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Recycling of Urban Solid Waste: A Perspective

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City refuse, the municipal solid waste, considered as a nuisance and a major health hazard, can meet a significant part of the fertilizer requirement and energy needs, if properly handled. This potentiality stems from three factors: the growing concern over environmental pollution, the soaring cost of land in and around cities, and the sky-rocketing cost of energy. A good deal of literature[1-18] is available on the recycling of urban solid wastes. This communication presents a critical analysis of the various facets of the problem, viz. availability and characteristics of city refuse, recycling of waste for energy, fertilizer and pollution control, factors influencing efficient management of wastes and the strategy to be adopted, not only for the present but also for the future 20 years or so.

Availability and Characteristics of City Refuse

A knowledge of the characteristics of city refuse is essential to choose the type of disposal technique to be adopted. The quantity and types of city refuse generated in urban areas depend on various factors, primarily the standard of living and occupations of the people and their dietary and climatic habits. It is estimated that about 20 million tonnes of city refuse gets generated annually in India. The estimated production of refuse and its manurial value in the city of Delhi and on all India basis for the years 1980-81 to 2000-01 AD are given in Table 1. This marks an increase of 36.7% during a period of 20 years.

The physical and chemical characteristics of city refuse from 33 Indian cities[19] are given in Table 2. The cities have been grouped into four categories on the basis of population. Out of these, 20 cities recorded per capita value ranging between 0.15 and 0.35 kg/day. The maximum per capita value recorded in a city was 0.481 kg/day in comparison to the average value of 1.0 kg/day and 2.4 kg/day in Japan and USA respectively[20]. The total compostable portion in refuse from India[21] ranges between 47 and 75% (Table 3), whereas in western countries[22], it ranges between 10 and 22%. The chemical compositions of city refuse from different countries, such as India[23], Germany[24], Korea[25], Japan[26] and those of city compost from India[27], Thailand[28], England[29], Japan[30] and Belgium[31] have been studied by various workers. These studies indicate the potential of utilization of urban solid waste for energy and fertilizer purposes[30,32,33].

Environmental Pollution Aspects

At present, a good proportion of the city refuse is dumped in low lying areas, and becomes a source of groundwater pollution. The runoff from the refuse mass causes pollution of surface waters. The movement of such water through soil also results in soil pollution. The gases produced during the decomposition of city garbage under anaerobic conditions and incineration under aerobic conditions result in air pollution. Thus, biodegradation, leaching and volatilization of city garbage result in serious land, air and water pollution[34-38].

Table 1—Production Potential and Manurial Value of City Compost in Delhi and on All-India Basis during the Period 1980/81 - 2000/2001 AD

Particulars	Delhi		All-India	
	1980/81	2000/2001	1980/81	2000/2001
Population × 10^5	45.49	62.20	1361.19	1861.21
Total quantity of city garbage* × 10^5 t/y	6.64	9.08	198.73	271.74
Non-compostable†	3.98	6.45	119.24	163.03
Compostable	2.66	3.63	79.49	108.71
Compost‡	1.33	1.82	39.75	54.36
Nutrient content and organic matter§ × 10^3 t/y				
Nitrogen	0.93	1.27	27.83	38.05
Phosphorus (P_2O_5)	0.80	1.09	23.85	82.62
Potassium (K_2O)	0.67	0.91	19.88	27.18
Organic matter (OM)	53.20	72.80	1590.00	2174.40

*Total quantity of city garbage available @ 0.4 kg/capita
†Non-compostable : compostable ratio in garbage, (60:40)
‡Compost obtained : 50% of the compostable material.
§N, 0.7%; P_2O_5, 0.6%; K_2O, 0.5%; and OM, 40%.

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Table 2 Physical Characteristics and Compostion of Mixed City Refuse of India[19]

Particulars	Population range (in lakh)				
	2	2-5	5-20	20	Av.
Moisture,	22.12	25.05	22.45	31.18	25.20
*p*H	8.18	8.16	8.34	7.68	8.09
Non-decomposables (% by wet wt)					
Paper	3.09	4.76	3.80	7.07	4.68
Rubber and leather	0.49	0.63	0.62	0.87	0.65
Plastics	0.57	0.59	0.81	0.86	0.71
Metals	0.51	0.39	0.64	1.03	0.64
Glass	0.29	0.34	0.44	0.76	40.46
Ash and fine earth	46.60	39.97	41.81	31.74	40.03
Total compostable matter	33.41	39.76	40.15	41.69	38.75
Miscellaneous	15.04	19.56	11.73	15.98	15.58
Chemical composition					
Organic matter, %	22.02	22.51	21.51	27.57	23.40
Carbon, %	12.26	12.51	11.95	15.32	13.01
Nitrogen, %	0.60	0.61	0.56	0.58	0.59
Phosphorus (P_2O_5), %	0.71	0.72	0.68	0.59	0.68
Potash (K_2O), %	0.71	0.74	0.72	0.68	0.71
C/N ratio	20.35	20.47	21.45	26.23	22.43
Energy content (kcal/kg)					
Calorific value	801	874	867	1140	920

Table 3 Physical Composition of Refuse from Different Cities in India[21]

Item	Lucknow	Delhi	Calcutta	Bangalore	Ahmedabad
Paper and cardboard	1.66	5.88	0.14	1.50	5.15
Metals	3.20	0.59	0.66	0.10	0.80
Glass	0.66	0.31	0.24	0.20	0.93
Textiles	2.91	3.56	0.28	3.10	4.08
Plastic, leather and rubber	4.20	1.46	1.54	0.90	0.69
Wood, hay and straw		0.42	-	0.20	1.50
Bones	0.18	-	0.42	-	0.12
Stones	5.27	5.98	16.56	6.90	8.77
Fine earth and ash	1.59	22.95	33.58	12.00	13.86
Decomposable material	60.31	57.71	47.25	75.20	48.95

