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Review

Municipal solid waste management in Indian cities – A review

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Abstract

Municipal solid waste management (MSWM) is one of the major environmental problems of Indian cities. Improper management of municipal solid waste (MSW) causes hazards to inhabitants. Various studies reveal that about 90% of MSW is disposed of unscientifically in open dumps and landfills, creating problems to public health and the environment. In the present study, an attempt has been made to provide a comprehensive review of the characteristics, generation, collection and transportation, disposal and treatment technologies of MSW practiced in India. The study pertaining to MSWM for Indian cities has been carried out to evaluate the current status and identify the major problems. Various adopted treatment technologies for MSW are critically reviewed, along with their advantages and limitations. The study is concluded with a few fruitful suggestions, which may be beneficial to encourage the competent authorities/researchers to work towards further improvement of the present system.

1. Introduction

Rapid industrialization and population explosion in India has led to the migration of people from villages to cities, which generate thousands of tons of MSW daily. The MSW amount is expected to increase significantly in the near future as the country strives to attain an industrialized nation status by the year 2020 (Sharma and Shah, 2005; CPCB, 2004; Shekdar et al., 1992). Poor collection and inadequate transportation are responsible for the accumulation of MSW at every nook and corner. The management of MSW is going through a critical phase, due to the unavailability of suitable facilities to treat and dispose of the larger amount of MSW generated daily in metropolitan cities. Unscientific disposal causes an adverse impact on all components of the environment and human health (Rathi, 2006; Sharholy et al., 2005; Ray et al., 2005; Jha et al., 2003; Kansal, 2002; Kansal et al., 1998; Singh and Singh, 1998; Gupta et al., 1998). Generally, MSW is disposed of in low-lying areas without taking any precautions or operational controls. Therefore, MSWM is one of the major environmental problems of Indian megacities. It involves activities associated with generation, storage, collection, transfer and transport, processing and disposal of solid wastes. But, in most cities, the MSWM system comprises only four activities, i.e., waste generation, collection, transportation, and disposal. The management of MSW requires proper infrastructure, maintenance and upgrade for all activities. This becomes increasingly expensive and complex due to the continuous and unplanned growth of urban centers. The difficulties in providing the desired level of public service in the urban centers are often attributed to the poor financial status of the managing municipal corporations (Mor et al., 2006; Siddiqui et al., 2006; Raje et al., 2001; MoEF, 2000; Ahsan, 1999). In the present study, an attempt has been made to provide a comprehensive review of MSWM for Indian cities to evaluate the current status and identify the problems of MSWM. The study also aims at encouraging competent authorities/researchers to work towards the improvement of the present system through suggestions and recommendations.

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2. Qualitative and quantitative analysis of MSW

There are many categories of MSW such as food waste, rubbish, commercial waste, institutional waste, street sweeping waste, industrial waste, construction and demolition waste, and sanitation waste. MSW contains recyclables (paper, plastic, glass, metals, etc.), toxic substances (paints, pesticides, used batteries, medicines), compostable organic matter (fruit and vegetable peels, food waste) and soiled waste (blood stained cotton, sanitary napkins, disposable syringes) (Jha et al., 2003; Reddy and Galab, 1998; Khan, 1994).

The quantity of MSW generated depends on a number of factors such as food habits, standard of living, degree of commercial activities and seasons. Data on quantity variation and generation are useful in planning for collection and disposal systems. With increasing urbanization and changing life styles, Indian cities now generate eight times more MSW than they did in 1947. Presently, about 90 million t of solid waste are generated annually as byproducts of industrial, mining, municipal, agricultural and other processes. The amount of MSW generated per capita is estimated to increase at a rate of 1–1.33% annually (Pappu et al., 2007; Shekdar, 1999; Bhide and Shekdar, 1998). A host of researchers (Siddiqui et al., 2006; Sharholy et al., 2005; CPCB, 2004; Kansal, 2002; Singh and Singh, 1998; Kansal et al., 1998; Bhide and Shekdar, 1998; Dayal, 1994; Khan, 1994; Rao and Shantaram, 1993) have reported that the MSW generation rates in small towns are lower than those of metrocities, and the per capita generation rate of MSW in India ranges from 0.2 to 0.5 kg/day. It is also estimated that the total MSW generated by 217 million people living in urban areas was 23.86 million t/yr in 1991, and more than 39 million t in 2001. The quantity of MSW generated (CPCB, 2000) and the per capita generation rate of MSW (CPCB, 2004) are shown in Table 1 and Fig. 1, respectively.

