A Test Device for Separating Municipal Solid Trash

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Abstract: An innovative prototype machine for sorting recyclables from municipal solid trash has been developed as a result of the research. It makes use of a rotating screen drum that is three times longer than it is wide. The initial half of this drum, which is separated into two sections and is one metre in length, is a screen with meshes that are graduated from 8 to 20 mm to separate the fine trash. The second section, which is 3 metres long and has a screen with meshes that are graduated from 20 to 200 mm to separate coarser debris, is made of this. The following rates were obtained from the separation of 30 tonnes of solid trash per day: metals 10.7%, paper 17.7%, plastics 4.0%, glass 2.0%, and textiles 1.3%. Moreover, 58% of the total solid wastes were made up of organic materials that might be composted. Such a prototype device can be generalised and used in other locations with comparable urban environments.

Keywords: municipal solid waste; rotary screen drum; compost unit; landfill unit; Recycling process.

1 Introduction

1975 saw the Consultative Council in the European Community establish the primary goals of any system or set of rules approved for the disposal of solid wastes, for the preservation of the environment and public health (Arab Institute for Town Development, 1986a). Such a system would cover the collection, transportation (or evacuation), treatment, and storage or disposal of solid waste. The research was conducted as part of a campaign to urge people to utilise the raw materials found in treated wastes as much as possible, helping to protect the raw materials' natural resources in the process.

In order to comply with Tabasaran (1978), the German government's Environmental Report from 1976 placed emphasis on the following national guidelines: "The solid wastes that cannot be avoided, for technical and economical reasons, should inevitably be subjected to recycling processes in order to benefit from the raw materials therein."

All of this means that if collecting, moving (or evacuating), treating, or storing solid wastes, the goal should be to recycle them as much as possible in order to recover the raw materials contained therein and profit from them (Peavy et al., 1985; Davis and Cornwell, 1991).

As of now, it is understood that the levels of recycling and reuse of municipal solid wastes are low and not at the necessary levels (Thome-Kozmiensky, 1975). The majority of studies conducted on the separation of solid waste components are focused on specific factors with limited success. Today, the waste's composition and requirements give rise to the potential of restoring a number of valuable and useable elements (US EPA, 1977).

There are many institutions in many cities of the world, particularly in the crowded ones, that get use of the wastes as a source of energy through regular incineration operations; though the efficiency rate for use does not exceed sometimes 40%, and this is due to the percentage of the burnable materials in the solid wastes and to the incineration system (Tabasaran, 1978). In addition, incineration has no clear characteristics related to

Environment. It rather raises in certain cases some environmental problems. At present, treatment system by composting is being applied for getting use of organic materials or components available in the solid wastes with high portions (Peavy et al., 1985). Furthermore, it is believed that more than one third of compost products in Germany are landfilled without getting any use therefrom. This is due to the following reasons:

- The mechanical equipment that will separate the components of the useful wastes (like paper, steel, glass, plastic) from the useless (inert) materials (like stone, wood pieces, textile…) such machines are not of good standard and do not meet separationrequirements optimally; and consequently affect the quality of the produced compost.
- The costs of composting units are relatively high, and sometimes too high (Davis andCornwell, 1991; World Health Organization, 1988), and represent in between the cost of landfill and incineration.
- It is considerably difficult to determine the quality of the compost produced from treating the wastes with natural biological or artificial methods. Such quality is not stable. It is changeable according to the wastes components, the nature of the climateor the conditions of the local site. In addition, the quality sometimes does not satisfy the market.

Sanitary landfill operations of the solid wastes, particularly for economic reasons, constitute today the most practical and most suitable ways to dispose of the solid wastes or to treat them. It is estimated that about 75% of the urban wastes in Germany are disposed by sanitary landfill (Tabasaran, 1978), and about 85% in the USA do same (Davis and Cornwell, 1991).

As a suitable mutual solution that combines between the method of raw solid waste landfill and the techniques of benefiting from its raw materials, this particular proposal has been presented for establishing a landfill unit with rather simple separation techniques. Thus, some of the useful waste components can be sold as they are or separated for recycling, and at the same time the size of the waste for landfill will be reduced.

The system proposed here is distinctive with a big advantage which is the supporting the market with its needs from the extracted raw materials, with the least risks. Also, this system can be applied and managed with low and economical cost. The restored raw materials such as ferrous metals or glass from the separation unit or the site of sanitary landfill, and the extent of marketing these materials will determine the volume and capacity of the separation unit. In case not all the separated materials have been marketed, then the remainder will be easily disposed of through the same landfill unit with no problem.