During decomposition, organic wastes normally produce a liquid termed as 'leachate'. In landfills, some of this liquid results from the pressure applied by the fill above, squeezing out fluid from the garbage. Another principal component of the leachate is rain water, which, during its passage through the landfill, dissolves a wide range of materials. The leachate may emerge from a landfill with a biological oxygen demand of over 20,000 mg/litre, which is about 100 times stronger than that for raw sewage[18]. Improper

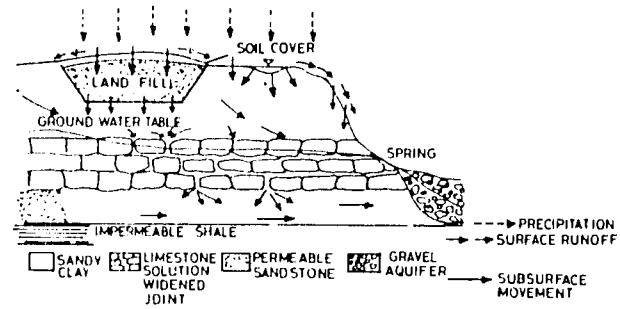

Fig. 1 Groundwater pollution through leaching of urban solid wastes

landfilling[12] leads to gas production, resulting in possible fires, asphyxiation and explosions in buildings, pollution of aquifers and rat and insect infestation. If landfill soil and solid waste receive enough water to reach their respective field capacities, the leachate may begin to be discharged. Under a situation where soil or rock strata are impervious, the leachate may rise and get discharged on the ground surface either at the landfill toe or somewhere down the slopes[39, 41]. In many cases, the leachate can migrate to the underlying ground and possibly contaminate a subsurface zone close to or at the top of the groundwater table[42]. Fig. 1 illustrates the mode of groundwater pollution through leaching of urban solid waste[43]. The leachate contains dissolved and suspended material[44] (Table 4).

Accumulation of urban solid waste increases the sediment load carried by streams, decreases groundwater recharge and promotes eutrophication resulting in degradation of water quality[45]. Increase in *p*H, electrical conductivity, total soluble organic carbon and naturally occurring metals like Fe[46] and also in the concentrations of heavy metals and pesticides like endrin, lindane, methoxychlor, toxapane 2,4-D and 2,4,5-TP above the toxic limits in the leachates was observed[47]. Estimation of the concentration of

Table 4 Ranges of Pollutant Concentrations in Leachate from Typical Domestic Refuse[44]

Pollutants	Conc. range (mg/litre)
*p*H	24.0-8.5
Chemical oxygen demand	100-51,000
Total residue	1000-45,000
Hardness (as $CaCO_3$)	200-5,250
Iron	200-1700
Zinc	1-135
Nickel	0.01-0.8
Copper	0.1-9.0
Sodium	100-3800
Nitorgen	20-500
Phosphate	5-130
Sulphate	25-500
Chloride	100-2400

pollutants[48] in the leachate coming out of city garbage revealed the presence of 1500, 10 and 2704 mg/litre of chlorides, sulphates and hardness respectively. Up to one month from the time the refuse was exposed to the leaching action, the leachate contained excessive quantities of pollutants. After two months, the values of all other pollutants were much less, while hardness continued to give quite high values. Most of the parameters, except hardness, were within the permissible limits. The total quantities of chlorides, sulphates and hardness that were leached during 4.5 months from Nagpur city refuse were 3.904, 0.278 and 9.586 kg respectively, which were higher than the values reported earlier[40,49,50]. Studies made on vertical migration of some nutrients from municipal solid waste showed more rapid movement of pollutants through soil when the leachate had low *p*H and high concentrations of total organic carbon, soluble common salts and some naturally occurring metals like iron[51]. When the leachate was used for growing soyabeans in sand culture, it resulted in an imbalance in the proportion of nutrients, causing stunted growth of plants[52]. Increased levels of zinc, copper, lead and cadmium in grain and stover of corn were observed in soil treated with city refuse[53].

Contamination of groundwater is common in areas surrounding city refuse dumping sites, more so where dumping is done in low-lying areas and the rate of percolation through the soil is high. The results of studies carried out on groundwater pollution by open refuse dumps at Jaipur are presented in Table 5. The leachates from refuse had high concentrations of organic carbon, iron and manganese coupled with high concentrations of dissolved solids. The leachate from tipped refuse was stronger than sewage at the time of formation in terms of its nitrogen, phosphate and chloride contents and COD[54]. During the percolation of the leachate through soil, it became weaker due to physical, chemical and biochemical changes before the groundwater got contaminated. The total hardness, total dissolved solids, chloride, iron and COD decreased in well water as the distance from the refuse dumping grounds increased. Well water down to a distance of 50 m was highly polluted, but beyond a depth of about 220 m, the values remained more or less unchanged up to a depth of 450 m, indicating the distance up to which the quality of well water was affected by the leachate. These well waters were polluted and not suitable for drinking and domestic purposes. The chemical quality of water in the third group of wells was within the chemical standards prescribed for drinking water[22].

