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Composition of Municipal Solid Waste Generation and Recycling Scenario of Building Materials

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ABSTRACT

Presently in India, about 960 million tonnes of solid waste is being generated annually as by-products during industrial, mining, municipal, agricultural and other processes. Of this 350 million tonnes are organic wastes from agricultural sources; 290 million tonnes are inorganic waste of industrial and mining sectors and 4.5 million tonnes are hazardous in nature. Advances in solid waste management resulted in alternative construction materials as a substitute to traditional materials like bricks, blocks, tiles, aggregates, ceramics, cement, lime, soil, timber and paint. To safeguard the environment, efforts are being made for recycling different wastes and utilise them in value added applications. In this paper, present status on generation and utilization of both non-hazardous and hazardous solid wastes in India, their recycling potentials and environmental implication are reported and discussed in details.

Keywords:

Hazardous and non-hazardous waste; Recycling; Construction materials; Environmental pollution; Resources conservation;

INTRODUCTION

Traditionally materials like clay, sand, stone, gravels, cement, brick, block, tiles, distemper, paint, timber and steel are being used as major building components in construction sector. All these materials have been produced from the existing natural resources and will have intrinsic distinctiveness for damaging the environment due to their continuous exploitation. Nevertheless, during the process of manufacturing various building materials, especially decomposition of calcium carbonate, lime and cement manufacturing, high concentration of carbon monoxide, oxides of sulphur, oxides of nitrogen and suspended particulate matter are invariably emitted to the atmosphere. Exposure to such toxic gases escaping into the environment does lead to major contamination of air, water, soil, flora, fauna, aquatic life and finally influences human health and their living conditions. The cost of construction materials is increasing incrementally. In India, the cost of cement during 1995 was Rs. 1.25/kg and in 2005 the price increased three times. In case of bricks the price was Rs. 0.66 per brick in 1995 and the present rate is Rs. 1.9 per brick. Similarly, over a period of 10 years from the year 1995 the price of sand has increased four times. Also due to high transportation costs of these raw materials, demand, environmental restrictions, it is essential to find functional substitutes for conventional building materials in the construction industry. In view of the importance of saving of energy and conservation of resources, efficient recycling of all these solid wastes is now a global concern requiring extensive R&D work towards exploring newer applications and maximizing use of existing technologies for a sustainable and environmentally sound management. As a result, in India, the informal sector and secondary industries recycle 15–20% of solid wastes in various building components [1–3]. More details on the availability of solid wastes of all kinds from different sources, their present utilization and recycling potentials for safe, sound and substantial development are summarised and discussed in this paper.

RESEARCH METHODOLOGY

The current research has approached its objectives by following these steps:

– Conducting a theoretical study: By reviewing the literature of both developed and developing countries and defining the concept of life cycle cost analysis and explaining its role in decision making.

– Demonstrating the CDWM approaches: A detailed study for two approaches of CDWM is provided. First CDWM lifecycle flowcharts for each approach are developed and the cost components of its related activities are clearly identified. Second the cost breakdown structure for CDWM lifecycle is constructed. Then the roles of different stake- holders for each approach are identified. And finally the paper came out with a penetration discussion of the pros and cons of each approach.

– Assessment of the two approaches: It is conducted, from a strategic perspective, by extracting, weighting and scoring the influencing attributes from all the above and applying Decision Matrix technique to decide on one of the introduced approaches.

LITERATURE REVIEW

Most developing countries do not have the technical and financial resources to manage solid wastes safely. This means that storage at the point of waste generation is often inadequate and collection services are inefficient and insufficient. Final disposal in those countries is usually a matter of transporting the collected wastes to the nearest available open space and then discharging them, (2002). Effective management of solid waste requires the cooperation of the general public. Lifting the priority of, and allocating more resources to, the solid waste management sector need the support from decision makers. It is, therefore, important to ensure that public and decision makers' awareness activities are incorporated into the external support package. The aim of these activities is normally long term and it takes some momentum to build up before the effects are realized. But, once the interests of the public and decision makers in improving solid waste management are created, the sustainability of solid waste management projects will be significantly improved, Ogawa (1996). The Government of Egypt identifies solid waste management as one of the most important environmental issues. It is related to the social, economic and technical factors, which affect the quantity of waste generated and its management. However, due to many financial, managerial, technical and institutional reasons, this system has been unable to adequately address the problem of solid waste management and thus contributed to different environmental problems, Bushra (2000).