Table 1
Municipal solid waste generation rates in different states in India

S. No.	Name of the state	No. of cities	Municipal population	Municipal solid waste (t/day)	Per capita generated (kg/day)
1	Andhra pradesh	32	10,845,907	3943	0.364
2	Assam	4	878,310	196	0.223
3	Bihar	17	5,278,361	1479	0.280
4	Gujrat	21	8,443,962	3805	0.451
5	Haryana	12	2,254,353	623	0.276
6	Himachal pradesh	1	82,054	35	0.427
7	Karnatka	21	8,283,498	3118	0.376
8	Kerala	146	3,107,358	1220	0.393
9	Madhya Pradesh	23	7,225,833	2286	0.316
10	Maharashtra	27	22,727,186	8589	0.378
11	Manipur	1	198,535	40	0.201
12	Meghalaya	1	223,366	35	0.157
13	Mizoram	1	155,240	46	0.296
14	Orissa	7	1,766,021	646	0.366
15	Punjab	10	3,209,903	1001	0.312
16	Rajasthan	14	4,979,301	1768	0.355
17	Tamil Nadu	25	10,745,773	5021	0.467
18	Tripura	1	157,358	33	0.210
19	Uttar Pradesh	41	14,480,479	5515	0.381
20	West Bengal	23	13,943,445	4475	0.321
21	Chandigarh	1	504,094	200	0.397
22	Delhi	1	8,419,084	4000	0.475
23	Pondichery	1	203,065	60	0.295
		299	128,113,865	48,134	0.376

Source: Status of MSW generation, collection, treatment and disposal in class-I cities (CPCB, 2000).

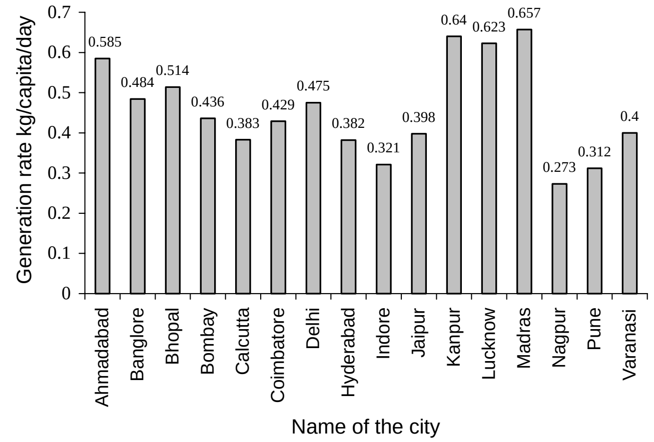

Fig. 1. Per capita generation rate of MSW for Indian cities (CPCB, 2004).

It can be seen from Table 1 and Fig. 1 that the per capita generation rate is high in some states (Gujrat, Delhi and Tamil Nadu) and cities (Madras, Kanpur, Lucknow and Ahmedabad). This may be due to the high living standards, the rapid economic growth and the high level of urbanization in these states and cities. However, the per capita generation rate is observed to be low in other states (Meghalaya, Assam, Manipur and Tripura) and cities (Nagpur, Pune and Indore).

3. MSW characteristics and composition

The composition and the quantity of MSW generated form the basis on which the management system needs to be planned, designed and operated. In India, MSW differs greatly with regard to the composition and hazardous nature, when compared to MSW in the western countries (Gupta et al., 1998; Shannigrahi et al., 1997; Jalan and Srivastava, 1995). The composition of MSW at generation sources and collection points was determined on a wet weight basis and it consists mainly of a large organic fraction (40–60%), ash and fine earth (30–40%), paper (3–6%) and plastic, glass and metals (each less than 1%). The C/N ratio ranges between 20 and 30, and the lower calorific value ranges between 800 and 1000 kcal/kg. The physical characteristics of MSW in metrocities are presented in Table 2. It has been noticed that the physical and chemical

