Physico-Chemical Analysis of Municipal Solid Waste (MSW) in the Accra Metropolis

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Abstract
Solid waste management programmes are driven by a desire to keep clean environment in the hope of promoting sound environmental quality and public health. Good solid waste management programmes rely upon a complete understanding of both physical and chemical attributes of the waste materials, which in turn govern their behaviour in the natural environment. These physico-chemical parameters, therefore, serve as proxy indicators of which waste management options would be most suitable for adoption in the implementation of an integrated municipal solid waste programme for a given community. The study was, therefore, undertaken to generate scientific information on both the physical and chemical composition of municipal solid waste (MSW) in the Accra Metropolis. The results showed that the MSW in the city was very wet with an average moisture value of 60% by weight of fresh wastes and calorific values ranging between 14.0–19.5 MJ/kg. The results also showed that the C:N ratios in the waste components were in the range of 27:1 - 100:1, and that these physical and chemical properties were very variable amongst the various waste components and among the waste zones. These results indicated that the MSW in the metropolis might be a good candidate for composting programmes and that waste-to-energy conversion by incineration might not be economically viable.

Introduction
Solid waste constitutes a major problem in Ghana and affects both the urban and peri-urban areas on a much similar scale of importance. Whilst in the urban areas the task is largely collection, storage, transport and disposal of municipal solid waste (MSW), in peri-urban areas the task is reduced to removal from homes. In Accra for example, the rate of generation of MSW was estimated at 0.4 kg/capita/day (Fobil, 2001; Carboo *et al.*, 2001). Accra, estimated to be 85% urbanized and covering 200 sq. km is the capital city and the seat of Government of Ghana. It is the hub around which both political and economic life in the country revolve. With an average per capita waste generation per day of 0.4 kg and an estimated city population of 2.7 million people (2000 population census), Accra alone generates approximately 1000 tons/day and an annual generation rate of 3.7 $\times 10^4$ tons/year (Fobil, 2001).

Existing collection capacity could only keep up with about 55% of this figure; which meant an excess of 1.7×10^4 tons/year was left to accumulate in the city core areas for long periods of several months, and became a veritable recipe, not only for mosquito and fly breeding, but also factories from which emanated obnoxious odours, as well as offensive smells (Armah, 2001; EPA-Ghana, 1997; Fobil, 2001; Fobil *et al.*, 2002). Most of the regional capitals in Ghana are facing similar solid waste management problems. The situation exacerbated in the post-independence era which witnessed a general deterioration and breakdown of public sanitation facilities in the major cities, notably the regional capitals, thus throwing urban environments into complete eyesore (Fobil, 2002).

For efficient and sustainable implementation of MSW management programmes, waste management authorities need to know the physical and chemical composition/properties of the kind of materials they would be handling and disposing off. The degree of biodegradability of urban solid waste in the environment depends largely on the types and nature of macromolecules and bond types present in the wastes. It is also important to differentiate between organic materials of biological origin and synthetic organic materials. The aim of this study was to generate scientific information on both physical and chemical composition of MSW in the Accra Metropolis.

Materials and methods

The Greater Accra Metropolitan Area (GAMA) is defined aggregately to include the Accra Metropolitan Area (which in limited terms describes Accra District), Tema and Ga districts. These three districts have become physically and functionally one single urbanized area. The GAMA had a combined population of 450,000 in 1960, which almost doubled by 1970, and stood at 1,300,000 as of 1984 census. The estimated population for the metropolitan area was put at 1.7 million in 1990. The average annual intercensal growth rates (6% between 1960 and 1970 and 3.5% from 1970-84) were both well above the national growth rate. The much higher growth rate between 1960 and 1970 coincides with the economic boom period for the metropolitan area consequent to the creation of the industrial township of Tema and the general rapid expansion of administrative, commercial, business and industrial activities in the Accra township itself (Benneh *et al.*, 1993). Today, the 2000 population census pegs current population figure of GAMA at 2, 500, 000 to the nearest hundred thousand.