In the meantime, an increasing inclination has been noticed towards recycling the raw materials from the solid wastes. For instance, Environment Protection Agency (EPA) in the USA has raised a national target stated that "25% of the collected wastes should be recycled up to the year 2010" (Davis and Cornwell, 1991).

This paper presents a developed machine for municipal solid waste separation together with the environmental and economical advantages associated with this process.

2 Kind of the materials that can be separated from municipal wastes

In general, the components can be separated and restored from the municipal wastes to bereused and to be profited from Table 1.

Table 1 Kind of materials and their expected prices

Kind of materials	*Expected price ($/ton)**	
	International	*Local*
Paper, cardboard	15–40	(31)
Metals (ferrous and non-ferrous)	25–80	(38)
Plastics	5–40	(28)
Glass	10–45	(40)
Organic materials	0–50	(350)**

Notes: * The mentioned costs taken from various resources, from discussions withspecialist engineers, and from the acquired experience.
** The rise in price of the organic materials is calculated on the basis of the priceper ton of compost.

The possibilities of getting use of the materials extracted from the waste separation are various and variable, such as:

- to be reused according to their basic nature
- to be used as raw materials for final product manufacture
- to have new products therefrom.

The following examples may be given about the possibilities of benefiting from the recycled materials (Peavy et al., 1985; World Health Organization, 1988; Arab Institute for Town Development, 1986b):

a Paper: To be carried to paper factories to be reprocessed as a new pulp, and exposed to thermal treatment for the production of cardboard for egg-packaging, plant pots as vases, newspapers, books and blended paper.

b Ferrous metals: To be pressed as scrap to be used for enforcement steel in construction. There are several methods for benefiting from the empty cans in thefactories including the restoration of the welding material by thermal treatment.

c Plastic materials: In blended condition, they can be of benefit in extracting oils and acids therefrom to be used in building materials or in making protection barriers for covering big areas of land decoratively, or in the construction of gardens and parks,
… etc.

Density separation processes based on cyclone type density media separation (DMS)was developed as an important potential method for increasing plastics recycling process capacities (Carvalho et al., 2009; Gent et al., 2011). There is a study of the separation of polystyrene (PS) from polyethylene terephthalate (PET) and polyvinyle chloride (PVC) from drop-off points using a fluidised bed separator. The laboratory tests continued with real mixtures of waste plastics (separation test) and the efficiency of the process was evaluated. From a PET – rich mixture, a concentrate ofPS with a 75% grade in PS was produced while the underflow was quite clear from PS (grade less than 0.5% in PS) (Gent et al., 2009).

d Glass: Part of the broken glass can be used in bottle making, other in sandpaper. Itcan be ground to be used in road construction instead of sand and gravel as a sub-layer under covering layer. It can be used as well in making gaskets for sound and heat isolation. For sanitary reasons, if some glass bottles have been found havingtraces of Kerosene, they should be crashed and cleaned with detergents.

e Textile: The woolen clothes may be reused in covers industries. Carpet and gunny may be used in manufacturing insulating materials saturated with bitumen. The textile may be sold blended, without being sorted, to rags traders who sort them. Here, and for sanitary reasons, it is recommended not to use the textile restored frompillows and furniture stuff.

f A two-step process consisting of vacuum pyrolysis and vacuum centrifugal separation was employed to treat waste printed circuit boards (WPCB). The results of vacuum centrifugal separation showed that the separation of solder was complete when the pyrolysis residue was heated at 400 co, and the rotating drum was rotated at 1,200 rpm for 10 min. The pyrolysis oil and gas can be used as fuel or chemical feed stock after treatment. The pyrolysis residue after solder separation contained various metals, glass fibres and other inorganic materials, which could be recycled for further processing. The recovered solder can be reused directly and it can also bea good recourse of lead and tin for refining (Zhou et al., 2010).

g Organic materials: Normally, they are carried to the sanitary landfill unit after being subjected to simple preliminary composting in the form of open accumulations piles,from which the resultant compost may be used as a cover material in establishing a sanitary landfill unit, and to insure longer and more economical exploitation of the landfill units. To give a real idea about the high economical value that can be achieved by using the organic composting wastes as covering material, an example has been given in Table 2 for a case of a city or governorate with about 400,000 inhabitants. This case uses landfill or burial system to dispose of its solid wastes, accrediting the value of about 370 Kgs for person per year (1.0 Kg of domestic solidwaste for person per day). The contractor or the contracting private company pays USD 0.5 for each m^3 of covering earth in landfill where the benefit of its layers amounts to about 1.5 m and the height of the upper covering layer amounts to 1.5 m as well. It is noticeable from Table 2 that there is a saving of about USD 1 million incase of substituting the soil layers by organic wastes subjected previously to preliminary composting.