Table 2
Physical characteristics of MSW in Indian metrocities

Characteristics (% by weight)								
Name of metrocity	Paper	Textile	Leather	Plastic	Metals	Glass	Ash, fine earth and others	Compostable matter
Ahmedabad	6.0	1.0	–	3.0	–	–	50.0	40.00
Banglore	8.0	5.0	–	6.0	3.0	6.0	27.0	45.00
Bhopal	10.0	5.0	2.0	2.0	–	1.0	35.0	45.00
Mumbai	10.0	3.6	0.2	2.0	–	0.2	44.0	40.00
Calcutta	10.0	3.0	1.0	8.0	–	3.0	35.0	40.00
Coimbatore	5.0	9.0	–	1.0	–	–	50.0	35.00
Delhi	6.6	4.0	0.6	1.5	2.5	1.2	51.5	31.78
Hyderabad	7.0	1.7	–	1.3	–	–	50.0	40.00
Indore	5.0	2.0	–	1.0	–	–	49.0	43.00
Jaipur	6.0	2.0	–	1.0	–	2.0	47.0	42.00
Kanpur	5.0	1.0	5.0	1.5	–	–	52.5	40.00
Kochi	4.9	–	–	1.1	–	–	36.0	58.00
Lucknow	4.0	2.0	–	4.0	1.0	–	49.0	40.00
Ludhiana	3.0	5.0	–	3.0	–	–	30.0	40.00
Madras	10.0	5.0	5.0	3.0	–	–	33.0	44.00
Madurai	5.0	1.0	–	3.0	–	–	46.0	45.00
Nagpur	4.5	7.0	1.9	1.25	0.35	1.2	53.4	30.40
Patna	4.0	5.0	2.0	6.0	1.0	2.0	35.0	45.00
Pune	5.0	–	–	5.0	–	10.0	15.0	55.00
Surat	4.0	5.0	–	3.0	–	3.0	45.0	40.00
Vadodara	4.0	–	–	7.0	–	–	49.0	40.00
Varanasi	3.0	4.0	–	10.0	–	–	35.0	48.00
Visakhapatnam	3.0	2.0	–	5.0	–	5.0	50	35.00
Average	5.7	3.5	0.8	3.9	1.9	2.1	40.3	41.80

Source: Status of solid waste generation, collection, treatment and disposal in metrocities, (CPCB, 2000).

characteristics of MSW change with population density, as shown in Table 3 and Table 4 (Garg and Prasad, 2003; CPCB, 2000; Bhide and Shekdar, 1998).

From Table 2, it is observed that the differences in the MSW characteristics indicate the effect of urbanization and development. In urban areas, the major fraction of MSW is compostable materials (40–60%) and inerts (30–50%). The relative percentage of organic waste in MSW is generally increasing with the decreasing socio-economic status; so rural households generate more organic waste than urban households. For example, in south India the extensive use of banana leaves and stems in various functions results in a large organic content in the MSW. Also, it has been noticed that the percentage of recyclables

Table 3
Physical characteristics of MSW in Indian cities population wise

Population range (in million)	No. of cities surveyed	Paper	Rubber, leather and synthetics	Glass	Metal	Compostable matter	Inert material
0.1–0.5	12	2.91	0.78	0.56	0.33	44.57	43.59
0.5–1.0	15	2.95	0.73	0.56	0.32	40.04	48.38
1.0–2.0	9	4.71	0.71	0.46	0.49	38.95	44.73
2.0–5.0	3	3.18	0.48	0.48	0.59	56.57	49.07
5.0 and above	4	6.43	0.28	0.94	0.8	30.84	53.9

All values are in percentage and are calculated on wet weight basis.
Source: NEERI report strategy paper on SWM in India, August 1995.

Table 4
Chemical characteristics of MSW in Indian cities population wise

Population range (in million)	Nitrogen as total nitrogen	Phosphorus as P_2O_5	Potassium as K_2O	C/N ratio	Calorific value kcal/kg
0.1–0.5	0.71	0.63	0.83	30.94	1009.89
0.5–1.0	0.66	0.56	0.69	21.13	900.61
1.0–2.0	0.64	0.82	0.72	23.68	980.05
2.0–5.0	0.56	0.69	0.78	22.45	907.18
5.0 and above	0.56	0.52	0.52	30.11	800.70

Source: NEERI report strategy paper on SWM in India, August 1995.

(paper, glass, plastic and metals) is very low, because of rag pickers who segregate and collect the materials at generation sources, collection points and disposal sites.

4. Storage and collection of MSW

Storage of MSW at the source is substantially lacking in most of the urban areas. The bins are common for both decomposable and non-decomposable waste (no segregation of waste is performed), and the waste is disposed at a communal disposal center. Storage bins can be classified as movable bins and fixed bins. The movable bins are flexible in transportation but lacking in durability, while the fixed bins are more durable but their positions cannot be changed once they have been constructed (Nema, 2004; Malviya et al., 2002).

The collection of MSW is the responsibility of corporations/municipalities. The predominant system of collection in most of the cities is through communal bins placed at various points along the roads, and sometimes this leads to the creation of unauthorized open collection points. Efforts to organize house-to-house collection are just starting in many megacities such as Delhi, Mumbai, Bangalore, Madras and Hyderabad with the help of NGOs. It has been observed that many municipalities have employed private contractors for secondary transportation from the communal bins or collection points to the disposal sites. Others have employed NGOs and citizen's committees to supervise segregation and collection from the generation source to collection points located at intermediate points between sources and dumpsites. In addition, the welfare associations on specified monthly payment arrange collection in some urban areas. A sweeper who sweeps the roads manually is allotted a specific area (around 250 m^2). The sweepers put the road wastes into a wheelbarrow, and then transfer the waste to dustbins or collection points (Colon and Fawcett, 2006; Nema, 2004; Malviya et al., 2002; Kansal et al., 1998; Bhide and Shekdar, 1998).