The Accra metropolis was first classified based on previous classification of socio-environmental zones (Songsore & Goldstein, 1995) into three distinct waste zones; namely high-income low-density population waste zone (HILDWZ), middle-income medium-density population waste zone (MIMDWZ), and low-income high-density population waste zone (LIHDWZ). From each waste zone, a representative area was selected consisting of Airport Residential for high-income low-density population waste zone (HILDWZ), Awudome Estates for middle-income medium-density population waste zone (MIMDWZ), and Adabraka Odawna representing low-income high-density population waste zone (LIHDWZ). Ten households were randomly selected from each of these waste zones, giving 30 households from which waste was sampled.

Sampling and sample preparation

An 85L calibrated plastic waste bin (acquired from Top Industry Ltd, Accra) was provided to each household and into which residents were required to dump their waste; refuse from each household was collected every other day in the morning for a period of 2 months. At the point of collection, refuse collected from each house was weighed using a spring balance. Then the volume was read directly from the garbage bin after the garbage had been compressed with a flat object as far as possible. The volumes obtained were plotted against the corresponding weights to obtain the densities of the waste.

After waste volume and density were measured, the waste was sent to a central point where waste from individual households in a waste zone was put together and thoroughly mixed to get a composite. From this composite, representative sub-samples were taken and dried for subsequent analysis.

Drying of waste

Sub-samples each weighing about 12-14 kg were extracted from the composite samples and put into 15 m^3 airtight metal containers and immediately covered and taken to the laboratory to avoid moisture losses. These were weighed with their respective metal containers in the laboratory, after which the waste was transferred into locally constructed solar dryers (2 m × 2 m) and spread out in thin layers to dry for 6 days. In the solar dryer, loss of moisture was very rapid since there was free passage of air. Also drying proceeded with minimum decomposition. The relative humidity in the solar drier was measured using a hygrometer (wet and dry bulb). The partially dried samples were then transferred into incubators (Lab-Line Instruments, Model # 310-1) set to uniform temperatures of 70 °C. The approximate moisture remaining in the waste samples was around 6-8%, and in which case the decomposition rate was drastically reduced as to be regarded as negligible. After 3 days the samples were transferred into an oven where they were then dried at high temperatures (100-110 °C) for 2-3 days to constant weight. Dried samples were kept in a dessicator and used for subsequent determinations.

Separation of waste

Twelve to fourteen kilogram sub-samples of each of the composite samples were taken and dried to constant weight. Dried samples were spread onto a white 2 m × 2 m polyethylene sheet and separated into the various waste components – organic (food, plant, etc.), plastic, paper, textile, metals, glass and inert materials. In separate sub-samples combustible materials (organic, paper, textile and plastics) were taken out and the remaining quantified as non-combustible. Similarly, compostable (organic, paper, textile and inert materials) and non-compostable materials were obtained. The various waste components were milled to pass 200-mesh using an electrical milling machine.

Derived samples

To find out whether variations in waste composition had any effects on such waste stream factors as total carbon, carbon of biological origin, total nitrogen contents and C:N ratios for different waste stream types as thus occur in the natural environment, the milled components were remixed to obtain "derived samples".

1. *Simulated samples.* These were prepared by remixing the various milled waste components in proportions by weight corresponding to their respective amounts as they occur in reality, i.e. simulation of real world events.
2. *Equal by weight samples.* These were prepared by remixing the various milled waste components in equal proportions by weight.

Procedures

Moisture content of the waste was

determined gravimetrically. Total carbon analysis was accomplished using an automatic carbon sulphur analyser (Eltra GmbH, Germany, Model No. C8500). The equipment was operated at a furnace temperature of 1075 °C and an oxygen pressure of 30 bars. Biologically originated carbon was determined by the Walkley and Black procedure (Walkley & Black, 1934), while biologically originated nitrogen in the MSW was determined by the Kjeldahl method. For the calorific value of MSW, known weights of the milled samples were moulded into pellets and fed into a bomb calorimeter (IKA Calorimeter, Germany) in which they were ignited in excess oxygen at 30 bars using an electrical arc. The rise in temperature due to combustion of the sample was used to calculate the caloric values of MSW.

Results and discussion

Moisture content is one of the most important parameters in determining the burning characteristics of a material. The higher the level of moisture the longer it will take the material to burn. It will also affect the useful energy obtainable from the waste. Table 1 shows the moisture contents of wastes from various zones.