Sanitary landfill This is a solid waste disposal facility wherein refuse is placed at the greatest possible density for final deposition. No open burning, no ground and surface water pollution and daily covering of the deposited refuse with earth are some of the features of the method. While the technique of sanitary landfilling is almost the same everywhere, three variations of refuse placement are used in the United States[26] the trench method, the area method and the ramp method. Certain parameters govern the construction of sanitary landfills. The operational parameters are topography and geology of the site, covering material, refuse characteristics, surface and groundwater hydrology of the site, and climatic features of the location. Components of sanitary landfill operation are the site itself, equipment and physical plant. Auxiliary operations include shredding and grinding and volume reduction, the limiting parameters being land availability and landfill byproducts.

Table 5 Physicochemical Characteristics of Well Water[54]

[Results are expressed in mg/litre, except *p*H and temperature; Groups 1,2 and 3 comprise wells within 20-45 m, 150-450 m and 5-6 km of the dumping sites respectively]

Characteristics	Group 1		Group 2		Group 3	
	Conc. range	Av.	Conc. range	Av.	Conc. range	Av.
Temperature, °C	20-24	22	20-22	21	20-21	20.5
*p*H	7.8-8.4	8.1	7.5-8.6	8.1	7.2-8.4	7.8
Total dissolved solids	1150-2136	1643	640-1260	950	320-510	415
Total alkalinity as $CaCO_3$	480-1244	862	270-480	375	110-204	157
Total hardness as $CaCO_3$	550-980	765	310-548	429	140-226	183
Chloride as Cl	336-680	508	180-380	280	80-140	110
Sulphate as SO_4	148-280	214	84-180	132	48-68	58
Ammonia nitrogen as N	0.2-2.0	1.1	0.0-0.4	0.2	0-0	0
Nitrate nitrogen as N	0.8-6.0	3.4	3.0-10	6.5	2-10	6
Phosphate as PO_4	1.0-3.0	2.0	0.0-0.8	0.4	0-0	0
Iron as Fe	0.8-3.0	1.9	0.3-1.0	0.7	0.0-0.2	0.1
COD	50-200	125	12-40	26	0-8	4

An important consideration in the disposal of solid waste in a sanitary landfill operation is the ultimate fate of the disposal site. Proper use of a landfill site may yield both economic and social benefits; improper use may lead to serious environmental problems[57]. Completed sanitary landfill sites are eventually levelled and used as recreational areas, as most sites are filled in a haphazard manner and are unsuitable for any other use. For agricultural use of landfill sites deep layers of the final cover soil are placed over the completed refuse cells. However, major difficulties are met with during percolation of irrigation water into the underlying refuse, with consequent leachate generation, and detrimental effects of the gases evolved from decomposing waste on growing plants[58,59]. The founding of important, heavy, extensive structures over decomposing refuse cells is not feasible[60]. Therefore only light construction can be built on such completed sites.

To avoid the pollution of groundwater and toxicity of soil, a material balance-sheet needs to be prepared for varying rates and frequencies of application of urban waste. No single method of waste utilization provides answers to waste management in every location. The role of evapo-transpiration in reducing landfill leachates has been discussed by Caffrey and Ham[61] and Lund *et al.*[62], while aerobic landfilling has been suggested by Hanajima[63] and Parker and Williams[64]. It is noteworthy that landfill gas is converted into electricity and supplied to thousands of households in USA[65] and UK[66].

Solid Waste as an Energy Source

City refuse is one of the potential sources of energy. The heating value of composite municipal waste varies between 4500 and 6500 Btu/lb. The moisture contents and heating values of combustible municipal refuse components are given in Table 6. Heating value can be raised by some type of drying process. Several solid waste processing systems have been developed during the past years which produce energy in the form of electricity, steam, gas or oil[67-80]. Some of these processes are proprietary in nature and are referred to as energy recovery systems; these include : the use of refuse as a supplementary fuel, waste heat recovery, gas turbine generation of electricity, pyrolysis and methane production by anaerobic fermentation.

Solid waste can be used as a supplementary fuel with coal in the generation of electricity, as a heat source in the production of steam and as a natural gas source[81-86]. The simplest method of recovering waste heat in the form of steam from existing or new incinerators is a boiler immediately following the combustion area of the incinerator[87,88]. The CPU-400 system is designed to recover energy from solid waste as electrical power. To recover this energy, the waste is burnt in a fluid-bed combustor. Hot gases from the combustor pass through a gas turbine to run an electrical generator[89]. Laboratory studies have indicated the feasibility of natural gas (methane) production from the anaerobic fermentation of solid waste. Basically, the system comprises the front end separation of non-degradables followed by anaerobic digestion, dewatering and ultimate disposal of the resulting residue[90-92].

Table 6 Typical Moisture Content and Heating Value of Municipal Refuse Components[2]

Component	Moisture, %	Btu/lb
Paper, cardboard, cartons, bags	3	7,660
Wood crates, boxes, scrap	7	7,825
Brush, branches	17	7,140
Leaves	20	4,900
Grass	50	3,820
Garbage	75	1,820
Garden stuff	50	3,470
Greens	50	4,070
Rags, cotton, linen	10	6,440

Pyrolysis is essentially the burning of organic matter in the absence of air at temperatures in the range 400-700 C. Since pyrolysis is endothermic, heat has to be provided from outside. Pyrolysis yields a number of products, gaseous and liquid, carbon monoxide, methane, butane, wood tar and a variety of other chemicals, all of which have a very high energy content[93,94]. The yields obtained during the pyrolysis of municipal solid waste by Garrett flash pyrolysis method[95] are as follows: char, 20; gas, 30; oil, 40; and water, 10% (by wt of incoming refuse).