CDWM in developed countries

The economical aspect of solid waste management is a debatable issue even in the developed countries. Developing countries have solid waste management problems different than those found in fully industrialized countries; indeed, the very composition of their waste is different than that of 'developed' nations, Mueller (2003). In California some studies addressed the economics of C&D waste management; unfortunately, the mainstream construction industry has been slow to view C&D waste management as a business opportunity. In fact, C&D waste management is often overlooked, even in large-scale construction projects. This oversight may occur because the decision-maker follows outdated conventional wisdom, which dictates that construction waste management is never cost-effective, Zerbock (2003). In US a study listed the factors related to generated quantities and composition of waste that should be considered by the solid waste and project managers before commencing with any form of a recycling operation to ensure that the recycling project is both financially and methodologically feasible, Dolan et al. (1999)

Life cycle cost (LCC)

Life cycle cost (LCC) is the total discounted cost of owning, operating, maintaining, and disposing of a building or a building breakdown. The LCC equation is a function of the following three variables: the pertinent costs of ownership, the period of time over which these costs are incurred, and the discount rate that is applied to future costs to equate them with present day costs. Plenty of efforts have been made to discuss life cycle cost analysis of waste management. These include; Reich (2005). Al-Salem and Lettieri (2009), and Massarutto et al. (2001). In a recent research that developed a contractual relation guideline, two essential contract documents for applying sustainable practices in construction projects were included; a waste management plan and a cost estimate for construction waste management activities, Abdelhamid (2013). Waste management plan and cost estimate are not only necessary but also related to each other where cost estimate is a prerequisite to waste management plan implementation. To implement a sustainable CDWM approach, first identify its lifecycle; it starts by waste generation in C&D site, passes through different processes to end in C&D site as a recycled product. So when cost information is available LCC should be used to estimate the cost of CDWM.

- **Solid Waste Generation and Their Environmental Importance**

Growth of population, increasing urbanisation, rising standards of living due to technological innovations have contributed to an increase both in the quantity and variety of solid wastes generated by industrial, mining, domestic and agricultural activities. Globally the estimated quantity of wastes generation was 12 billion tonnes in the year 2002 of which 11 billion tonnes were industrial wastes and 1.6 billion tonnes were municipal solid wastes (MSW). About 19 billion tonnes of solid wastes are expected to be generated annually by the year 2025 [4]. Annually, Asia alone generates 4.4 billion tonnes of solid wastes and MSW comprise 790 million tones (MT) of which about 48 (6%) MT are generated in India [4,5]. By the year 2047, MSW generation in India, is expected to reach 300 MT and land requirement for disposal of this waste would be 169.6 km2 as against which only 20.2 km2 were occupied in 1997 for management of 48 MT [5]. Fig. 1 shows the details on current status of solid waste (non-hazardous and hazardous waste) generation from different sources in India [2,6]. As can be seen from Fig. 1 that apart from municipal wastes, the organic wastes from agricultural sources alone contribute more than 350 MT per year. However, it is reported that about 600 MT of wastes have been generated in India from agricultural sources alone [7]. The major quantity of wastes generated from agricultural sources are sugarcane baggase, paddy and wheat straw and husk, wastes of vegetables, food products, tea, oil production, jute fibre, groundnut shell, wooden mill waste, coconut husk, cotton stalk etc., [2,6,8]. The major industrial non-hazardous inorganic solid wastes are coal combustion residues, bauxite red mud, tailings from aluminum, iron, copper and zinc primary extraction processes. Generation of all these inorganic industrial wastes in India is estimated to be 290 MT per annum [6,9]. In India, 4.5 MT of hazardous wastes are being generated annually during different industrial process like electroplating, various metal extraction processes, galvanizing, refinery, petrochemical industries, pharmaceutical and pesticide industries [7,10]. However, it is envisaged that the total solid wastes from municipal, agricultural, non-hazardous and hazardous wastes generated from different industrial processes in India seem to be even higher than the reported data. Already accumulated solid wastes and their increasing annual production are a major source of pollution. Due to environmental degradation, energy consumption and financial constraints, various organizations in India and abroad, apart from the regulatory frame work of United States Environmental Protection Agency (USEPA), have recommended various qualitative guide- lines for generation, treatment, transport, handling, disposal and recycling of non-hazardous and hazardous wastes [10–14]. Safe management of hazardous wastes is of paramount importance. It is now a global concern, to find a socio, techno-economic, environmental friendly solution to sustain a cleaner and greener environment.