Table 2 Example of calculating the saving that could be achieved through the use of solid waste compost as a cover material at the landfill proposed for Lattakia City – Syria

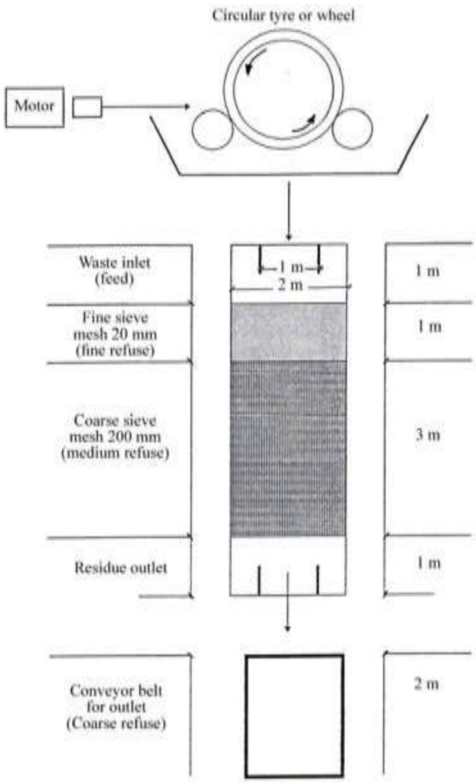
• Population	400,000 equival. person
• Solid waste amount	150,000 ton/year
• Volume or capacity of landfill unit	10.5×10^6 m^3
• Landfill height	15 m
• Landfill area	70×10^4 m^3
• Top cover layer height	1.5 m
• Cover layers height in landfill body	1.5 m
• Cover layers volume	2.1×10^6 m^3
• Chargeable fee per m^3	USD 0.5
• Total fees (savings)	USD 1 million

3 Materials and methods

In developing this Pilot Machine, the Researchers have taken by the experiences published in many references (Homes, 1981; Sullivan et al., 1992; Sundberg et al., 1994; Tchobanoglous et al., 1993; Tchobanoglous, 1977; Wilson, 1981) to realise the research targets. The solid wastes come from a collecting container with a capacity of about 15 m^3, on a sliding conveyor to a rotating screen drum. The total length of the unit is 6 ms. The drum is divided into two parts, the first part is one meter long, consists of a screen having meshes graduated from 8 to 20 mm to separate the fine refuse. The second part is three meter long, consists of a screen having meshes graduated from 20 to 200 mm to separate coarser refuse. The diameter in the two parts is 3 m (Figure 1).

This drum rotates symmetrically round its longitudinal axle by an engine linked to big tyres at its sides. When the engine starts it moves the tyres which in turn move the drum. The drum moves horizontally and it can move upward within 10 degrees. It can rotate from 5 to 10 rotations per minute, liable to change or adjustment as required. The raw refuse falls from the reception and collecting container almost one meter high to the inside of the rotating drum through a hopper opening with a diameter of about 1 metre, extending from the drum centre about 0.5 m long inside the drum in order to prevent the accumulation of the refuse lots when entering the drum. Parallel to the drum's axle there are big plates each 30 × 10 cm at the acute angle and distributed inside the drum for the purpose of stirring and mixing the refuse. These plates are arranged in a spiral form to help in pushing the refuse inside the drum. At their edges, there are sharp pins to tear the plastic bags and the like. The fine screen separates the fine inert materials such as earth and glass and metals. The coarse screen consists of plain steel pipes in the form of rings. The big pieces particularly the textile and which do not pass with the screened materials are sucked to the rings surface in the second half of the coarse screen. Most of the medium screened refuse are separated in the first half of the coarse screen. Both fine and coarse screens are covered with protective plates in the form of funnel extending along the bottom of the rotating drum up to the conveyor or withdrawal tape for the discharged refuse. The role of the funnel is to collect the discharged refuse during screening operation at the sides of the drum and to carry it to the external duct that collects the refuse.