The currently used pyrolysis methods fall into two categories: high temperature and conventional. Conventional pyrolysis can be further subdivided into gas producing and liquid fuel producing systems[12]. In a typical high temperature pyrolysis plant, the refuse is charged into a reactor through an air seal. Heated air, introduced at the bottom of the reactor, dries, partially volatilizes, oxidizes and finally melts the refuse as it descends through the reactor. The molten material is collected in a quenching tank to form a glass-like aggregate. The gases produced in the reactor are removed and burnt in a secondary combustion chamber. Here, temperature exceeds 1100 C. The hot gases from the afterburner may be utilized to produce power and/or sustain the process.

In the conventional pyrolysis process designed to optimize gas production, the shredded refuse is continuously fed into a reactor against the direction of flow of hot gases. The temperature varies between 815 and 1100 C, which is enough to pyrolyze the refuse

into gases and solid residue. Another conventional pyrolysis method is designed to produce liquid fuel oil. This method is based on flash pyrolysis and is designed to produce one barrel of synthetic fuel oil per tonne of refuse received. This fuel is a low-sulphur oil with a heating value equivalent to 75% of No. 6 oil on volumetric basis.

Four basic critical parameters are associated with pyrolysis of solid wastes: heating rate[96], temperature[97,98], waste composition and marketability of byproducts. The effect of temperature on the pyrolysis process has been studied by Hoffman and Fitz[99] and McFarland *et al.*[100]. The yields of gases, organic liquids and char at these temperatures[101] are given in Table 7. The pyrolysis temperature is found to influence the quantity and quality of the gases produced and their composition[101] (Table 8). Variation in pyrolysis temperatures also affects the char composition. Waste composition and preparation method influence the composition of pyrolysis byproducts[102]. In a study on raw municipal refuse, Sanner *et al.*[103] observed that this refuse produces more ammonium sulphate, gas, tar and liquor, and less solid residue and light oil than industrial waste.

Compost from Urban Solid Waste

Composting process It is a biological process for converting solid waste into a stable, humus-like product which finds use as a soil conditioner. It is a self-heating, thermophilic and aerobic process which proceeds naturally in accumulations of biodegradable solid organic matter[104-107]. Keeping in view the bulky nature of city garbage, composting has become acceptable both environmentally and agriculturally[108-112].

A survey conducted on various aspects of garbage of 33 Indian cities revealed that the municipal authorities spent on an average about 10% of their annual budget on solid waste management[113]. Under such circumstances, composting of refuse is found to yield more revenue than the expenditure incurred. Disposal of urban waste in big cities by conventional composting is posing a serious problem by way of high cost, non-availability of land (for composting), labour needed for composting operations (which involve contact with filthy and obnoxious material) and marketing of compost. City refuse continues to be handled in an uneconomic and unhygienic manner. Mechanized composting seems to be the answer. In big cities, it can be located centrally and in a small compact area, thus doing away with long haulage and search for new dumping sites. The other advantages of mechanized composting are: sanitary control possible through the use of odour-proof devices, ability to work in both dry and wet seasons, possibility of recovering discarded materials like metal, glass and other non-compostable fractions, and the superior quality compost obtained in a short time[114-117].

Composting systems These can be classified on the basis of technological approach, oxygen requirement and temperature. The following 14 types of composting processes[18] are in use: Bangalore (India), Cospari (Germany), Dano Biostabilizer (Europe), Earp-Thomas (Germany, Switzerland, Italy), Fairfield-Hardy (USA), Fermascreen (England), Frazer-Eweson, Jersey (UK, Thailand), Metrowaste (USA), Naturiser (USA), Riker, T.A. Crane (Japan), Tollemache (Spain, South Rhodesia), Triga (France, USSR, Argentina), Windrowing (USA, Israel) and van Maanen (USA, Netherlands).

The main operational steps in a modern, mechanized and automated plant are as follows: (i) pre-sorting to remove bulky materials unsuitable for composting (salvaging), (ii) shredding the coarser components, (iii) removing glass and metal fragments, (iv) composting the organic material at accelerated rates in fully enclosed chambers for 1-3 days (including partial recirculation for seeding purposes) under controlled aerobic moisture and temperature conditions, (v) completing the maturation in windrows for a further period of 3-10 weeks to produce a stable, odour-free end-product, and (vi) addition of chemical fertilizers as needed, either during or at the end of the process, to obtain the required fertilizer characteristics[118-120]. A lot of research work has been done on

Table 7 Effect of Pyrolysis Temperature on Product Yield[10]

Product	Temperature, F			
	900	1200	1500	1700
Gases	12.33	18.64	23.69	24.36
Pyroligneous acids and tars	61.08	59.18	59.67	58.70
Char	24.71	21.80	17.24	17.67
Mass accounted for	98.12	99.62	100.59	100.73

Table 8 Effect of Pyrolysis Temperature on Gas Composition[101]

Constituent	Temperature, F			
	900	1200	1500	1700
H_2	5.56	16.58	28.55	32.48
CH_2	12.43	15.91	13.73	10.45
CO	33.50	30.49	34.12	35.25
CO_2	44.77	31.78	20.59	18.31
C_2H_4	0.45	2.18	2.24	2.43
C_2H_6	3.03	3.06	0.77	1.07
Accountability	99.74	100.00	100.00	99.99