TABLE 1

Moisture content of MSW in the Accra Metropolitan Area

Zone	*Moisture (%)*
A	62.2
B	46.9
C	39.8

The moisture contents for the three zones range from 39.8% to 62.2%. This is high compared to the moisture content of about 26% generally associated with MSW in North America (Kreith, 1994). The values, however, indicate that the waste in the study area is very wet and might not readily be suitable for waste to energy conversion.

Fig. 1 indicates the mean gross energies per unit weight of the solid waste components from the individual districts or zones. This is equivalent to the gross energies obtainable from each zone. The gross energy per unit weight decreased from high-income waste zone (zone A) through the middle-income waste zone (zone B) to the low-income waste zone (zone C). This probably means that the solid waste from high-income areas is richer in compounds containing high-energy bonds than those of middle and low-income zones. This trend may be due to the fact that in high-income areas residents are more likely to dispose of refuse that contain materials with high amounts of energy-rich bonds than those in middle-income areas and, similarly, residents in middle-income areas tend to dispose of material that contain higher amounts of energy-rich bonds than those in low-income areas. This is in conformity with our initial assumption that residents in high-income areas are less sparing in their consumption of goods and services because of their affluence. And so they tend to discard energy-rich materials.

Fig. 2 shows how variation in composition of waste stream affected the energy content of mixed waste. Since municipal solid waste shows a significant variation in composition and each single variant combination of waste components has a unique or given gross energy content, it was important to investigate the relationship between the amount of energy in a mixture of waste and the percentage in which each waste

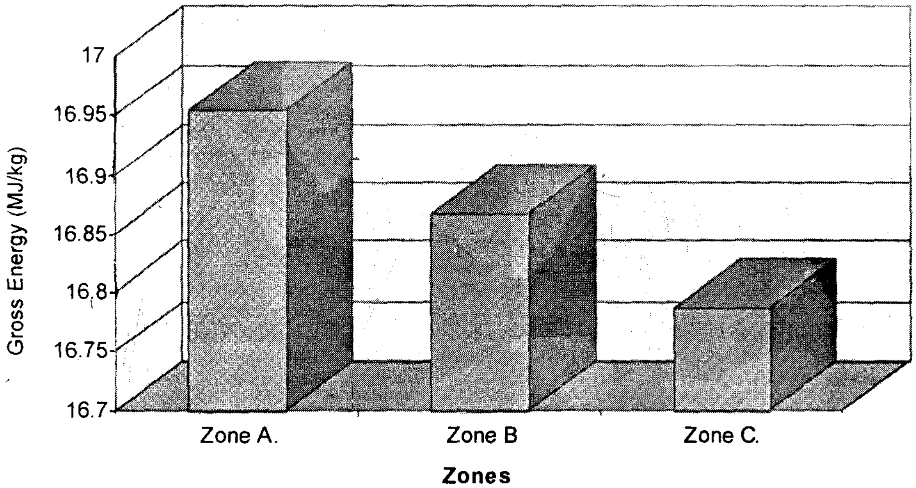

Fig. 1. Comparison of mean gross energy per unit weight of solid waste in three waste zones