Figure 1 Plan of test separation of solid waste



Since there is no necessity for protective plates around the whole drum, the screening drum can be easily dismantled when needed for maintenance or repair, without any fixatives such as bolts, bands or the like.

The big pieces within the refuse coming from furniture or the like that remain on the coarse screen are to be broken through the protective plates.

The groups of separated or screened refuse (20 mm to 200 mm) are stored in big tanks with volume may reach 30 m^3 or even 60 m^3 according to the treated quantities. The big refuse with diameters exceeding 200 mm, after crossing the rotating drum, reach a thin tape that moves under a magnet for the purpose of attracting the steel pieces and separating them. The remaining refuse will be subjected to manual separation of the paper, plastics and glass. The fine refuse to be formed at the beginning of screening operation (up to 20 mm diam.), most of which are mineral materials such as sand, mud or the like, will be suitable for use directly as a covering material in the sanitary landfill units. The medium refuse (up to 200 mm diam.) will be subjected to aero-fermentation or natural preliminary composting where they are left as piles in the open for a period of four to six weeks, after which the compost can be used as a covering material in the sanitary landfill unit. There are good opportunities for marketing locally the separated materials (metal, glass, paper and plastics) to be reused as raw materials according to demand and circumstances.

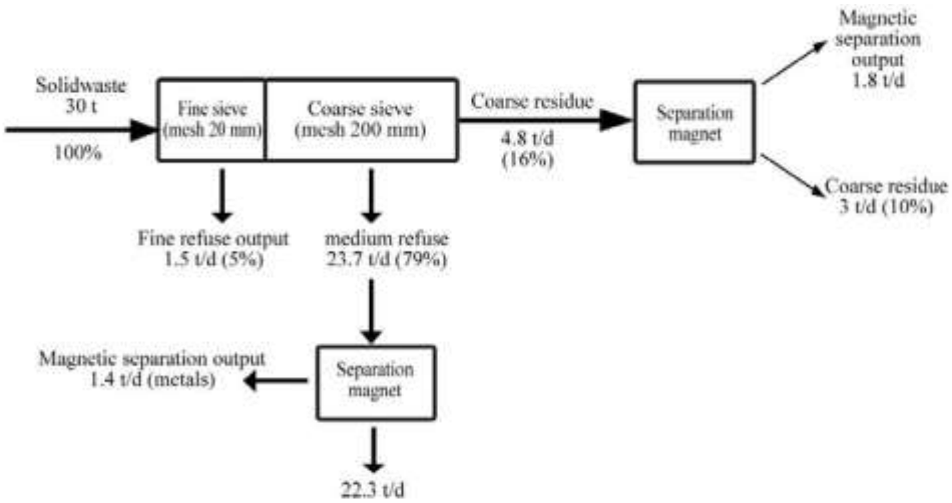
4 Results and discussion

From the domestic wastes collected at the composting unit or landfill plant out of the city, in the first stage 30 tons have been subjected to separation each day, through using a pilot machine like the one described in Figure 1. The purpose of this separation is to assist in obtaining a high quality compost, part of which can be used for enhancing the farming soil and the remainder as a cover in the sanitary landfill unit.

The recycled raw materials (like paper, steel pieces and plastic materials) from the coarse products will be sought to be marketed locally where there are customers interested in them. Thus, they can constitute a source of profit as well.

The results obtained from the above application allow to set the average balance among the separated waste materials (Figure 2).

Figure 2 Average balance of the separated waste material



The balance of distribution is not fixed. It is liable to change according to the composition and properties of the collected domestic solid waste and the screen mesh diameters existing in the rotating drum.

The medium refuse quantity (passing through the coarse screen) which constitutes the major amount of the treated domestic refuse, and after the magnetic separation process, is distributed as shown in Table 3, the thing that indicates that about 78% of weightrepresents a portion liable to composting.

The remnants of the coarse refuse (mesh > 200 mm) are distributed as shown in Table 4 (after removing the magnetic separated materials).

The quantities resultant from the medium refuse (22.3 tons/day) are to be subjected to composting operation where they are to be left in piles for a period of four to six weeks and accordingly they lose about 10% of weight, thus dropping to about 20 tons/day with specific weight of 0.5 tons/m^3, to be used as a cover in the landfill, or as a compost, as per need, circumstances and market demand.