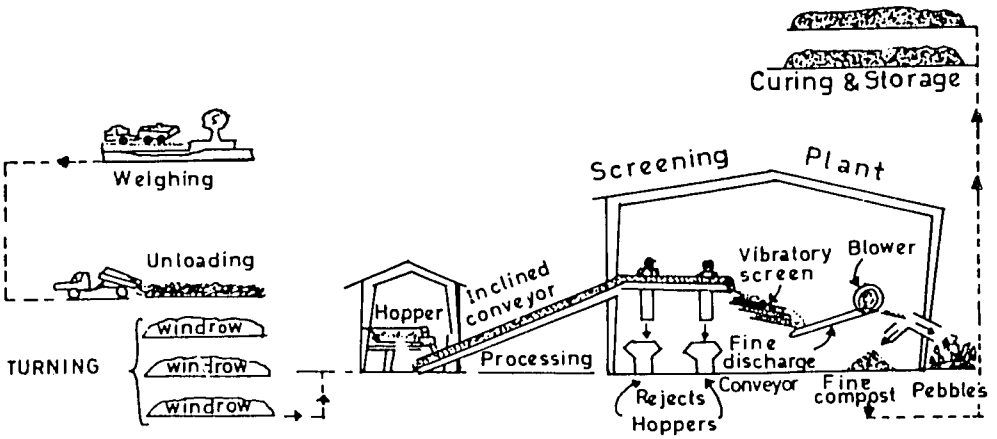

Fig. 2 – Mechanical composting plant at Okhla : Processing steps

the processing steps of mechanized composting and suitable modifications have been suggested for different conditions[121-127]. A broad outline of the process adopted by Municipal Corporation of Delhi at Okhla (Fig. 2) is discussed by Jain[128].

Factors affecting composting of city refuse—Temperature, moisture, aeration, substrate composition and *p*H are some of the factors affecting composting of city refuse.

Temperature has long been recognized as one of the key factors affecting biological activity. Temperature generally increases from ambient to 50°C within one or two days after the material has been piled in windrows. After four days, temperature reaches between 60 and 70°C. A high temperature is maintained from the centre of the mass to the outer 2-4 in layer until the readily decomposable refuse has been completely humified. At this point, the microbial activity begins to decline and the temperature drops off correspondingly[129-132].

The optimum moisture content for composting is in the range 45-55%, but composting also occurs in the range 25-75%[133]. Aeration efficiency and moisture content are inversely related. High moisture composting systems need much more air than the conventional systems[134].

Oxygen is necessary for the growth of the microorganisms. If the oxygen level becomes too low, aerobic organisms are replaced by anaerobic organisms; this retards the process of composting. The optimum oxygen requirement of microbes at various stages of humification has been determined by several workers[135-142]. The optimum range for air flow rates for windrow composting is 0.6-1.8 m^3 air/day. Volatile solids during thermophilic stage decrease progressively during cooling and maturing.

With the exception of N, all elements needed for microbial growth are present in requisite concentrations in municipal solid waste. Therefore, it is necessary to enrich it with nitrogenous sources[143,144]. The most important aspect of successful composting is the relationship between carbon-nitrogen ratio and the rate of organic matter decomposition. The optimal values reported lie between 26 and 35[145,146].

Initially, the material is acidic due to cell sap of plants followed by a further increase in acidity on account of the presence of acid-forming bacteria Subsequently, the reaction becomes alkaline due to ammonia formation, and finally near neutral or slightly alkaline due to natural buffering of the humus[147].

Transformation during humification of city garbage—A number of factors like volume reduction, colour change, microbial succession, chemical composition, amd maturity or degree of stability affect the agricultural value and hygiene aspects of the finished product.

The extent of volume reduction increases in proportion to the amount of readily decomposable material in the waste[148]. The windrows of city garbage shrink by 30-50% in volume, showing a corresponding weight loss[149].

The material undergoing humification has a greyish green colour after being ground. This colour gradually turns to brown or brownish-grey; the transition is generally over within 4 or 5 days after grinding. A colorimetric method for studying the colour of a mature compost has been suggested by Sugahara *et al.*[150].

Composting is a dynamic process, representing the combined activity of a wide succession of mixed microflora. The types and numbers of organisms involved in composting[107] are given in Table 9. In various studies[151-154], a typical and continual change in the microfloral population was observed. Initially, the fungi and acid producing bacteria appear during the mesophilic stage. As the temperature goes beyond 40°C, these are replaced by thermophilic

tonnes/ha resulted in an increase in yield by about 62% over the control[195]. In Japan[219], application of compost increased the yields of upland crops by about 25% and those of paddy by about 10% as compared to controls. The response of paddy to city compost in combination with inorganic N-fertilizer under different water regimes in Thailand[195] is evident from the data presented in Table 11. Because of low nutrient content of city compost, its enrichment with chemical fertilizers[220-223], sewage sludge[224,225] and microbial cultures[226,227] is suggested for increasing the nutrient availability to crop plants. With the use of nitrogen- and phosphorus-enriched products of city compost, it would be possible to substitute 25% nitrogen and 50% phosphorus doses recommended for paddy, when applied on nitrogen- and phosphorus-substitution basis respectively (Fig. 3).

Pelletized municipal compost was tried as a source of nutrients by Hortenstine and Rothwell[228]; they observed an increase in the uptake of all nutrients, except that of manganese. An increase in phosphorus levels in sorghum plants with increasing compost rates was recorded by Terman and May[191]. City compost raised the zinc and iron contents of plants from deficiency to sufficiency levels[196].

Health aspects Solid wastes generated in urban surroundings are contaminated with a wide variety of organisms pathogenic and parasitic—for both human beings and animals. With increasing use of night soil and sewage sludge in combination with city refuse, the significance of pathogen survival, fly breeding and their destruction during composting has increased. The destruction of pathogens and flies during the thermophilic stage of composting has been reported[229-236]. The thermal death points of some of the common pathogens and parasites[105] are given in Table 12. Wiley and Westerberg[237] studied the survival of pathogens in compost and reported that only aerobic composting where a high temperature profile of 60-70°C is obtained and retained for at least 3 days, could destroy these indicator organisms. To obtain a clean material from the public health point of view, care needs to be taken to ensure that all portions of the windrow are fully exposed to these temperatures. The extent to which ascaris eggs are destroyed during composting of garbage and night soil[238] is evident from the data presented in Table 13.