In most cities, a fraction of MSW generated remains uncollected on streets, and what is collected is transported to processing or disposal sites. The collection efficiency is the quantity of MSW collected and transported from streets to disposal sites divided by the total quantity of MSW generated during the same period. Many studies on urban environment have revealed that MSW collection efficiency is a function of two major factors: manpower availability and transport capacity. The average collection efficiency for MSW in Indian cities and states is about 70%, as shown in Fig. 2 and Table 5 (Rathi, 2006; Siddiqui et al., 2006; Nema, 2004; Gupta et al., 1998; Maudgal, 1995; Khan, 1994). Table 5 and Fig. 2 show that the collection efficiency is high in the cities and states, where private contractors and NGOs are employed for the collection and transportation of MSW. Most of the cities are unable to provide waste collection services to all parts of the city. Generally, overcrowded low-income settlements do not have MSW collection and disposal services. The reason is that these settlements are often illegal and the inhabitants are unwilling or unable to pay for the services. They throw away the waste near or around their houses at different times, which makes the collection and transportation of waste very difficult in these areas. The Central Pollution Control Board (CPCB) has collected data for the 299 Class-I cities to determine the mode of collection of MSW. It is found that manual collection comprises 50%, while collection using trucks comprises only 49% (CPCB, 2000).

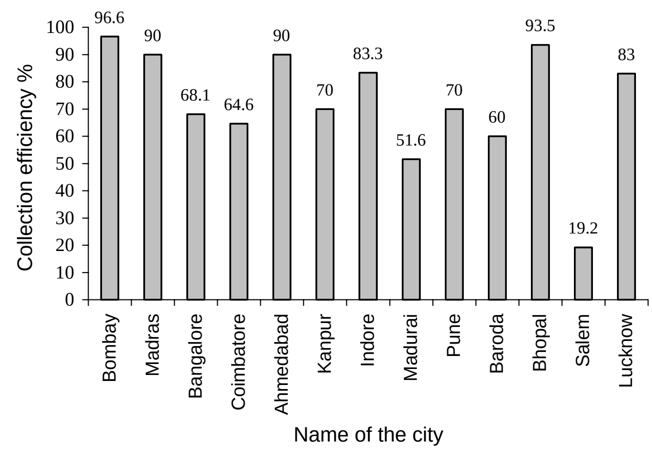

Fig. 2. Collection efficiency of MSW for Indian cities (Gupta et al., 1998; Khan, 1994; Maudgal, 1995).

Table 5
Per capita generation, disposal and collection efficiency of MSW for Indian state

State	Per capita generation (g/cap/day)	Per capita disposal (g/cap/day)	Collection efficiency (%)
India (sample average)	377	273	72
Andhra Pradesh	346	247	74
Bihar	411	242	59
Gujarat	297	182	61
Haryana	326	268	82
Karnataka	292	234	80
Kerala	246	201	82
Madhya Pradesh	229	167	73
Maharashtra	450	322	72
Orissa	301	184	61
Punjab	502	354	71
Rajasthan	516	322	62
Tamil Nadu	294	216	73
Uttar Pradesh	439	341	78
West Bengal	158	117	74

Source: (Nema, 2004).

5. Transfer and transport of MSW

Transfer stations (except in a few cases as in Madras, Mumbai, Delhi, Ahmedabad and Calcutta) are not used, and the same vehicle, which collects refuse from individual dustbins, takes it to the processing or disposal site (Colon and Fawcett, 2006; Khan, 1994). The MSW collected from the dustbins and collection points is transported to the processing or disposal sites using a variety of vehicles. In smaller (rural) towns, bullock carts, tractor-trailers, tricycles etc., are mainly used for the transportation of MSW. Light motor vehicles and lorries are generally used in big towns or cities for transport of MSW. The trucks used for transportation of MSW are generally of an open body type and are usually kept uncovered; thus during transportation, the waste tends to spill onto the road resulting in unhygienic conditions. In some cities, modern hydraulic vehicles are gradually being introduced (Bhide and Shekdar, 1998; Reddy and Galab, 1998).

Collection and transportation activities constitute approximately 80–95% of the total budget of MSWM; hence, it forms a key component in determining the economics of the entire MSWM system. Municipal agencies use their own vehicles for MSW transportation although in some cities they are hired from private contractors (Ghose et al., 2006; Siddiqui et al., 2006; Nema, 2004; Bhide and Shekdar, 1998).