Consequently, out of the basic treated quantity of 30 tons/day, only 1.5 tons/day is extracted as fine refuse which is to be taken directly to the sanitary landfill unit. This quantity may be disposed of, reused, or entered in road construction. From the resulting refuse remnants (medium and coarse), 3.2 tons/day of metals may be recycled. From the resulting coarse refuse, 2.1 tons/day of old and used paper can be recycled, 0.45 ton/day from the plastic materials, 0.38 ton/day from the textile and about 0.1 ton/day from glass.

Table 3 Distribution of the separated medium refuse quantity

Recyclable materiel	*Tons/day*	*% of weight*
Organic compounds	17.3	77.5
Paper	3.2	14.2
Plastics	0.74	3.3
Broken glass	0.56	2.5
Various remnants	0.56	2.5
Total	*22.3*	*100*

Table 4 Distribution of the separated coarse refuse quantity

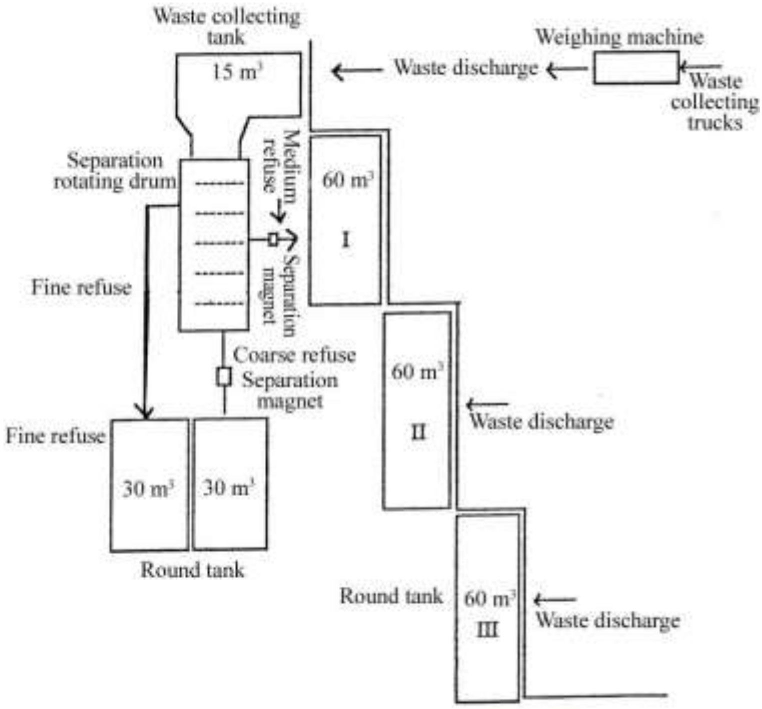
Recyclable materiel	*Tons/day*	*% of weight*
Paper	2.1	70
Plastics	0.45	15
Textile, wood	0.38	12.5
Glass	0.05	1.7
Various remnants	0.02	0.8
Total	*3*	*100*

Transfer to integral treatment unit with macro-scale

After obtaining a group of results from the successful application of the experimental separation model, where separation of the coarse refuse products effected manually and with a team of labourers not exceeding five for the whole separation operation, there should be a transfer from the experimental application stage to a full treatment unit with macro-scale, with the target of recycling the raw materials for the market in the first place, providing the need for high quality compost in the second place, and providing the covering material for the proposed sanitary landfill unit in the third place. In a city of 400,000 population for instance, with considering that the quantity of the expected solid wastes to be collected is 400 tons/day will be treated in 250 working days per year (i.e., running the separation rotating drum for about 250 working days per year), there will be a need to provide another rotating screening drum to join the already talked about drum, where the capacity of each would be within 8–10 tons/hour. The remainders resultants from the coarse refuse that will amount then to about 40 tons/day (400 tons/day × 10/100 = 40) will be separated either mechanically by using specific equipment or manually for economical reasons. This model can be generalised to be applied to industrial solid wastes.

The form of the design proposed for the treatment unit in macro-scale (separation + composting) on site for a city with 400,000 inhabitants can be seen in Figure 3.