Table 11 Response of Paddy to City Compost in Combination with Inorganic N-Fertilizer under Different Water Regimes at Surin (Thailand)[195]

Water regime	Treatment	Nitrogen level, kg/ha 0	37.5	75.0	112.0	Av. kg/ha
Undrained	Control	2010	2631	2865	2989	2624
	Compost	2621	3071	3699	3970	3340
	Average	2316	2851	3282	3480	2982
Drained	Control	2019	2704	3236	3522	2870
	Compost	2806	3543	4225	4326	3725
	Average	2413	3124	3731	3924	3298

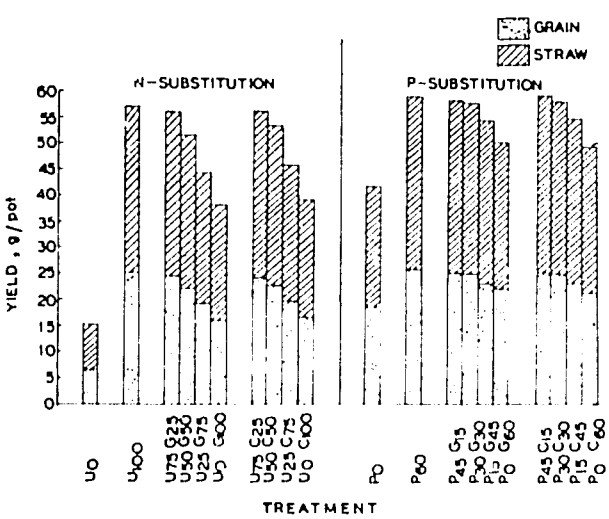

Fig. 3 Effect of enrichment of garbage (G) and urban compost (C) with urea (U)/superphosphate (P) on dry matter yield of paddy (subscripts refer to dosage of nutrients in kg/ha)

Table 12 Thermal Death Points of Some Common Pathogens and Parasites[105]

Organism	Observations
Salmonella typhosa	No growth beyond 46°C, death within 30 min at 55-60°C
Shigella sp.	Death within 1 hr at 56°C
Escherichia coli	Most die within 1 hr at 55°C and within 15-20 min at 60°C
Entamoeba hystolytica cysts	Death within a few minutes at 45°C and within a few seconds at 55°C
Mycobacterium tuberculosis	Death within 15-20 minutes at 66°C
Necator americanus	Death within 50 minutes at 45°C
Ascaris lumbricoids eggs	Death in less than 1 hr above 50°C

Table 13 Percentage Destruction of Ascaris Eggs during Composting of Garbage and Night Soil (5:1)[238]

Pile No.	Days after piling	Total No. of eggs observed	Viable eggs	Dead eggs	Destruction %
1	0	322	300	22	6.8
	25	130	59	71	54.6
	45	166	2	164	98.8
	65	134	1	133	99.3
2	0	322	300	22	6.8
	25	156	0	156	100.0
	45	245	0	245	100.0
	65	314	0	314	100.0

Table 9 – Organisms Involved in Compositing[107]

Organism type		No./g of moist compost
Microflora	Bacteria	10^8-10^9
	Actinomycetes	10^5-10^8
	Fungi	10^4-10^6
	Algae	10^4
	Viruses	
Microfauna	Protozoa	10^4-10^6
Macroflora	Fungi	
Macrofauna	Mites, ants, termites, millipedes, centipedes, spiders, beetles, worms	

bacteria, actinomycetes and thermophilic fungi. Finally, mesophilic bacteria and fungi reappear as the temperature falls.

Many workers have studied the losses in the chemical constituents of city garbage as it is subjected to microbial degradation. Sugar and starch are most readily utilized by microbes, resulting in a heavy loss of water soluble materials. Lipids or fats are not very resistant to degradation. Cellulose and hemicellulose are intermediate in resistance, while lignin is the most difficultly decomposable component[155]. The average reduction values of mixed refuse after composting[156] are as follows: total matter, 40; volatile matter, 45; carbohydrate, 65; lipids, 86; protein, 22; and crude fibre, 30%.

The changes in chemical composition of compost at the end of composting of city garbage and mechanized compost[157] are presented in Table 10. Composting results in an increase in the content of major and minor nutrients[158–161]. Co-composting of city refuse with sewage sludge decreases the heavy metal content of sludges[162,163].

The result of the composting step is the stabilization of the organic matter in the waste. The desired degree of stability is one at which the material does not give rise to nuisances when stored – even if it is wet. Parameters of stability of compost other than appearance and odour[164] are final drop in temperature[165], self-heating capacity[166], proportions of decomposable and resistant organic matters in the material[167], rise in redox potential[168], oxygen uptake[169], CEC of the product[170,171], carbon-nitrogen ratio[172], the ratio of the carbon in reducing sugar to the total carbon, stability of *p*H[173], growth of *Chaetomium gracilis*[174], starch test[175] and toxicity to plant roots[176]. Spohn[177] has suggested a laboratory test for checking whether materials have reached a mature stage.