6. MSW disposals and treatment

The two leading innovative mechanisms of waste disposal being adopted in India include composting (aerobic composting and vermi-composting) and waste-to-energy (WTE) (incineration, pelletisation, biomethanation). WTE projects for disposal of MSW are a relatively new concept in India. Although these have been tried and tested in developed countries with positive results, these are yet to get off the ground in India largely because of the fact that financial viability and sustainability is still being tested (Lal, 1996; Khan, 1994). Different methods for the disposal and treatment of MSW have been discussed in the subsequent sections.

6.1. Landfilling

In many metropolitan cities, open, uncontrolled and poorly managed dumping is commonly practiced, giving rise to serious environmental degradation. More than 90% of MSW in cities and towns are directly disposed of on land in an unsatisfactory manner. Such dumping activity in many coastal towns has led to heavy metals rapidly leaching into the coastal waters. In larger towns or cities like Delhi, the availability of land for waste disposal is very limited (Mor et al., 2006; Siddiqui et al., 2006; Sharholy et al., 2006; Gupta et al., 1998; Das et al., 1998; Kansal et al., 1998; Chakrabarty et al., 1995; Khan, 1994). In the majority of urban centers, MSW is disposed of by depositing it in low-lying areas outside the city without following the principles of sanitary landfilling. Compaction and leveling of waste and final covering by earth are rarely observed practices at most disposal sites, and these low-lying disposal sites are devoid of a leachate collection system or landfill gas monitoring and collection equipment (Bhide and Shekdar, 1998; Gupta et al., 1998). As no segregation of MSW at the source takes place, all of the wastes including infectious waste from hospitals generally find its way to the disposal site. Quite often, industrial waste is also deposited at the landfill sites meant for domestic waste (Datta, 1997). Sanitary landfilling is an acceptable and recommended method for ultimate disposal of MSW. It is a necessary component of MSWM, since all other options produce some residue that must be disposed of through landfilling. However, it appears that landfilling would continue to be the most widely adopted practice in India in the coming few years, during which certain improvements will have to be made to ensure the sanitary landfilling (Kansal, 2002; Das et al., 1998; Dayal, 1994).

6.2. Recycling of organic waste

If the organic waste is left unattended, it will tend to decompose by natural process giving rise to odors, hosting and feeding a variety of insects and pests, which in turn, form the carriers of disease creating severe health problems. The segregation, decomposition and stabilization of the organic waste by biological action forms the basis of recycling through different natural cycles.

6.2.1. Aerobic composting

The bacterial conversion of the organics present in MSW in the presence of air under hot and moist conditions is called composting, and the final product obtained after bacterial activity is called compost (humus), which has very high agricultural value. It is used as fertilizer, and it is non-odorous and free of pathogens (Ahsan, 1999; Khan, 1994). As a result of the composting process, the waste volume can be reduced to 50–85%. The composting methods may use either manual or mechanical means and are accordingly termed as a manual or mechanical process. Manual composting is carried out in smaller urban centers and mechanical composting plants have been set up in big Indian cities. (Bhide and Shekdar, 1998; Chakrabarty et al., 1995).

Composting was encouraged in the early initiatives of the Government of India (GOI) regarding MSWM focused primarily on promoting composting of urban MSW. In the 1960s, the Ministry of Food and Agriculture offered soft loans to urban local bodies for this purpose. The 4th 5-year plan (1969–1974), block grants and loans were provided to state governments for setting up MSW composting plants. Finally, in 1974, GOI introduced modified scheme to revive MSW composting, particularly in cities with a population over 0.3 million. As far as large-scale composting is concerned, many mechanical compost plants with capacities ranging from 150 to 300 t/day were set up in the cities of Bangalore, Baroda, Mumbai, Calcutta, Delhi, Jaipur and Kanpur during 1975–1980 under the central scheme of MSW disposal. Indore city was a famous center for MSW composting, and the name was used to describe the composting process. The composting was done successfully for many years up to 1980, but after that the compost from MSW was not used for soil enrichment due to many problems. The first large-scale aerobic composting plant in the country was set up in Mumbai in 1992 to handle 500 t/day of MSW by Excel Industries Ltd. However, only 300 t/day capacity is being utilized currently due to certain problems, but the plant is working very successfully and the compost produced is being sold at the rate of 2 Rs./kg (US$0.046/kg). Another plant with af 150 t/day capacity has been operated in the city of Vijaywada, and over the years a number of other plants have been implemented in the principal cities of the country such as Delhi, Bangalore, Ahmedabad, Hyderabad, Bhopal, Luknow and Gwalior. Many other cities have either signed agreements or are in the process of doing so to have composting facilities very soon. Now, about 9% of MSW is treated by composting (Gupta et al., 1998; Gupta et al., 2007; Sharholy et al., 2006; Srivastava et al., 2005; Malviya et al., 2002; Kansal, 2002; CPCB, 2000; Reddy and Galab, 1998; Kansal et al., 1998; Dayal, 1994; Rao and Shantaram, 1993).