The heterogeneous characteristics of the huge quantity of wastes generated lead to complexity in recycling and utilisation. The comparative physicochemical characteristics of solid wastes generated from hazardous and non-hazardous sources over clay and cement. The physicochemical properties of solid wastes depend on the properties of feed raw materials, mineralogical origin, operating process and their efficiency. It is evident from the characteristics of these wastes, generated from different processes, that they have good potentials for recycling and utilization in developing various value-added building components.

- **Organic solid wastes generation, recycling and utilization**

Solid waste generation from organic sources includes municipal and urban wastes, animal wastes, farming wastes, horticulture wastes, domestic refuses and other agro industrial wastes. A number of wide ranging agro industries have come up in India due to availability of agricultural resources, manpower and technological innovations. The main objective of waste management system is to maximise economic benefits and at the same time protection of the environment. The urban waste mainly consists of organic matter (46%), paper (6%), glass (0.7%), rags (3.2%), plastic (1%) and the rest is moisture [8]. Animal wastes are primarily composed of organics and moisture. Decomposition of both the animal and urban organic wastes can be done in an aerobic or anaerobic digestion. Since, huge quantity of both these organic wastes are produced annually in India, there is great potential for production of CH4 and also which will help to reduce the green house gases thereby contribute to reduction of global warming. India is one of the richest countries in agricultural resources. Agricultural wastes are the by- products of various agricultural activities such as crop production, crop harvest, saw milling, agro-industrial processing and others. In India sugar industry alone produces about 90 MT of baggase per year and being used in manufacturing of insulation boards, wall panels, printing paper and corrugating medium. [2,20]. There is a growing concern for agricultural wastes, which are mostly being burnt thereby contributing considerably to global warming. Use of organic wastes such as peanut husk, mahau and linseed residues, coconut coir dust, rubber seedpod, spent cashew nut shell etc., were explored and used for different applications.

- **Inorganic solid wastes generation, recycling and utilisation**

Inorganic solid wastes are of both non-hazardous and hazardous in nature. Inorganic non-hazardous solid wastes are primarily from mining sector and these wastes are the primary process rejects which constitute over- burden wastes. However, the inorganic hazardous wastes are mainly from the secondary process of non-ferrous metal extraction like lead, zinc, and copper. The details of both non-hazardous and hazardous inorganic wastes generation, recycling potentials and their environmental concerns are reported and discussed in the following section.

- **Solid waste generation from mining operations and their utilisation**

In India, more than 200 MT of non-hazardous inorganic solid wastes are being generated every year [15,21], out of which 80 MT are mine tailings/ores of iron, copper and zinc mines etc., [6,16]. India has considerable economically useful minerals and they constitute one-quarter of the world’s known mineral resources. In India, Rajasthan, Chhattisgarh, Bihar, Madhya Pradesh, Orissa, Andhra Pradesh are rich in minerals, especially non-ferrous and ferrous metals/minerals. India has considerable mining deposits of iron ore, bauxite ore, tin ore, dolomite, chromite, manganese, limestone, diamonds, gold, lignite, bituminous and sub-bituminous coal etc. After the ore is extracted from the mine, the first step in beneficiation is generally crushing and grinding. The crushed ores are then concentrated to separate the valuable mineral and metal particles from the less valuable rock. Beneficiation processes include physical/chemical separation techniques such as gravity concentration, magnetic separation, electrostatic separation, flotation, solvent extraction, electro-winning, leaching, precipitation, and amalgamation. The beneficiation processes generate tailings, which generally leave the mill as slurry consisting of 40–70% liquid and 30–60% solids. Most mine tailings are disposed of in on-site impoundments/ponds.

Mining operations are the primary activity in any industrial process and major sources of pollutants include overburden waste disposal, tailings, dump leaches, mine water seepage and other process wastes disposed near-by the industries. Management of mining wastes is likely to be of some significance in many developing countries where recycling/extraction and processing of minerals have important economic values. In coal washery operations about 50% of the material is separated as colliery shale or hard rock. Most of this spoil is used as filler in road embankments. Some spoils, be considered for use in producing lightweight aggregate. Presently most of these wastes are being recycled and used for manufacture of various building materials. Studies on potential use of different mining tailings in bricks have revealed that this waste alongwith clay can be effectively utilized for making better quality red bricks and use of copper tailing (60%) has resulted in achieving strength of 190 kg/cm2 under firing temperature of 950 1C [22].