Agricultural value of city compost Use of city compost promotes soil aggregation and stabilizes soil structure. This improves the air-water relationship of soil, thus increasing the water retention capacity and facilitating extensive development of root systems of plants[178–188]. Hart[189], while evaluating municipal compost as an erosion control residue, observed that it can be a good substitute for straw and manure over a 7-year period. The erosion losses from small plots on a 30% slope were reduced from 5.0 to 0.2 m^3 of soil per hectare/year, when 60 tonnes of compost was applied as mulch.

The release of nutrients during the decomposition of urban compost in soil is similar in effect to that of other manures. Substantial improvement in *p*H[190,191], organic matter[192–194], major[195,196], secondary[197,198] and micro-nutrients[199–204] of the soil was observed on the application of city compost. The application of urban compost increases the biological activity of soil by acting as food substrate to the native soil microflora, as reflected by CO_2 evolution, nitrification and ammonification[205,206].

Garbage compost is used in all areas of crop growing and soil amelioration – in crop farming, grassland, farming, horticulture, forestry and land reclamation and also for landscaping. It not only improves the physical health of soils, but also provides nutrients to the crops, resulting in improved crop productivity. A good deal of work[207–215] has been carried out on the use of city compost for optimizing agricultural production under limited availability of fertilizers. However, the information available on the work done in India is very meagre[216–218]. At Jumla in Nepal, application of mechanized compost at the rate of 20

Table 10 – Change in Chemical Properties of City Garbage and Mechanized Compost After Humification for 91 Days[157]

Property	City garbage		Mechanized compost	
	Initial	Final	Initial	Final
Electrical conductivity, mmhos/cm	10.77	4.48	10.07	4.52
Organic carbon, %	27.03	12.37	18.56	12.45
Nitrogen, %	0.65	0.73	0.71	0.76
C:N ratio	41.37	16.88	26.34	16.36
NH_4^+ – N, ppm	79.90	150.30	80.60	150.10
NO_3^- – N, ppm	19.41	39.76	18.67	39.76
Phosphorus as P_2O_5, %	0.46	0.50	0.50	0.52
C:P ratio	135.25	57.55	86.29	55.55
Potassium as K_2O, %	0.51	0.80	0.72	0.80
Calcium, %	0.28	0.60	0.31	0.56
Magnesium, %	0.14	0.23	0.13	0.25
Zinc, ppm	246	403	255	412
Manganese, ppm	39.0	77.7	43.0	81.0
Copper, ppm	152	217	162	233
Iron, ppm	4433	8500	5200	8833

Factors Influencing Efficient Management of Solid Waste

Improper solid waste disposal is a health hazard. Open dumping of refuse results in serious land, air and water pollution. To solve these problems, it is essential to recycle urban wastes in an efficient and safe manner, but resource recovery is beset with a number of constraints. This is illustrated by the role of non-compostable components, e.g. metals can be easily recycled from industrial scrap, but the present methods of making steel can tolerate only limited scrap input and thus the scrap recovered has low market value. Glass is easy to reprocess and can be used in many ways, but the raw materials for glass are available so abundantly that there does not seem to be any gain through recycling. Although the residues of pyrolysis – combustible gas, tar and charcoal – have economic value, yet these products have not found wide acceptance commercially. Most of the gas is used in supplying energy for the process itself. The tar is full of water and must be refined. The charcoal is full of glass and metals, which have to be separated prior to its use. This separation makes the charcoal too expensive compared to wood charcoal.

Because of the horizontal growth of cities, no land is available in big cities for dumping of refuse (even by sanitary landfill methods). Non-availability of agricultural land in the vicinity of cities increases the cost of transportation of compost to the field. Local and traditional needs for FYM and farm compost limit the use of the compost prepared from city solid waste due to the influence of social customs and taboos: excreta have been regarded as something very obnoxious and highly polluting. It is true that their biodegradation can be a source of diseases and health problems, but right attitude to their potential value as a source of nutrients can help in devising methods to derive full benefits from them. The poor nutrient content and the non-uniformity of refuse limit its use for composting.

The high cost of mechanical composting plants and the non-utilization of byproducts are among the factors which make the process an uneconomic proposition. The most critical link in the process of composting is the segregation operation. Hand-sorting of garbage at the compost plant is tedious, expensive and insanitary. Detailed investigations are needed to evolve better separation methods. It is felt that if separation of non-compostables could be achieved economically, composting could become an attractive method for resource recovery. Supply of compost at subsidized rates and its free transportation to farms may help to popularize this product. There is need for co-ordination between the civic bodies charged with solid waste management in cities and research organizations for the efficient recycling of wastes. The various factors affecting the management of solid wastes are summarized in Table 14.

Table 14 – Factors Influencing Management of Urban Solid Waste

Material factors
- Non-uniformity of refuse
- High moisture content
- High content of non-compostables
- Poor nutrient content
- Low energy content
- Presence of pathogens and foul smell

Local factors
- Non-availability of land for dumping
- No agricultural land nearby
- Local/traditional needs

Social factors
- Traditionalism, taboos and superstitions

Techno-economic factors
- Level of technology available
- Processing cost
- Degree of recycling
- Economic use of byproducts

Fiscal factors
- Policy of incentives subsidy and controls

Organisational factors
- Level of co-ordination between civic bodies and research organizations

Strategies

An ideal approach would be to find out a suitable method for separating glass, metals, paper, wood, plastics and other non-compostables from the putrescible compostable fraction. Glass and metal scrap can be recovered in original form. Material having high heating value, such as paper, wood and plastics, should be pyrolysed for recovering energy, while the putrescible organic material should be processed through the mechanical composting plant for conversion into fertilizer.