6.2.2. Vermicomposting

Vermicomposting involves stabilization of organic waste through the joint action of earthworms and aerobic microorganisms. Initially, microbial decomposition of biodegradable organic matter occurs through extra cellular enzymatic activity (primary decomposition). Earthworms feed on partially decomposed matter, consuming five times their body weight of organic matter per day. The ingested food is further decomposed in the gut of the worms, resulting in particle size reduction. The worm cast is a fine, odorless and granular product. This product can serve as a biofertilizer in agriculture. Vermicomposting has been used in Hyderabad, Bangalore, Mumbai and Faridabad. Experiments on developing household vermicomposting kits have also been conducted. However, the area required is larger, when compared to dry composting (Ghosh, 2004; Bezboruah and Bhargava, 2003; Jha et al., 2003; Sannigrahi and Chakrabortty, 2002; Gupta et al., 1998; Reddy and Galab, 1998; Jalan, 1997; Khan, 1994).

6.2.3. Anaerobic digestion (biomethanation)

If the organic waste is buried in pits under partially anaerobic conditions, it will be acted upon by anaerobic microorganisms with the release of methane and carbon dioxide; the organic residue left is good manure. This process is slower than aerobic composting and occurs in fact naturally in landfills. However, thermophilic digestion for biomethanation is much faster and has been commercialized. Anaerobic digestion leads to energy recovery through biogas generation. The biogas, which has 55–60% methane, can be used directly as a fuel or for power generation. It is estimated that by controlled anaerobic digestion, 1 t of MSW produces 2–4 times as much methane in 3 weeks in comparison to what 1 t of waste in landfill will produce in 6–7 years (Ahsan, 1999; Khan, 1994).

In India, Western Paques have tested the anaerobic digestion process to produce methane gas. The results of the pilot plant show that 150 t/day of MSW produce 14,000 m^3 of biogas with a methane content of 55–65%, which can generate 1.2 MW of power. The government is looking forward to biomethanation technology as a secondary source of energy by utilizing industrial, agricultural and municipal wastes. A great deal of experience with biomethanation systems exists in Delhi, Bangalore, Lucknow and many other cities. There is little experience in the treatment of solid organic waste, except with sewage sludge and animal manure (e.g., cow dung). Several schemes for biomethanation of MSW, vegetable market and yard wastes, are currently being planned for some cities (Ambulkar and Shekdar, 2004; Chakrabarty et al., 1995).

The study reveals that in all situations (rural, urban or city, etc.) where space is available, composting is the better option because it prevents the load on municipalities for collection and transport of MSW and then reduces the pressure on the landfills. It also provides a valuable byproduct for agriculture.

6.3. Thermal treatment techniques of MSW

The destruction of MSW using heat energy is called thermal treatment. Although there are many thermal processes, incineration is the most widely used at present.

6.3.1. Incineration

Incineration is the process of control and complete combustion, for burning solid wastes. It leads to energy recovery and destruction of toxic wastes, for example, waste from hospitals. The temperature in the incinerators varies between 980 and 2000 °C. One of the most attractive features of the incineration process is that it can be used to reduce the original volume of combustible solid waste by 80–90%. In some newer incinerators designed to operate at temperatures high enough to produce a molten material, it may be possible to reduce the volume to about 5% or even less (Jha et al., 2003; Ahsan, 1999; Peavey et al., 1985). Unfortunately, in Indian cities, incineration is not very much practiced. This may be due to the high organic material (40–60%), high moisture content (40–60%), high inert content (30–50%) and low calorific value content (800–1100 kcal/kg) in MSW (Kansal, 2002; Joardar, 2000; Bhide and Shekdar, 1998; Sudhire et al., 1996; Jalan and Srivastava, 1995; Chakrabarty et al., 1995). The first large-scale MSW incineration plant was constructed at Timarpur, New Delhi in 1987 with a capacity of 300 t/day and a cost of Rs. 250 million (US$5.7 million) by Miljotecknik volunteer, Denmark. The plant was out of operation after 6 month and the Municipal Corporation of Delhi was forced to shut down the plant due to its poor performance. Another incineration plant was constructed at BARC, Trombay (near Mumbai) for burning only the institutional waste, which includes mostly paper and it is working as of this writing. In many cities, small incinerators are used for burning hospital waste (Sharholy et al., 2005; Lal, 1996; Chakrabarty et al., 1995; Dayal, 1994).