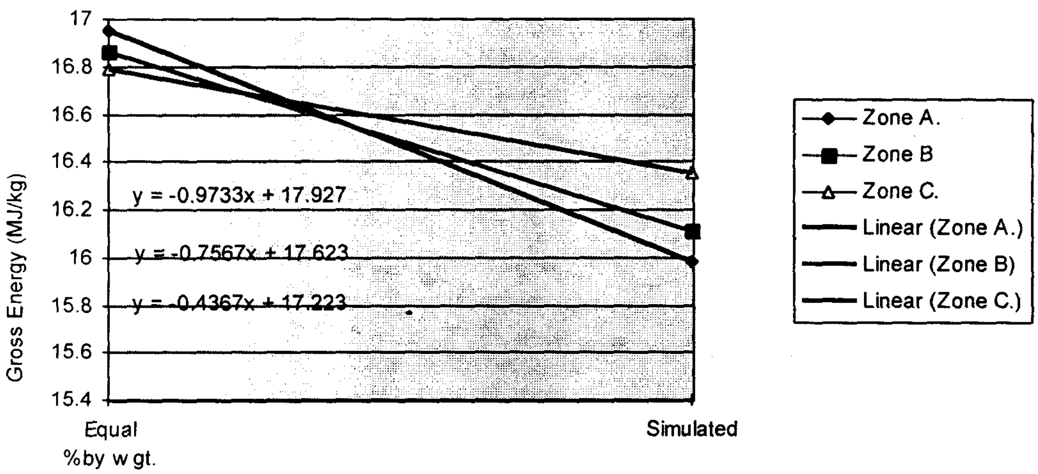

Fig. 2. Relationship between gross energy and component combinations in mixed wastes

component occurs. Fig. 2 shows a negative relationship with decreasing gross energy values for a sample with equal proportions by weight of each component to a point where each component existed in isolation. This means that mixing the solid waste components tends to increase the amount of gross energy per unit of composite waste sample. The negative slope is steepest for solid waste from zone A, followed by that from zone B, with that for zone C the least steep.

It is not very clear what factors are responsible for this trend, but it is suspected that the different waste components combine or mix in several different ways in a given waste stream type and even more so in different waste stream types. The different combinations yield different gross energy values depending on what types of chemical bonds are present in the resultant mixed waste. Therefore, the resulting gross energy per unit weight of mixed waste is different for different combinations of mixed waste. This means that in some cases the resultant gross energy of mixed waste may be greater than those of the individual combining constituent waste.

Paper is predominantly made of cellulose that has high gross energy per unit weight and is, therefore, likely to have its gross energy level decreased when combined with amorphous waste components such as food wastes. The resultant gross energy per unit weight of mixed waste is based on the probability of the kind of the combining chemical bonds having considerably high energy content or having relatively low energy content and it is, therefore, not likely to have two wastes with the same energy content. This is typically based on chance and since solid wastes are crack heterogeneous entities, the probability that the resultant mixed waste would have identical gross energy value is sharply narrow.

Fig. 3 shows a composite relationship between the % total carbon, the % biologically available carbon and gross energy of municipal waste. The amount of energy in a given waste sample has no well-defined relationship with the amount of total carbon in the waste. The amount of energy per unit mass of solid waste depends on the amount of energy-rich bonds such as double and triple bonds per unit weight of waste and not on the amount of total carbon present in the sample. Formation of double and triple bonds would result in higher calorific values while the breaking of such bonds would result in lower calorific values.

One other indicator which may serve a useful purpose in determining whether biologically modified organisms can be used to improve compostability of solid waste is the ratio of total carbon (C_T) to biologically available carbon (C_{BA}), (C_T:C_{BA}). The higher the ratio, the greater the possibility that biotechnology would offer a new opportunity for enhancing composting. This is because high ratios may mean that there is a lot more total carbon than the biologically originated

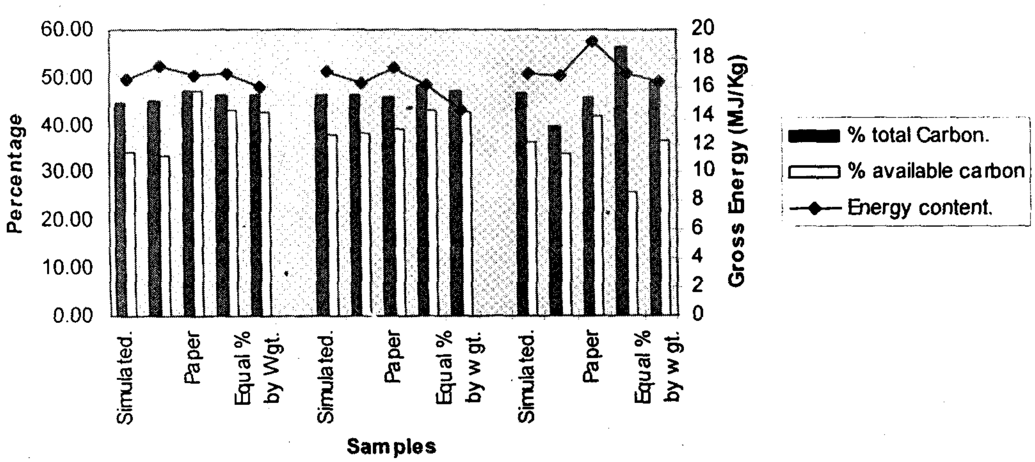

Fig. 3. A composite relationship among % total carbon, % biologically available carbon and gross energies per unit weight of solid waste in three zones