Variations in the composition of city refuse as well as in its moisture content result in significant differences in its heating value (Table 7). It is, therefore, necessary to pyrolyse the constituents of municipal waste individually and to determine the overall yield by additive process and to standardize the pyrolysis and gasification steps under Indian conditions.

The traditional method of urban composting is highly unscientific. Care is not taken to provide a balanced food and optimum environmental conditions for the microbes to convert the wastes rapidly into good quality compost and to minimize leaching and volatilization losses. This calls for investigations on various aspects of the composting process in mechanical composting plants so as to handle in the

shortest possible time huge heaps of refuse gathered everyday in the cities. The quality of the final product should be enriched with mineral fertilizers and microbial cultures, so as to make the setting up of mechanical composting plants economically viable. The high investment on complete mechanization of the compost plant coupled with the costs of repair and servicing emphasizes the need for setting up mini-mechanical compost plants which would be more appropriate under the socio-economic conditions prevailing in India.

Where it is not possible to recycle the whole quantity of refuse efficiently for energy and fertilizers, part of it can be disposed of around the cities through the use of sanitary landfill methods.

A number of other organic wastes are available in India from animal sheds, farms, fish and marine sources. These neglected materials, if exploited efficiently, could significantly help to meet the energy, fertilizer and material needs of the country, of course, with adequate attention to the overcoming of pollution hazards[239].

Summary

Urban solid wastes are a major source of land, water and air pollution if exploited inefficiently. Use of these biodegradable materials as sources of energy and fertilizer could help to meet the growing needs, consistent with the maintenance of health and sanitary conditions. But the whole problem is beset with a number of limitations—local, material, technological, economic, organizational and fiscal. This paper analyses the magnitude of the problem and the alternative disposal/utilization systems and in this context the criteria for formulation of strategies which are not only desirable but also feasible.

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Production Mechanism of Hard X-Rays in Solar Flares—A Review

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During the explosive phase of a flare, there is sudden release of about 10^{35} electrons, possibly in various directions. Sometimes the particles (electrons and protons) attain energies of several MeV or even higher[1]. Some of the electrons which move downwards are trapped by the magnetic field of the active region located above sunspots and having an electron density several times the coronal density. The accelerated electrons produce impulsive burst at centimetre wavelength by synchrotron mechanism and the high energy X-ray burst by bremsstrahlung process. The distribution of energetic electrons and their total energy are deduced from hard X-ray observations.

Hard X-ray spectra at the peak of the impulsive emission have been reported by Hoyng *et al.*[2] and Kane and Anderson[3]. The observational characteristics of solar hard X-ray bursts, generally referred to as small flares or sub-flares, have been analysed in detail by different workers[3-8]. Hard X-ray bursts occur during the flash phase and peak usually 0.5-3 min before the flare maximum observed in H_α light. The increases and decreases in the X-ray flux at 40 keV are roughly exponential with e-folding rise time of 2-5 sec and similar or slightly lower e-folding decay times. For larger flares, the X-ray time profile consists of many spikes of the order of 1 min duration; short lived spikes of the order of 1 sec duration are superimposed on top of them[9]. The peak X-ray at the earth above 10 keV is found to be usually in the range 10^{-7}-10^{-5} ergs cm^{-2} s^{-1}. Further, the X-ray spectrum is of the power law form: $\frac{dQ}{d(h\nu)}(E) \sim h\nu^{-\gamma}$ (photons cm^{-2} s^{-1} keV^{-1}) with $3.5 \leq \gamma \leq 5.5$ (medium $\gamma \approx 4.6$) in the range 10-80 keV at the maximum flux; above about 80 keV, the spectrum becomes much steeper. Spectral indices larger than 7 are very rare and hard to determine because of the pile-up effect[8]; they almost never become smaller than 2.5[6,8]. The spectrum is hardest near the flux maximum[3,5].

Once measurements of the energy of solar hard X-rays became available, it was possible to deduce the number and energy spectra of the accelerated electrons[10]. Electrons with power law energy spectra can produce the usually observed power law photon spectra; this fact was regarded as evidence for the non-thermal origin of the solar hard X-rays[11-13]. However, power law spectra of hard X-rays can also be due to multi-temperature plasma[14,15]. Because thermal and non-thermal interpretations require quite different flare models, it is very important to determine the nature of solar flare hard X-rays.

Accelerated electrons having 10 keV energy can produce hard X-rays with energy ≥ 10 keV. Protons and heavy nuclei produce narrow gamma-ray lines in MeV range. In addition, synchrotron radiation due to the motion of relativistic electrons in magnetic field, inverse Compton scattering of relativistic electrons with thermal solar photons[16] and bremsstrahlung due to collision of accelerated electron with the ambient protons[17] can produce hard X-rays.

We shall, to start with, briefly discuss the favourable conditions for the generation of hard X-rays in a flare by each one of the three mechanisms referred to above and thereby show that inverse Compton scattering and synchrotron mechanism are not important under normal conditions. We shall then proceed to discuss at greater depth the generation of hard X-rays by bremsstrahlung of accelerated electrons. The characteristic features of the electron-electron and electron-ion bremsstrahlung X-rays shall also be reviewed and discussed.

Synchrotron Radiation

When a charged particle traverses a region containing a magnetic field, it undergoes acceleration and emits photons. This emission is called cyclotron radiation or magnetic bremsstrahlung. Further, when the electron speeds lie in the relativistic range, the radiation acquires certain characteristic features different from those of the normal cyclotron radiation. This emitted radiation is known as synchrotron radiation and is illustrated in Fig. 1. Since for a given particle energy the energy loss by this process is reduced by the square of the particle mass, we shall

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