6.3.2. Gasification technology

Incineration of solid waste under oxygen deficient conditions is called gasification. The objective of gasification has generally been to produce fuel gas, which would be stored and used when required. In India, there are few gasifiers in operation, but they are mostly for burning of biomass such as agro-residues, sawmill dust, and forest wastes. Gasification can also be used for MSW treatment after drying, removing the inerts and shredding for size reduction. Two different designs of gasifiers exist in India. The first one (NERIFIER gasification unit) is installed at Nohar, Hanungarh, Rajasthan by Narvreet Energy Research and Information (NERI) for the burning of agro-wastes, sawmill dust, and forest wastes. The waste-feeding rate is about 50–150 kg/h and its efficiency about 70–80%. About 25% of the fuel gas produced may be recycled back into the system to support the gasification process, and the remaining is recovered and used for power generation. The second unit is the TERI gasification unit installed at Gaul Pahari campus, New Delhi by Tata Energy Research Institute (TERI) (CPCB, 2004; Ahsan, 1999).

6.3.3. RDF Plants

The main purpose of the refuse derived fuel (RDF) method is to produce an improved solid fuel or pellets from MSW. In India, many RDF plants are in operation at Hyderabad, Guntur and Vijaywada in Andhra Pradesh State. The Hyderabad RDF plant was commissioned in 1999 near the Golconda dumping ground with a 1000 t/day capacity (but receiving only 700 t/day at present). The RDF production is about 210 t/day as fluff and pellets, and it is going to be used for producing power (about 6.6 MW). The RDF plant at Deonar, Mumbai was set up in the early 1990s for processing garbage into fuel pellets. It is based on indigenous technology. However, the plant has not been in operation for the last few years and it is owned by Excel India at present. A similar project has been established in Bangalore and has had regular production of fuel pellets since October, 1989, compacting 50 t/day of garbage, converting into 5 t of fuel pellets, which can be designed both for industrial and domestic uses (Yelda and Kansal, 2003; Reddy and Galab, 1998; Khan, 1994).

Gasification–combustion seems to be promising as it can reduce pollution and increase heat recovery. RDF is another promising technology, which is going to be used for producing power. In addition, the RDF plant reduces the pressure on landfills. Combustion of the RDF from MSW is technically sound and is capable of generating power. RDF may be fired along with the conventional fuels like coal without any ill effects for generating heat. Operation of the thermal treatment systems involves not only higher cost, but also a relatively higher degree of expertise.

6.4. Recovery of recyclable materials

A number of recyclable materials, for example paper, glass, plastic, rubber, ferrous and non-ferrous metals present in the MSW are suitable for recovery and reuse. It has been estimated that the recyclable content varies from 13% to 20% (for example, in Mumbai 17% and in Delhi 15% of MSW is recyclables). A survey conducted by CPCB during 1996 in some Indian cities revealed that rag pickers play a key role in SWM. They work day and night to collect the recyclable materials from the streets, bins and disposal sites for their livelihood, and only a small quantity of recyclable materials is left behind them. In India, about 40–80% of plastic waste is recycled compared to 10–15% in the developed nations of the world. However, the recovery rate of paper was 14% of the total paper consumption in 1991, while the global recovery rate was higher at 37% (Pappu et al., 2007; CPCB, 2004; Yelda and Kansal, 2003; Shekdar, 1999; Ahsan, 1999; Dayal, 1994; Khan, 1994).

The role of governments in recovering secondary materials is small compared to the informal sectors. In Delhi, there are more than 100,000 rag pickers and the average quantity of solid waste materials collected by one rag picker is 10–15 kg/day. About 17% of Delhi waste handling is done by rag pickers, who collect, sort and transport waste free of cost, as part of the informal trade in scrap, saving the government Rs 600,000 (US$13,700) daily. In Bangalore, the informal sector is attributed with preventing 15% of the MSW going to the dumpsites. The municipalities in Pune save around Rs. 9 million/yr (US$200,000) on account of waste pickers. In Hyderabad, the cost of MSWM per ton is less in the areas where THE private sector participated compared to the areas serviced by municipality. In Mumbai, it is found that the cost of per ton of MSWM is US$35 with community participation, US$41 with public private partnership (PPP) and US$44 when only Municipal Corporation of Greater Mumbai (MCGM) handles the MSW. Hence, community participation in MSWM is the least cost option and there is a strong case for comprehensively involving community participation in MSWM. Many other studies that have been undertaken by different institutes and authorities revealed that the role of the informal sector in MSWM is very important because it provides a livelihood to many immigrants and marginalized people. The informal collection avoids environmental costs and reduces capacity problems at dumpsites; also, rag pickers can provide excellent segregation of MSW (Sharholy et al., 2005, 2006, 2007; Rathi, 2006; Joseph, 2006; Agarwal et al., 2005; Srivastava et al., 2005; CPCB, 2004; Kansal, 2002; Reddy and Galab, 1998; Khan, 1994).

