Conversion of Electronic Wastes into Valuable Metallic wealth for green Environment

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Abstract - The use of electronic devices has proliferated in the recent decades, and proportionately, the quantity of electronic devices, such as personal computers, mobile phones, entertainment electronics and electrical home appliances that are disposed of, is growing rapidly throughout the world. Disposal of such heterogeneous mix of organic materials, metals, etc., entails a scientific approach and special treatment to prevent exposing the inhabitants to the consequential damage implications arising from leakage and dissipation of the same for effectively mitigating the emerging risk phenomena escalating with the passage of time. The threat perception arising over the last decade from accelerated accumulation of e-waste on account of the emerging consumption patterns across all sections of the society, influenced by the associated advantages ranging from advancement in technology, affordability, comfort in day-to-day utility, etc., with respect to computers, cell phones, and other personal electronic equipment has been found to be phenomenal. The said discarded electric and electronic devices contain various non-ferrous and ferrous metals such as lead ,copper ,gold ,aluminum, silver, palladium, which as such gets disposed off as waste, even though it has immense potential of being converted to wealth from waste, including but not limited to serving the purpose of catering to as vital inputs in new product cycle.

The printed circuit board (PCB) is a major constituent of these obsolete and discarded electronic scraps. The typical composition of PCBs are non-metals (plastics, epoxy resins, glass) more than seventy percent , while others like copper, solder, iron, ferrite, nickel, silver, gold, palladium, including bismuth, antimony, tantalum, etc., comprises of thirty percent. As a matter of fact, the embedded metallic content in PCBs treasure gold content exceeding 400-500 ppm and silver 2500ppm, along with various other precious and rare metals.

The phenomena of e-waste processing comprising dismantling and recycling for extracting valuable metals from PCBs, including CRT re-gunning, etc., adopting crude process methodology such as open-air burning or incineration, use of acid bath, etc., is primarily focused upon profiteering motive with minimal capital investment. Such crude processing methodology is usually adopted in the un-organized sector. Open-air burning of plastics, PVC-coated wires, and PCBs are known to produce carcinogens such as dioxin and furan emissions. The recovery of lead from circuit boards also emits dioxin and other chlorine compounds into the air.

On the other hand, non-recyclable components are either dumped as landfill or burned in the open, releasing toxins into the environment. The role of the unorganized sector involved in the processing of such highly complex waste, exposing the life and environment to toxic pollution, has since long been a subject of debate in the scientific sphere and the society at large.

Safe and scientific disposal management with respect to WEEEs continues to remain an uphill task, in both developing and developed countries, and in the process, the former, more often than not, gets cannibalized by the developed countries on account of their illegal and irresponsible approach of shipping the same to developing countries, as an easy escape route. Advancement in technology for the sustainable recovery of valuable materials from e-waste needs to be an evolving process to resolve this escalating problem with respect to environment and life. However, usage of the technology comprises many processing techniques of thermal processing, bioleaching, hydrometallurgy, Pyrometallurgy, etc., deployment of which is interdependent upon the intended processing and recovery objective, commercial feasibility of the process involved, mandatory and regulatory issues in place, etc.

In view of acute water scarcity and also aimed at pollution mitigation, dry processing methods are emerging as effective and preferred alternative for the enrichment of metallic value by discarding the non-metallic components from electronic waste. The emergence of highly advanced Magnetic Elutriation System based on alternating current, pulsed magnetic field is expected to be a path breaking technology with promising future, for meeting the stringent qualitative requirements especially for eliminating the usage of the highly toxic chemicals used in conventional processing applications for recovery of valuable metals from the e-waste.

Keywords: Electronics waste, Mechanical Recycling, Physical Beneficiation, Metal Recovery, and Waste Management.

I. INTRODUCTION

In the developed and developing countries, the materials are used and discarded at a rapid rate unlike in the past when the sustained use of material was in vogue. Safe and sustainable disposal of electronic waste has been considered to be a major sphere of concern both by the government and public as well, due to its serious effect on human life and environment, arising from its hazardous and highly toxic constituents. Considerable studies have been carried out and waste recycling facilities have been established in western countries. The strategies and solutions amply demonstrated the many uses to which the so called waste can be put to for technical, economical and environmental benefits. Recycling of Electronics waste containing metals, glass, plastic, paper, wood and various other harmful materials are still in their nascent stages. It is without doubt, an opportunity for the mineral scientists to focus their attention towards this important and critical area of the economy. The success of such efforts would not only minimize any loss of values in the so called wastes but also would supplement/augment the resource base of high quality raw materials for a sustainable growth.