- **Construction debris, marble processing waste and their recycling potentials**

In India, about 14.5 MT of solid wastes are generated annually from construction industries, which include wasted sand, gravel, bitumen, bricks, and masonry, concrete. However, some quantity of such waste is being recycled and utilised in building materials and share of recycled materials varies from 25% in old buildings to as high as 75% in new buildings [23,24]. In India, about 6

MT of waste from marble industries are being released from marble cutting, polishing, processing, and grinding. Rajasthan alone accounts for almost 95% of the total marble produced in the country and can be considered as the world largest marble deposits. There are about 4000 marble mines in Rajasthan and about 70% of the processing wastes is being disposed locally [6,15,25]. The marble dust is usually dumped on the riverbeds and this possesses a major environmental concern. In dry season, the marble powder/dust dangles in the air, flies and deposits on vegetation and crop. All these significantly affect the environment and local ecosystems. The marble dust disposed in the riverbed and around the production facilities causes reduction in porosity and permeability of the topsoil and results in water logging. Further, fine particles result in poor fertility of the soil due to increase in alkalinity. Attempts are being made to utilise marble wastes in different applications like road construction, concrete and asphalt aggregates, cement, and other building materials. [25]. Earlier work carried out on polymer composites substituting wood products indicates that about 40% of marble slurry waste can be utilized. Importantly, these artificial wood products have showed better quality compared with teak wood, medium density and particle boards [15]. It is evident from such studies that there is a great potential for recycling of wastes released from different industrial processes. Work carried out by earlier researchers has shown that marble process residues could be used in road construction since they help to reduce permeability and improve settlement and consolidation properties [26,27]. Waste of marble slurry showed great potential in improving quality of jarosite bricks and also to immobilise the hazardous substances leaching from jarosite [6]. Nevertheless, detailed studies are required for effective recycling of marble wastes.

- **Bauxite red mud and waste gypsum generation, recycling and utilisation**

Bauxite red mud is a by-product, released in Bayer process of aluminium extraction from bauxite ore. In this process, bauxite is reacted with caustic soda under heat and pressure. The major solid components of the red mud includes iron minerals goethite, hematite and magnetite [29] and about 60% of them are released as by products/ wastes. In India, current status of total quantity of bauxite consumption is about 8.375 MT and annually releases 5.5 MT of red mud. The quantity of red mud generated during the aluminum extraction process varies significantly on the properties of bauxite, operating conditions of the Bayer process, the process temperature and pressure [17,30,31]. Red mud released from aluminium production, during processing of bauxite, are highly alkaline in nature, which need special attention to avoid contamination of soil, surface and ground water.

Red mud has been used as a substitute for ordinary clay for producing bricks [32]. Below 900 1C red mud can be considered an inert component in mixtures with carbonate rich clays so that the mechanical strength decreases as the red mud concentration increases [32]. Several attempts have been made to recycle red mud not only to avoid environmental pollution, but also to use it in developing polymer composites, wood substitute products, bricks, ceramic glazes such as porcelain, sanitary ware glazes, electroporcelain glazes, tiles and extraction of metals [17,32,33]. For production of glazes up to 37% of red mud was used in achieving good quality of surface finish, strength and abrasion resistance [17]. During high temperature fifiring at 1050 1C, addition of red mud increases the density and extural strength and formation of glassy phase. One of the studies carried out in Spain showed that red mud could be used as adsorbent for wastewater treatment especially for adsorption of Cu^{2+}, Zn^{2+}, Ni^{2+} and Cd^{2+} [34]. Lightweight aggregate is produced from red mud by adding gas-producing materials such as carbonaceous materials, sodium carbonate and talc [34].

In India, about 6 MT of waste gypsum such as phosphogypsum, flurogypsum etc., are being generated annually [18] and plaster developed from these waste gypsum has showed improved engineering properties without any harmful effect. Phosphogypsum and lime sludge were recycled for manufacture of portland cement, masonry cement, sand lime bricks, partition walls, flooring tiles, blocks, gypsum plaster, fibrous gypsum boards, and super-sulphate cement [6,18,20]. Phosphogypsum could also be used as a soil conditioner for calcium and sulphur deficient-soils and it also has fertilizer value due to the presence of ammonium sulphate [3].