7. MSWM rules in India

The Ministry of Environment and Forest (MoEF) of the government of India has issued MSW (management and handling) rules in the year 2000 for scientific MSWM, ensuring proper collection, segregation, transportation, processing and disposal of MSW and upgrade of the existing facilities to arrest contamination of soil and ground water. As per the provision, CPCB has been assigned to monitor the implementation of these rules, and the municipalities will be required to submit annual reports regarding the status of MSW in their areas to the CPCB. These rules are applicable to every Municipal Authority in India, which is responsible for MSWM. In addition, there are Municipal Corporation Acts by different states such as the Delhi Municipal Corporation Act 1959, Uttar Pradesh Municipal Corporation Act 1959 and Karnataka Municipal Corporation Act 1976. These Acts also deal with environmental pollution caused by improper disposal of MSW, for example The Delhi Plastic Bag (Manufacture, Sales and Usage) and non-biodegradable garbage (control) Act, 2000, was enacted to prevent contamination of foodstuff carried in recycled plastic bags, reduce the use of plastic bags, throwing or depositing non-biodegradable garbage in public drains, roads and places open to public view. Local authorities often see MSWM as a poor service compared to other basic services because MSWM can barely recover operating costs. However, most of the municipalities are unable to provide the desirable level of conservancy services. Due to a number of problems, they have not been very effective as far as SWM services are concerned (Siddiqui et al., 2006; Kansal, 2002; MoEF, 2000; Gupta et al., 1998).

8. Concluding remarks

The informal policy of encouraging the public to separate MSW and market it directly to the informal network appears to be a better option. The involvement of people and private sector through NGOs could improve the efficiency of MSWM. Public awareness should be created among masses to inculcate the health hazards of the wastes. Littering of MSW should be prohibited in cities, towns and urban areas notified by the state government. Moreover, house-to-house collection of MSW should be organized through methods like collection on regular pre-informed timing and scheduling. The collection bins must be appropriately designed with features like metallic containers with lids, and to have a large enough capacity to accommodate 20% more than the expected waste generation in the area, with a design for mechanical loading and un-loading, placement at appropriate locations, etc. Municipal authorities should maintain the storage facilities in such a manner that they do not create unhygienic and unsanitary conditions. Proper maintenance of the MSW transportation vehicles must be conducted, and the Dumper Placer should replace the old transportation vehicles in a phased manner. Currently, at the level of waste generation and collection, there is no source segregation of compostable waste from the other non-biodegradable and recyclable waste. Proper segregation would lead to better options and opportunities for scientific disposal of waste. Recyclables could be straightway transported to recycling units that in turn would pay a certain amount to the corporations, thereby adding to their income. This would help in formalizing the existing informal set up of recycling units. It could lead to several advantages such as enabling technology upgradation, better quality products, saving of valuable raw material resources of country, reducing the need for landfill space, a less energy-intensive way to produce some products and employing labor in recycling industries. Organizing the informal sector and promoting micro-enterprises are an effective way of extending affordable services. Promotion and development of recycling is a means of upgrading living and working conditions of rag pickers and other marginalized groups.

Most of the MSW in India is dumped on land in an uncontrolled manner. Such inadequate disposal practices lead to problems that will impair human and animal health and result in economic, environmental and biological losses. Comparing the biological, chemical and thermal treatment options in the Indian scenario, perhaps the biological processing options get the priority. Composting and vermicomposting are successful and quite popular now in India instead of incineration. But, it is slow process and requires a large space. An open dump or an uncontrolled waste disposal area should be rehabilitated. It is advisable to move from open dumping to sanitary landfilling in a phased manner. Landfilling should be restricted to non-biodegradable, inert waste and other waste that are not suitable either for recycling or for biological processing.

The current regulations (MSWM rules, 2000) are very stringent. Norms have been developed to ensure a proper MSWM system. Unfortunately, clearly there is a large gap between policy and implementation. The producer responsibility is to avoid having products on the market that cannot be handled effectively and environmentally correctly when they become waste products. A new survey should be carried out on the generation and characterization of MSW in India. Since the MSW is heterogeneous in nature, a large number of samples have to be collected and analyzed to obtain statistically reliable results.

Finally, the study concluded that the lack of resources such as financing, infrastructure, suitable planning and data, and leadership, are the main barriers in MSWM. The increase of service demands combined with the lack of resources for municipalities are putting a huge strain on the existing MSWM systems.

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