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Research Article

Characterization of End of Life Personal Computers for Optimum Resource Recovery

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Abstract: The End of Life Personal Computers (EOL-PCs) generated by Information and Communication Technology (ICT), end up in waste streams and form a part of E-waste. This waste forms a secondary resource for many metals and non metals recovered through recycling processes. The computers have undergone revolutionary change in size, shape, configuration and its material content, particularly from the last two decades. However, the Handy-Harmann data of 1966 related to quality and quantity of the material used in manufacturing of computer has been very old and not updated since 1966. This may result in inefficient resource recovery and partially treated waste containing hazardous substances may end up in unauthorized landfill or water bodies causing permanent damage to the environment. Therefore, an attempt has been made to characterize the EOL-PCs model P-III which form a major part of E-waste even today. The results obtained help assessment of economic viability of recoverable and recyclable quantities of metals viz., Fe, Cu, Al, Au, Ag, Pd, etc., non metals like plastics and glass from P-III model computers. The paper also discusses comparative study of latest characterization of EOL-PCs with Handy-Harmann data of 1996.

Keywords: E-Waste; EOL PCs Characterization; Resource Recovery; Metals & Non-metals; Handy-Harmann

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1. Introduction

Electronic waste or E-waste is one of the most rapidly growing environmental problems of the world. A survey conducted by UNEP estimates 20-50 million tons of E-waste discarded worldwide with i.e. on an average of 4000 tons per hour, which is an equivalent to1000 elephants. According to EPA more than 4.6 million tons of E-waste ended up in landfill in USA during 2000. Of this, about 25% was Personal computers only [1]. According to a survey conducted by GTZ-MAIT-IMRB [2] during 2009, indicates, that in India produces 8, 6362 tons of EOL-PCs (equivalent to 27 lakh PCs) tons of E-Waste per annum, and was to touch 32, 8750 tons (equivalent to 105 lakh PCs) by 2011. At present, according to E-Waste Monitor 2017 (UNU) report, globally 44.7 million tons of E-waste is generated and expected to reach 52.2 million tons by 2021.Asia-Pacific countries produce highest amount E-waste with India producing about 2 million tons. Further, a sample survey conducted by a team of E-Parisaraa in Bangalore, a middle class family generates about 18 kg per capita per annum of E-waste. Recent data indicates in Karnataka State alone ranking seventh, 5, 26,628 tons of E-waste is generated annually. At national level, Maharashtra State ranks first and the State of Madya Pradesh ranks ninth. Amongst cities, Mumbai tops the list, Bangalore popularly known as silicon city ranks third in generating E-waste.

Problem:

Currently E-waste recycling, especially processing remains concentrated in the informal sector. Due to incomplete knowledge of its content, poor processing technology and very small capacities contribute significantly to the loss of valuable resources in addition to pollution and environmental degradation. Around 50,000 workers are employed at scrap yards in Delhi alone to handle about 40,000- 50,000 tons of E-waste every year of which includes 25% obsolete PCs. Similar situation exists in E-waste scrap yards in other cities of India- Meerut, Firozabad, Chennai, Bangalore and Mumbai.

Bangalore, 'silicon city' of India, the backyard practitioners adopt unscientific recovery methods for recovery of metals and non metals from E-waste namely;

(a) Liberally handling Mercury, Nitric acid, etc. without safety measures

(b) Breathe in hazardous oxides of Nitrogen,

(c) Remnants/residues of the recycling process are released to the nearby ponds or public drains instead of being sent for effluent treatment,

(d) School dropouts involved in chemical recovery processes

(e) Operations are generally carried out in open areas and contaminate soil and air due to release of heavy metals [3]. The methods adopted by this informal sector, not only result in inefficient resource recovery and occupational hazards but also, cause irreversible damage to the ecology and environment. This is probably due to the non availability of the recent scientific data regarding the characterization of the E-waste in general and EOL-PCs in particular. Also all this can be attributed to lack of appropriate processing technology.