Figure 3 Proposed plan for waste separation unit and simple compost unit affiliated to solidwaste landfill unit



According to this design, the trucks that collect the city garbage proceed to the site where they are weighed before discharging their contents in the collection container with a capacity of 15 m^3, and they are weighed as well after discharge. Then, the garbage is moved from the container to the rotating screening drum with a capacity of 8–10 tons/hour, supported by another parallel drum with the same capacity. It passes through one or both of the drums depending on the entered quantity where it is subjected to fine screening (up to 20 mm), medium screening (up to 200 mm) and coarse screening (over 200 mm). The fine refuse is collected in a cylindrical tank or trailer with a capacity of 30 m^3 to be carried to the sanitary landfill unit, supposed to be close to the site to be used as a covering material in the unit. The medium refuse, and after recycling the ferrous metals therefrom by separation magnet, will be subjected to preliminary composting in a trailer or cylindrical tank (I) with a capacity of (60) m^3, then to be carried as well to the sanitary landfill unit to be used as a covering material in the same unit, or can be sold as compost to purchasers. The major part of the medium refuse is composting materials (organic). As for the coarse refuse, and after the magnetic separation, it will be subjected to manual separation in case mechanical equipment are not available in a trailer or cylindrical tank with a capacity of 30 m^3, for recycling the raw materials such as paper,plastics, glass, textile and others.

The existence of more than one cylindrical tank (II–III) allows all the trucks to discharge their loads of the city garbage there, the thing that facilitates carrying it later on by the trailers to the sanitary landfill unit without separation, if desired. Any quantity of the garbage collected in these tanks can be separated according to the rotating drum capacity and to the market's need. The capacity of the tank or trailer can be increased from 30 m^3 to 40 m^3, and the big ones from 60 m^3 to 80 m^3, according to the collected garbage quantity and the available trucks.

The economical feasibility of the developed system

In addition to the economical and environmental advantages of this developed separating machine, applied successfully as regards the economical value of the recycled materials, there are other important economical advantages come from the use of the organic refuse as pure compost to enhance the farming soil and by covering the sanitary landfill units. This provides a saving of about USD 1 million in a city with 400,000 inhabitants planning to apply a modern sanitary landfill system in addition to composting in order to dispose of its solid wastes, considering an amount of about 370 kgs for person/year (1 kg domestic solid waste or the like for person per day). The contractor or the private company pays USD 0.5 per m^3 of covering earth, where the height of its layers is supposed to be 1.5 ms and the height of the upper layer to be 1.5 m. From Table 2, a saving of more than one million dollars could be noticed, due to the substitution of the earth layers for covering the sanitary landfill unit by the organic refuse subjected to preliminary composting. At the same time, thus longer and more economical use could be achieved to the sanitary landfill units (volume of saving is about 40%), in addition to the big economical value of the materials recycled from the wastes providing total profits estimated by USD 215,000 per year Table 5, considering the treatment of 25% of the total domestic wastes collected from a city of 400,000 inhabitants and solid waste quantity estimated annually by 150,000 tons by separation and composting in order to provide covering for the remaining treated refuse (75%) in the sanitary landfill unit, based on the minimal price expected internationally for the recycled materials.

The findings can be summarised by the following:

- The pilot machine is innovative so it cannot be compared with any previous studiesof such a machine.
- Separation of the recyclable waste materials take place out of the cities particularlyin landfill. The thing which is compatible with the circumstances of developing countries.
- The separation output is optimal and accurate among the fine, medium and coarsematerials.
- Simplicity of operation and the few operators thereon.
- Free of maintenance.

Table 5 Example of calculating the profits that could be achieved from the recycled materialsby solid waste separation for Lattakia City (population 400,000 person)

Recycled materials	*Ratio %*	*Expected amount (ton/year)**	*Expected world price (USD/ton)*	*Expected mini profit (USD/year)*
Paper	17.7	6,637.5	15–40	99,562.5
Metals	10.7	4,012.5	25–80	100,312.5
Plastics	4.0	1,500	5–40	7,500
Glass	2.0	750	10–45	7,500
Textiles	1.27	476.25	0–7	0
Total				*215,000*

Note: * The amount estimated based on the rate of 25% out of total solid waste subjectedto separation by the innovated separation model.

5 Conclusions

To meet the sanitary conditions in disposing of the solid wastes, and at the same time to meet the economisation and profitability thereof, a simple and flexible separation unit could be established on the site of the treatment unit by composting or sanitary landfill or by both together, for the purpose of disposing of the municipal solid wastes. Thus, the research has realised the following achievements:

- transferring part of the waste separation products to the markets to be sold andprofited from
- converting the organic elements or compounds therein, through composting by usingopen piles, to be covering materials at the sanitary landfill units, or to benefit from the resultant high quality compost for farming purposes
- affording actual durability in operating the sanitary landfill units.