carbon, which could still be degraded by genetically modified micro-organisms. In Fig. 3, total carbon far outstrips available carbon, and so biotechnology may be a potentially useful tool in solid waste management.

In biological/biochemical decomposition process of waste, microbial activities proceed using MSW as a substrate (Kreith, 1994; Diaz *et al.*, 1996; WHO/EURO, 1991-93; Mitchell, 1992). Carbon is oxidized (respired) to produce energy and metabolised to synthesize cellular constituents. Nitrogen is an important constituent of protoplasm, proteins and amino acids and, therefore, an organism can neither grow nor multiply in the absence of nitrogen in a form that is accessible to it. Although microbes continue to be active without nitrogen source, the activity rapidly dwindles as cells age and die. The ratio of available carbon to available nitrogen (C:N) is, thus, one of the most important nutritional factors and the optimum value required for a desirable rate of progress of biodegradation is about 20-25 parts of carbon to 1 part of nitrogen (Kreith, 1994; WHO/EURO, 1991/93; Diaz *et al.*, 1996).

Fig. 4 relates the values of total carbon to those of biologically originated carbon and the C/N ratio. No clear relationship seems to exist among the three parameters, as there is no uniformity in the pattern of variation among the parameters. But the C:N ratio ranged from 27:1 to 100:1

Fig. 5 shows a composite situation of two parameters, namely C/N values and the percent available carbon of the waste components from the three zones. The C:N ratio and percent available carbon for simulated samples are far less than those for the "equal percent by weight" samples. The "equal percent by weight" was made by taking equal weights of the various waste components and mixing them together to get a homogenous mixture. Generally, if different waste components are mixed together as in typically unsorted household solid wastes, the values of C/N ratio and the percentage available carbon fall. The reason may be that when the components are

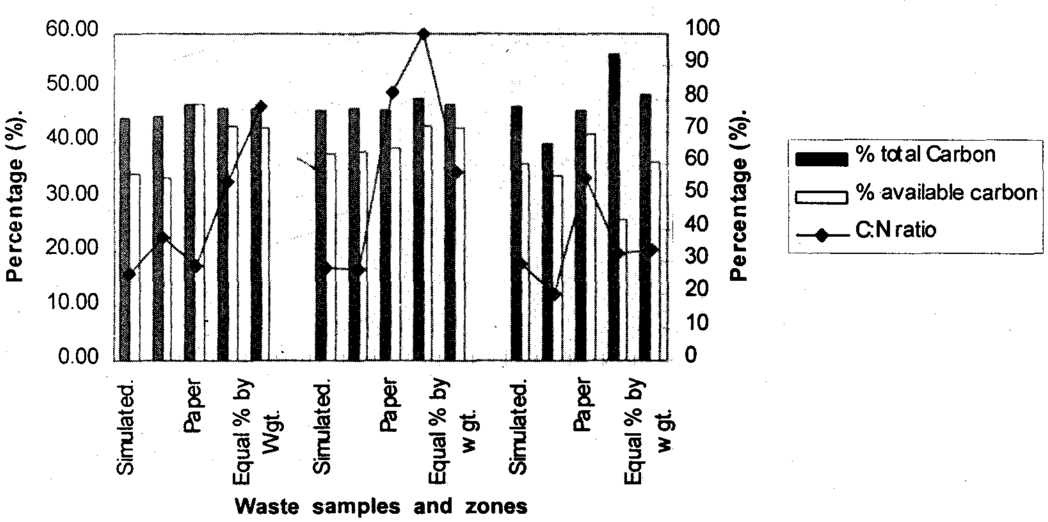

Fig. 4. A composite relationship among % total carbon, % biologically available carbon and C:N ration of solid waste in three waste zones