- **Non-ferrous metal wastes**

It is estimated that annually about 11 MT of blast furnace slag is being released from steel plants [2,20]. There are three types of slags namely, blast furnace slag, converter slag and electric furnace slag. The first two are produced by pig iron industries and the third is generated by the steel industry. The blast furnace slag, is categorized as group I waste and has been used in the manufacture of blended cement improving its soundness, strength, morphology, and abrasion resistance. However, group II materials, i.e. ferro-alloy industrial waste, have not been used extensively, but have great potential for recycling. All these solid wastes have been used in production of portland blast furnace slag cement, super sulphate cement, as an aggregate in high strength concrete and light weight concrete [6,21]. The group III materials include the tailings of iron, zinc, copper and gold ore beneficiation and have been used as fine aggregate or concrete filler material in the construction industries [3].

- **Solid waste generation, disposal and recycling in copper industries**

Copper melting and refining activities are often associated with generation of a large quantity of wastes as sediments from concentrator plants and scrap, slag, dust, dross and sludge. Worldwide, annually about 50,000 t of hazardous wastes, containing copper as the major compound, are imported and exported [40]. Copper based industrial waste is suitable for copper recovery and is classified on the basis of physical form, copper content, chemical nature, chemical composition and recycling potential. Certain solid wastes from the copper industries are real assets and become important secondary source to the other industries [3,16]. These secondary sources include converter slag, anode slag, effluent treatment plant sludge, anode slime etc. The metallic wastes and certain other wastes like dross, reverts etc. are best recycled by pyrometallurgical process including melting, fire refining and electro-refining. Copper slag is also being used in making tiles, mine backfill materials, granular materials [41].

- **Solid waste minimization and safe management options**

The optimal solution for solid waste management is to minimize the quantity of waste both at generation and disposal stage followed by preventive environmental management action. Recycling of solid wastes is another major productive area in which considerable quantity can be utilised for manufacturing new products. The enforcement of the Resource Conservation and Recovery Acts (RCRA) of US is one of several interacting mechanism for controlling damages from hazardous wastes [14]. As per USEPA the hazardous wastes are defined as the wastes, which possess the characteristics of ignitability, reactivity, corrosivity, and toxicity [13,14]. As per the guidelines of Hazardous and Solid Wastes Amendment (HSWA), several wastes have been prohibited for land disposal. The work done both in India and abroad showed various environmental threats due to disposal of these wastes without minimising/detoxifying the contaminants. Very little work has been reported on the beneficial aspects of hazardous waste especially in ceramic products. Some of the wastes are indeed resources and raw materials and can be used in another industry. However, opportunities for this approach may be limited as a result of mismatches between waste stream composition and process specifications. These approaches can be justified because of savings in raw materials and energy inputs, as well as reductions in the costs of disposal.

CONCLUSIONS

Sampling methodology was comparable among the state sample and sort studies. Inconsistencies in the designation of waste component categories and definitions were the primary differences between study methodologies. The increased use of regionalized waste disposal and waste transport across state boundaries suggests that uniformity in waste categories among state characterization studies is desirable.

While there were some variations in waste composition between the effect on the average CSF and *Lo* was relatively minor, suggesting that variation in waste composition for the studies is not a significant consideration in a decision landfill disposal.

Data show that carbon sequestration in landfills is driven primarily by recyclable organic materials and that carbon sequestration from C&D wastes is significant. However, detailed characterization of the entire C&D waste stream is critically needed before accurate estimates of C&D carbon sequestration can be made. From a management perspective, carbon sequestration, methane recovery for energy, recycling and airspace recovery are interdependent factors. These factors typically act against one another since an increase in carbon sequestration occurs only when recycling of organics and methane yield decrease per unitmass of refuse.

Variability due to recycling, waste-to-energy, and other management practices at the county, municipal, or landfill scale could greatly affect the CSFs and *Lo* values estimated here and caution should be used when extrapolating these values to scales below the level. However, if detailed composition data are available at these scales, a site-specific CSF and *Lo* could be reasonably estimated using the approach described here.

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