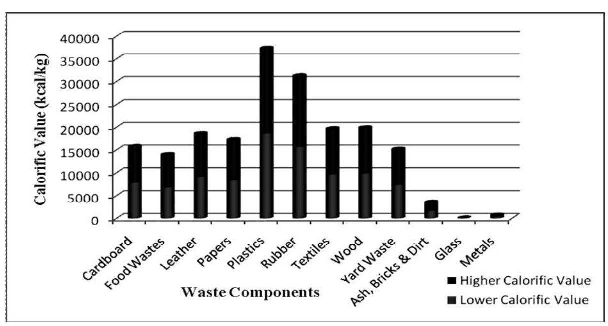

Figure 3. **LCV and HCV of MSW Components**

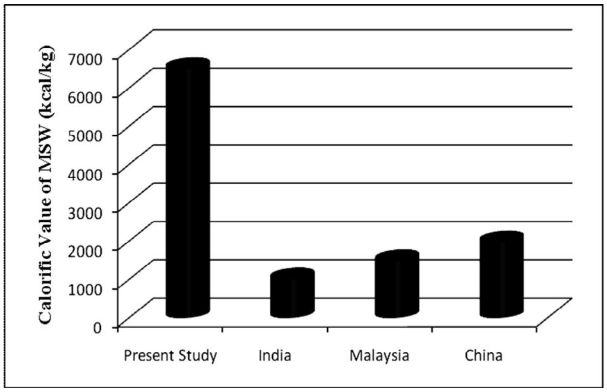

Figure 4. **Calorific Value of MSW of Different Countries and Present Study**

Energy recovery potential of each components of MSW is shown in (Fig. 5). From figure it is clear that energy recovery potential of plastic, rubber, wood, textile and leather components of MSW is highest than all of other waste components. Energy recovery potential of others (i.e ash, bricks, dust, glass and metal) is lowest than all of other waste components approximately their value is zero. Also energy recovery potential of mixed MSW was calculated as 756 2KWh/ton (8kWh/kg) which is higher than energy recovery potential of MSW generated in Eluru, A.P, India i.e 500 – 600 KWh per ton of MSW [26].

From results, it has been observed that energy recovery potential of MSW is directly proportional to the calorific value of MSW and have a very good correlation. It is also mentioned (Fig. 5) that as the calorific value increases the energy recovery potential also increases. This figure shows the trend of variation of energy recovery potential with calorific value.

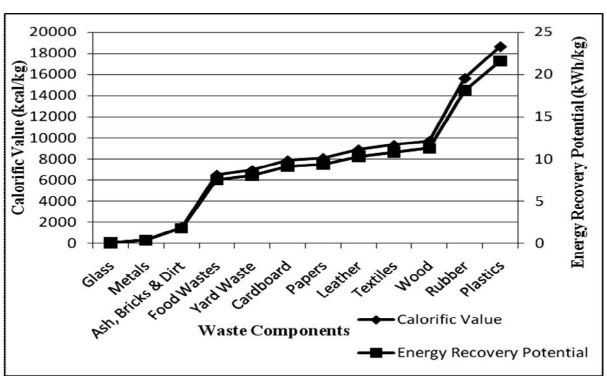

Figure 5. **Relationship between Caloric value and Energy Recovery Potential**

Net Power calculation

Net power generation can be calculated from following data as:

Energy recovery potential (ERP)	=	7561.79KWh/ton
Considering the conversi on efficiency (Ƞ)	=	25%, Therefore,
Power generation potenti al (KW)	= =	ERP /24 x Ƞ 7561.79/24x0.25= 78.77kW/ton
Total energy generated (TEG)	= =	(Net Power Generation x 24) 78.77x 24 = 1890.48kWh/ton
Now by considering, Station service allowance (SSA)	= =	11% of energy generated 207.9 kWh / ton
Unaccounted heat loss (UHL)	= =	9% of energy generated 170.14 kWh / ton
Net electric power generation	= = =	TEG – (SSA + UHL) 1890.48 – (207.9 + 170.14) 1512 kWh / ton

The high calorific value and power generation potential of the MSW generated in the city of Hyderabad, results that there should be proper thermal treatment technology for converting MSW into electricity.

Selection of appropriate technology for MSW

At present, different types of methods are being used for energy recovery from various types of MSW in South Asia countries [33]. Most popular among all is sanitary landfill, by which the large amounts of waste can be handled and also open burning is reduced but on the other hand the efficiency of leachate and gas extraction is also doubtful in the landfill. However, sanitary landfill has significant impact on photochemical oxidation, global warming and acidification [34]. It is estimated that at least 1.2 tons of CO_2 increased by landfilling only one ton of MSW in terms of environmental impacts [35]. There is a serious threat for deterioration of surrounding water quality due to continuously reaction within the landfill for many years even centuries after closure during the life time of modern landfill [36].

To overcome these problems associated with landfill, WTE is the best solution for reducing solid waste volume by combustion. According to the USEPA, WTE has been considered as an environment friendly and renewable source of energy. About 130 million tons of MSW are worldwide burned annually in 600 plants based on WTE that generate electricity, steam for heating purpose and recovered metals for recycling [35]. upon either biological or thermal conversion [37-40]. However, biological conversion system (i.e Composting, Anaerobic Digestion etc.) can only be used for the treatment of biodegradable fraction of the MSW. In Pakistan, composting is not fully recognized because it has odor problems and having less market [25]. Although it is principally possible to use the digested/composted organic fraction for agricultural purposes but most probably it does not fulfill the environmental criteria with regards to soil & groundwater protection [41]. Thermal conversion systems are suitable to treat various MSW fractions. So for According to the concept of WTE, the options regarding the selection of technology for processing the MSW into useful product depends. here only thermal treatment technologies are briefly discussed and compared. There are various WTE technologies currently available and in use globally for the thermal treatment of MSW. Thermal treatment of MSW involves the oxidation of combustible materials found within the waste. These technologies can be generally classified into main two types named as conventional combustion and advanced thermal treatment. Conventional combustion is most popular treatment technology which was developed over 100 years ago for generation of energy from MSW.