As far as authors are aware, the only data available (for P-III) thus far is 1996 from Handy Harman Electronics Materials Co. Ltd [4], who has determined the elemental composition of EOL-PC with 14 inch monitor weighing about 70 lbs. However, the same data is being used by the formal sector for recycling of EOL-PCs even after one and a half decade, though this old data of 1996 is absolutely irrelevant because of revolutionary changes in the computer technology, configuration, replacement of expensive materials by less expensive ones, increased speed and efficiency of the equipments etc. For sustainable development, conserve natural resources and to curtail environmental damage there is an urgent need to characterize the EOL-PCs [5]. With the unbelievable technological advancement characterization helps to evaluate and optimize the resource recovery and to contain the impacts on environment from toxic substances. With this as the main objective E-Parisaraa, Bangalore [India's First E-waste Recycling Facility Approved by the Karnataka State Pollution Control Board (KSPCB) and Central Pollution Control Board (CPCB).India in association with Kuvempu University, Shimoga, Karnataka, has carried out characterization of EOL-PCs, for major recyclable metals including the precious metals along with non metals by following pollution free, eco-friendly manual dismantling and selective segregation and quantification using standard analytical procedure. The data generated by the present study not only helps to identify recyclable resources, but also to assess economic viability for resource recovery by recycling of E-waste in general and EOL-PC in particular.

2. Materials

Pentium III, End of Life (EOL) Personal Computers (Desk Top) of different brands, date of manufacture were chosen for the present study, because, presently these PCs represent majority of the EOL-PCs in E-waste. The standard PC consists of various units and they are; Central Processing Unit (CPU), Cathode Ray Tube (CRT) monitor, Key board, Mouse with cord and dot-matrix printer. The weight of each unit and the number of units per ton is presented in (Table 1)

Table 1 Components number of units per ton and average weight of each unit

Sl. no	Component	No. of Units/ton	Average Wt. of each in kg
1	CPU- P-III Model	96	10.4
2	13 inch monitor	80.6~81	12.4
3	Key Board	1006	0.9941
4	Mouse with cable	7692	0.13
5	Dot-matrix Printer (90 pins 80 columns	132	7.6

3. Methodology

a) Physical Characterization

The manual dismantling of each unit of EOL-PC, such as Central Processing Unit (CPU), Key board, Mouse with cord and Printer (Dot matrix) was carried out. These units were further dismantled manually into subassemblies and to various components of basic materials, which were identified, weighed and presented in (Table 2).The CPU Unit was further disassembled in to subassemblies viz., Cabinet, Hard Disc Drive (HDD), Switch Mode Power Supply (SMPS), Floppy Disc Drive (FDD), Compact Disc Drive (CDD) and Mother Board. During dismantling, inventory of each identified component is maintained. The resources such as Iron, (Mild Steel), Aluminium, Copper and various other plastics (Polymer) glass (Silica) which can be physically reclaimed during dismantling are collected separately. Weights of all the identified assemblies and sub assemblies were recorded using a calibrated digital balance. Repeated experiments were conducted to ensure reproducibility and accuracy for the purpose of characterization. The observations recorded have been reduced to one unit of CPU, monitor, key board, mouse and Dot matrix printer, and further the quantities are extrapolated to %. For dismantling of Cathode Ray Tube (CRT), the method practiced at E-Parisaraa has been unique, (designed and developed indigenously by the first author), consists of safe and partial vacuum maintained chamber provided with filters, blowers, operating gloves and dismantling of CRT was carried out by the operators with the help of Personal Protection Equipments (PPEs) so that they were not exposed to hazardous materials [5]. The hazardous materials collected during dismantling of CRT were handled carefully and accounted for characterization and stored separately for scientific disposal [6].

b) Chemical Characterization:

For chemical characterization, the precious metals, like Gold, Silver Palladium and metals like Nickel, Lead, Tin, from the complex components like circuit boards, connectors and various other sub assemblies, are removed by cutting, shredding and chiseling and sent to UMICORE, Precious Metal Refinery, Belgium (world market leader in recycling of complex materials) for recovery and quantification of precious metals.

c) Sample preparation and chemical analysis of precious metal recovery from Printed Circuit Boards (PCBs)

At Umicore Precious metal Refinery, pre-shredded electronic scrap like mother board of CPU, daughter boards from Hard Disc Drive (HDD), Floppy Disc Drive (FDD), CRT monitor, Switch Mode Power Supply (SMPS) were further shredded to a maximum size of 4 x 4 cm. Through a conveyer belt, the shredded scrap further passes through a cross cut type sampling unit. Here, the particle size of the primary sample was reduced in a four axis slow rotating knife mill (stream sampling).Samples prepared with rotary sampler was further milled and screened to diameter of 0.1 or 0.3 mm and sent for analysis.