This developed machine has presented a pioneer technical model for a separation system where a rotating screen drum is the central part of the Unit. In moving to the macro scale for treating the total solid wastes collected from the city, about 25% of the wastes should be treated by separation and composting to provide a covering material for the remaining wastes (amounting to 75%) to be treated in the sanitary landfill unit. From the coarse refuse product, paper, metals, glass and plastics could be recycled. The fine refuse (fine separation) could be used directly as a covering material for the sanitary landfill or for road construction. The medium refuse (coarse separation) could be used as a primary compost after being subjected to composting as a fertiliser for farming soil and as a covering material for sanitary landfill. Some row materials like the metals, paper and plastics could be recycled from the medium refuse, according to the market's demand.

References

Arab Institute for Town Development (1986a) *Federal Germany Experiences*, Vol. II of Questionnaire Study about General Cleanliness and Disposal of Waste in the Arab Cities, p.428, Al Riyadh.

Arab Institute for Town Development (1986b) *Policy of Waste Disposal Management in ECC*, Vol. II of Questionnaire Study about General Cleanliness and Disposal of Waste in the Arab Cities, pp.361–380, Al Riyadh.

Carvalho, M.T., Ferreire, C., Portela, A. and Santos, J.T. (2009) 'Application of fluidization to separate packaging waste plastics', *Waste Management*, Vol. 29, No. 3, pp.1138–1143.

Davis, L.M. and Cornwell, A.D. (1991) *Introduction to Environmental Engineering*, McGraw-Hill, New York, USA.

Gent, M.R., Menendez, M., Torano, J. and Torno, S. (2011) 'Optimization of the recovery of plastics for recycling by density media separation cyclones', *Resources, Conservation and Recycling*, Vol. 55, No. 4, pp.472–482.

Gent, M.R., Menendez, M., Torano, J., Isidro, D. and Torno, S. (2009) 'Cylinder cyclone (LARCODEMS) density media separation of plastic wastes', *Waste Management*, Vol. 29, No. 6, pp.1819–1827.

Homes, J.R. (1981) *Refuse Recycling and Recovery*, Wiley, New York, USA.

Peavy, S.H., Rowe, R.D. and Tchobanoglous, G. (1985) *Environmental Engineering*, McGraw-Hill, New York, USA.

Sullivan, J.W., Hill M.R. and Sullivan, F.J. (1992) 'The place of the Trommel in resource recovery', *Proceedings of the 1992 Waste Processing Conference*, American Society of Mechanical Engineers, New York, USA.

Sundberg, J., Gipperth, P. and Wene, C.O. (1994) 'A system approach to municipal solid waste management: a pilot study of Goeteborg', *Waste Management & Research*, Vol. 12, No. 1, pp.73–91.

Tabasaran, D. (1978) 'Deponie als Standort fur Abfallbehandlungsanlage', *Stuttgarter Berichte zur Abfallwirtschaft*, Band 9, pp.1–13.

Tchobanoglous, G., Theisen, H. and Vigil, S. (1993) *Integrated Solid Waste Management*, McGraw-Hill Edition, New York, USA.

Tchobanoglous, G.H. (1977) *Solid Wastes Engineering Principles and Management Issues*, McGraw-Hill, New York, USA.

Thome-Kozmiensky, J.K. (1975) 'Neu Technology in der Abfallbeseitigung', *Stuttgarter Berichte zum Abfallwirtschaft*, Band 1, pp.1–2.

US EPA (1977) 'Resources recovery and waste reduction', *Fourth Report to Congress*, EPA-ASWMP, Washington, DC, USA.

Wilson, D.C. (1981) *Waste Management Planning, Evaluation Technologies*, Clarendon Press, Oxford, England.

World Health Organization (1988) *Solid Waste Treatment in the Developing Countries*, 286pp, Regional Office of East Mediterranean, Alexandria.

Zhou, Y., Wu, W. and Qiu, K. (2010) 'Recovery of materials from waste printed circuit boards by vacuum pyrolysis and vacuum centrifugal separation', *Waste Management*, Vol. 30, No. 11, pp.2299–2304.