Table 3. **Overview of the Major Types of WTE Technologies Used Worldwide [44].**

Characteristic/ Parameters	Conventional Combustion	Advance Thermal Treatment		
	Mass Burn Incineration	Gasification	Plasma gasification	Pyrolysis
Feedstock	MSW, biomass	MSW, biomass, black liquor, coal, hospital waste, sludge, tires	Hazardous waste, hospital waste, organic waste	Biomass, MSW coal, hospital waste, plastics, sludge, tires,
Suitability to unprocessed MSW with variable composition	Yes suitable but minimal waste pre-processing required and designed to process variable wastes	Pre-processing required & difficulties in accepting heterogeneous wastes	Pre-processing required & difficulties in accepting variable wastes	Pre-processing required & difficulties in accepting variables wastes
Commercially Proven System and Degree of reliability [45]	Proven & relatively simple operation than others. Scheduled/unscheduled downtime is as <10%.	More complex than combustion and less reliable. Scheduled and unscheduled downtime is as 20%.	Complex operation Scheduled and unscheduled downtime unknown	Not reliable data
Capital Cost	$775/annual design tone +/- 50%	$850/annual design tone +/- 40%	$1,300/annual design tone +/- 45%	Not reliable data
Operating Cost	$65/tone +/- 30%	$65/tone +/- 45%	$120/tone +/- 55%	Not reliable data
Residual to Disposal [46]	5% (by weight) if the bottom ash can be marketed for other applications.	<1 % if bottom ash can be marketed for other applications.	>1 to 10% varying due to the nature of the waste.	If treated, residues reduced to 0.1 to 0.3 tons per input tone.
Landfill capacity consumption	Reduced by 90 to 95%	Reduced by 90 to 95%	Reduced by up to 99% [46]	Reduced by up to 90%
Product	Electricity, heat (steam and/or hot water), recyc-metals, const: aggregate	Electricity, syngas, aggregate recovered from ash.	electricity, syngas, aggregate substitute	Electricity, syngas, pyrolysis oil
Energy recovery potential [46]	Ranges from 0.75 to 0.85 MWh/annual tone of MSW	Ranges from 0.4 to 0.8 MWh/annual tone of MSW	Ranges from 0.3 to 0.6 MWh/annual tone of MSW	Ranges from 0.5 to 0.8 MWh/annual tone of MSW [45]
Scalability	Various sizes of mass burn units; use of multiple units also possible	Usually built with a fixed capacity; modular [45]	Multiple modules can be built on a single site with some sharing of infrastruc:	No reliable data

The first attempts to dispose of solid waste using a furnace were taken place in England in the 1870s [42]. Among all the conventional combustion approach, the most common is single-stage combustion or mass burn incineration (sometimes referred to as grate-fired technology). Worldwide, the mass burn incineration is the most common type of WTE technology. About 750,000 tons per year of MSW is treated by mass burn incineration in over 90% facilities of WTE in the Europe [43]. Two other conventional combustion approaches i.e modular, two stage combustion and fluidized bed combustion are used to manage MSW, but are less common. Both processes generally are more complex than single-stage mass burn incineration. For that reason, generally when considering conventional combustion systems in planning processes, single stage combustion systems are usually assumed. One of the disadvantages of the fluidized bed systems (FBS) is that a larger portion of fly ash (i.e 6% compared to 2% for mass burn systems) is generated by the fluidized bed process due to the particulate present in the fluidized bed itself and also FBS is not suitable for unprocessed MSW with variable composition [44]. Advanced thermal treatment technologies for MSW are gasification, pyrolysis and plasma gasification. These technologies tend to be less proven on a commercial scale and involve more complex technological processes. Table 3 indicates the technical properties and application ranges for the conventional combustion (mass burn incineration) and advance thermal treatment.

From comparison of various thermal treatment technologies for MSW, it is quite clear that all existing thermal technologies have lower energy recovery efficiencies than those currently being achieved by mass burn incinerators. This is due to the fact that a mass burn process generally results in more complete combustion of the fuel compared to gasification and/or as the support fuel/electrical inputs for gasification tend to be higher [44]. The uncertainties (regarding performance, reliability and economics) associated with using advance thermal technologies that are commercially unproven for the treatment of waste is generally considered to be high [47]. Therefore, considering volume reduction of MSW, electricity generation capacity, requirement of less area, the mass burn incineration technology would be more suitable for conversion of MSW into power generation in the Hyderabad city of Pakistan.

Conclusion

The assessment and analysis of MSW generated at Hyderabad city of Pakistan for power generation leads us to realize that there is a great potential of power generation from it. Lower calorific as well as higher calorific value of each component of MSW was determined. From which calorific value of plastic & rubber is highest and glass & metals is lowest than all of other waste components. Net and Gross calorific value of mixed MSW was also estimated as 6518.79 & 6748.85 kcal/kg respectively which was compared to calorific value of MSW generated in other countries. From comparison it has been observed that MSW generated in the study area possess highest calorific value than others. From calorific value, energy recovery potential of each components of MSW was estimated and also net power generation of mixed MSW was estimated as 1512.44 kWh / ton. This represents that MSW generated in the study area is more suitable for thermal treatment process. In this regard different thermal treatment technologies have been compared with respect to various parameters and mass burn incinerator was found suitable for generation of power. This technology for conversion of MSW into power generation would not only be beneficial to meet the power demand but also reduce the environmental pollution to certain extent.

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