Precious metals like Gold and Silver were estimated by the standard "Fire Assay" method. Other metals were estimated by standard analytical procedure using Inductively Coupled Plasma Mass Spectrometry (ICPMS- ULTIMA 2 CHEM).

4. Results

The results obtained during present study on the materials tabulated in Table 1 provide information about the number of units/ components of EOL-PC for one ton.

Table 2 explains weight percentage of metals and nonmetals (polymer and glass) which can be segregated and recovered during manual dismantling.

Component	Av. Wt in kg	Fe	Al	Cu	Polymer	Circuit Boards	Processor	Ceramic	Li Battery	Phosphor	SiO2	Connects	Efficiency
CPU-P-III	10.4	65.422	4.2121	4.627	12.41	10.24	0.19	1.19	0.03066	0	0	0.285	98.094
Key Board	0.9941	24.2	0	5.619	68.75	0.137	0	0	0	0	0	0	99.7
Mouse with cable	0.13	21.53	0	30	40.76	7.69	0	0	0	0	0	0	99.98
Printer	7.6	41.94	0	5.205	46.08	5.571	0	0	0	0	0	0	99.53
Monitor	12.4	**12.729**	**0.144**	**3.162**	**18.08**	**9.654**	**0**	**2.4139**	**0**	**0.01609**	**41.64**	**4.014**	**91.856**
Total wt. in kg	**31.5241 kg=69.35lbs**												

Table 3 Chemical Analysis of PCBs

Content	Au	Ag	Pd	Ni	Pb	Sn	Cu
%	0.0012	0.005264	0.000334	0.03	0.027	0.0689	1.38

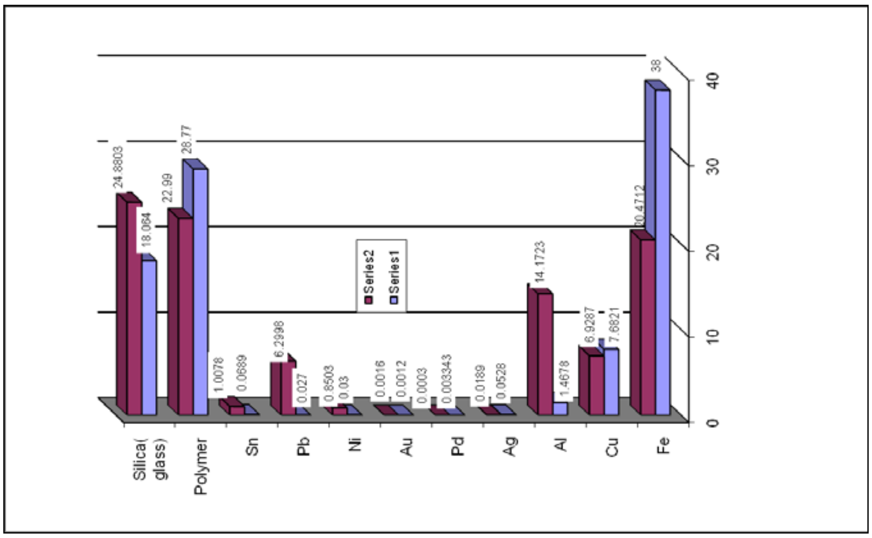

Fig. 1 Comparison of present characterization of EOL-PC with that of Handy Harmann data of 1996

5. Discussion

Comparative study of present characterization of with that of Handy–Harmann data of 1996 reveals the following:

a) CPU, which is one of the main units of desktop PC contains an average 65.42 wt.% Fe, (mainly in the cabinet) 4.2121% Al, 4.627% Cu, 12.41% Polymer, 10.24% Circuit Board,0.19 % Processor, 0.19 % Ceramic,1.19% 0.03066% Li Battery and 0.285% cables and connectors 0.285%, and which can be manually segregated with a recovery efficiency of 98.094%.