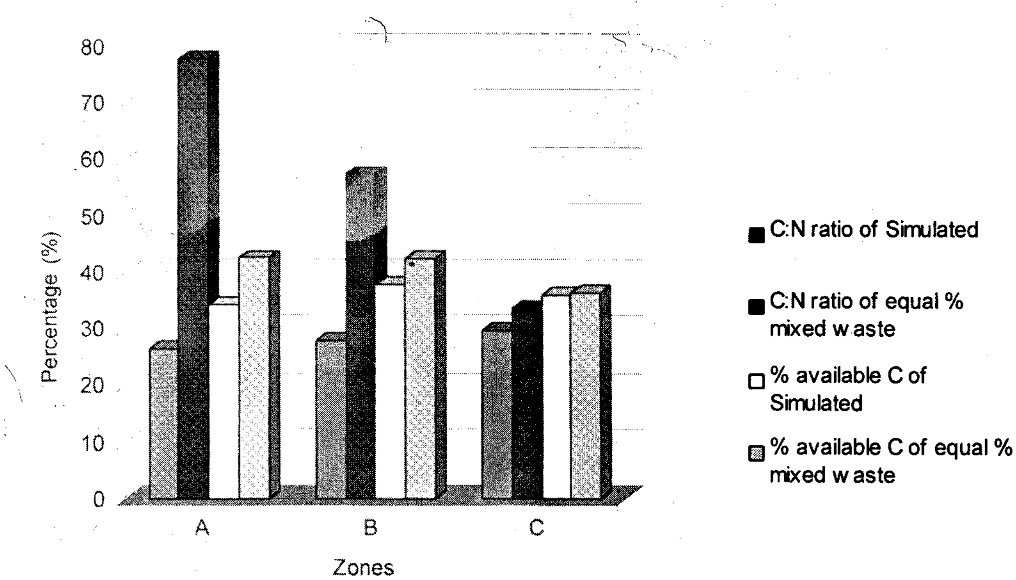

Fig. 5. Effects of mixing solids components on the value of C:N ratio and biologically available carbon

mixed up, there is enhanced mobilisation of nitrogen whose levels rise. But this rise is often compensated for by a corresponding rise in the proportion of available carbon due to enhanced mobilisation of biologically originated carbon from the constituent waste. Therefore, the resultant effects cancel out each other. There may not be a net change in the magnitudes of the values of these parameters.

In the case of the simulated sample which was obtained by mixing waste constituents in percentages or proportions as was observed in the waste stream analysis, mixing causes relatively much higher mobilisation in nitrogen content than available carbon and the net effect is the fall in the C:N ratio. Similarly, considering the high C:N ratio of "equal percent by weight" sample, mixing results in a relatively higher amounts in available carbon content as compared to those of nitrogen. Consequently, the C/N values for these samples rise as seen in the three zones.

Conclusion

The largest portion of MSW in Accra consists of easily degradable components loosely termed "organic material", which were estimated to be 80-90% by weight of the total waste generated. The materials typically found in the waste streams of the metropolis include organic materials, paper and cardboard, plastics and rubbers, textiles, glass, metals and inert materials. The physical and chemical forms of these materials in the metropolis by nature are very heterogeneous and, thus, may not lend themselves to easy handling by waste disposal technologies. This suggests that any attempt to design a relevant and effective waste management programme for the metropolis will mean putting together waste treatment technologies which are interdependent in a manner that allows the by-product of one unit to serve as a raw material/precursor for another unit in a cyclical fashion. Such a multi-unit system function will not only consider the feasible technical and scientific explanations (i.e. a conducive C:N ratio means a compost programme is viable), but it will also take into account both economic and social factors that impinge upon the system. This means that such programmes will normally be preceded by preliminary investigation of the prevailing economic and social conditions. For instant, a proposed compost programme can only follow carefully after a detailed compost market survey such as willingness-to-pay study to establish the market size for the compost that will be produced from household wastes. It is concluded that the physico-chemical characteristics of wastes alone cannot be used to inform decision on the type of waste management programme to be designed for an area, unless it is done so with an understanding of other non-technical conditions in the given area.

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