b) Key board contains 24.2 % Fe in the form of MS Sheet , Cu 5.619%, Polymer 68.75%, Circuit board 0.137% with recovery efficiency of 99.7%

c) Mouse with cord has 21.53 % Fe in the form of movable ball, 30.0% Cu as cable, 46.08% polymer and 7.69% Circuit board. The recovery efficiency is 97.68%

d) Dot matrix printer is found to have Fe- 41.94%, Cu- 5.205 %, Polymer- 46.82 %, Circuit boards- 5.5711% and the recovery efficiency is 99.53%

e) The CRT monitor consists of 12.729 % Fe mainly as shadow mask, 0.14481%, Al as heat sink in the circuit board, 3.162 % Cu available in the yoke, 18.08 % polymer present mainly monitor cabinet 9.654 % circuit board, 2.4139 % ceramic, 0.01609 % Phosphor coated over the inner surface of the front glass, 41.64 % Silica mainly in the form of front glass, funnel glass and frit glass, 4.014 % cables and connectors. The recovery efficiency of the material is 91.856%

f) Non recyclable, non hazardous ceramic- an electrical insulator is located in SMPS and yoke of CRT is 7.657 % of polymer indicated is from both apparent as well as from complex circuit boards.

The data generated for precious and other metals through chemical analysis presented in Table 3 indicates the availability of precious metals like Gold (0.0012 %), Silver (0.005284 %), and Palladium (0.000334 %) which are present in the mother board, processor and circuit boards of HDD, CDD, connectors, and various RAM cards. Metals like Copper (1.38 %), Tin (0.0689 %), Lead (0.027), Nickel (0.03%) also occurs in the complex circuit boards. These metals are difficult to be retrieved physically.

The overall recycling efficiency of EOL-PC is 98.1171 %

The analytical data obtained in the present study, when compared with that of Handy Harman (1996) data as presented in Table Number 4 indicates the significant increase in Fe and Polymers, and decrease in Al, Pb and Sn content. For these change in composition of desktop PCs the following reasons are ascribed:

- ***18% increase in iron,*** is mainly in the form of Mild steel (MS) used for casing of CPU, SMPS etc. It should be noted that, the earlier PCs were heavy when compared to the lighter/slimmer versions available now. Probably consumer prefers a metal casing rather than a fragile plastic, also increased usage of MS by the designers of electronic equipments, explains the economics involved in the manufacture of PCs.
- ***Marked 12% decrease in Aluminum content:*** is due to advancement in technology, miniaturization and energy efficient designs have given rise to reduced composition of heat sinks where Aluminium is predominantly used.
- ***Increased use of polymers*** is noticed in the latest PCs, to an extent of about 4% mainly due to the increased introduction of engineering plastics in place of metal parts.
- ***Reduction in lead and tin content:*** are mainly used in combination for solder circuit boards and other components. The lead in CRT funnel glass and frit glass etc. are separated in the present analysis, therefore, the comparison with Handy Harman data can not be made. However, it should be noted that, the CRT glass (Funnel glass, frit glass and front glass) is 100% recycled in closed loop at E-Parisaraa. The reduced use of lead and tin also reflects on the technological advancement in the production of printed circuit boards such as surface mount devices and miniaturization

Further, analytical results helped in identifying not easily recyclable hazardous materials like Barium Getter and Phosphor (in CRT), and Lithium battery (in the mother board) which should be stored separately and sent to Treatment Storage and Disposal Facility (TSDF) until recyclable solutions are found for them. The composition of precious metal shows a decreased trend, particularly usage of gold in P-III PCs mainly by reducing gold plating thickness and increase in Silver consumption, is driven by economics. Similar observations are seen with respect to the usage of Palladium.

Since 2004 eco and environmental friendly, scientific recycling process carried out have proved that the results of the characterization of EOL- PCs presented in this paper.

6. Conclusion

Recycling is key feature of E-waste and which can be the best secondary resource for many metals, plastics and glass. Characterization of EOL-PCs clearly indicates the following:

- Economic criteria and advancement of technology, has made the designers to conserve precious natural resources with environment friendly designs
- Reduction in the contents of Au and Platinum Group Elements (PGE) and increased usage of Ag and Fe.
- Helps in identifying recyclable, non recyclable and hazardous content of EOL-PCs
- Becomes an important data for optimum recyclable resource recovery especially for the developing countries including India.

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