As a consequence, development of a viable mechanical process for the consumer electronic scraps is of interest in upgrading the metal content which can yield high material recovery. Recycling of Electronics waste is an important subject not only from the point of waste treatment to minimize environmental pollution and associated health hazards, but also from the recovery aspects of valuable materials. Typically Electronics waste comprises of 90-95% by weight composite metals, plastics, cables, wires and glasses which can easily be dissembled and separated without damaging environment. Remaining 5-10% by weight of WEEE actually consists of PCBs for which there is a need of developing environmentally friendly recycling technique to recover all valuable metals (EEA, 2003). WEEE is the fastest growing waste stream in the industrialized and urbanized world due to the frequent disposal of the used items by the consumers which is associated with the rapid technological changes leading to improved/ advanced features of the products, low initial cost and even planned obsolescence.

According to the estimates of UN Environment program the world generates 20-50 million tons of WEEE each year and the amounts are rising three times faster than that of the municipal waste (Burke, 2007). Also, global generation of Electronics waste is predicted to increase by 16–28% every year (Nnorom et al., 2009). In view of this, total resource recycling with minimum pollution is of prime concern to manage WEEE effectively. WEEE is thus, considered a valuable secondary resource, if treated properly. However, if not treated properly it is a major source of toxins and carcinogens. Recycle and reuse of obsolete WEEE have now been recognized as a big challenge because of the presence of a number of metallic elements such as Cu, Pb, Sn, Ni, Fe, Al, Cd, Be etc. including the precious metals such as Ag, Au, Pd etc. Many of these metals such as Be, Pb, Cd, Sb etc., and the non-metals particularly acrylic and phenolic resins, and epoxides in such wastes are hazardous to the living being. The shear volume of these wastes generated today poses a great problem in terms of handling and allocating the storage/disposal space.

Computer wastes and IT equipments form the major portion of the total WEEE generated. In addition to that there are large volumes of waste electrical and electronic home appliances such as TVs, refrigerators, washing machines, air conditioners etc, that are continuously generated. As mentioned above the PCBs available in all these equipments and appliances are very rich in metal contents and are considered as urban resources. The needs for processing these wastes to remove the non-metallic constituents and extract the metal values effectively felt all over the world with the aim of producing ‘wealth from the waste. Basically after dismantling the steps involved in recycling are refurbishment and reuse, shredding and mechanical separation, recovery of valuable materials, recycling of glass and plastics and treatment of hazardous materials for their safe disposal.

II. OBJECTIVE OF THIS PAPER

The above mentioned objectives can be accomplished by a well defined, well formulated, well-coordinated and well implemented strategies on a long term basis with a short term targets and achievements. The approach should be holistic involving personnel, organization, facilities of different disciplines and expertise developed in the different region of the globe with a common goal. In this context multi-disciplinary approach in the mission mode while integrating the novel processes including that of mechano-chemical grinding, mechanical / physical processing and extractive metallurgy appears to be promising for effective liberation and separation, and enhanced recovery of metals. In the mechano-chemical grinding two kinds of wastes containing non-ferrous metals (as oxide or metal) and iron / aluminum metals are ground with sulphur to mechanically induce solid state reaction and form non-ferrous metal sulfides and iron /aluminum oxides. This could allow the use of current processing technologies to recover metals from various kinds of wastes (Xiuying et al., 2010) and may emerge as an effective alternative to the existing energy intensive pyrometallurgical process operated on a commercial scale using a copper smelter that is associated with-environmental hazards, without recovering Al, Zn, Sn, Pb and precious metals.

The relevance of the proposed methodology lies in the fact that it addresses most issues related to Electronics waste and at the same time envisages finding a solution. Application of the suggested approach will reduce environmental pollution that is attributed to the waste PCBs, particularly lead, cadmium and beryllium, the acrylic and phenolic resins and epoxides. Metal recovery would certainly go a long way in providing a fillip to the struggling metal production, especially copper. The precious metals such as gold and silver may also be recovered. A proper commercial utilization for the non-metallic constituents would eliminate the problem of storage and disposal of such large volume of waste. Novelty lies in the processing approach that involves application of inexpensive and chemical free physical beneficiation unit operations and further processing for individual metal extraction using hydrometallurgical techniques. Currently, recycling of WEEE can be broadly divided into three major stages: Disassembly (dismantling)- selective disassembly, targeting on singling out hazardous or valuable components, is an indispensable process. Upgrading- using mechanical/physical processing and/or metallurgical processing to upgrade desirable materials content, i.e. preparing materials for refining process. Refining- in the last stage, recovered materials return to their life cycle. Separation techniques based on physical properties are extensively used in mineral industry for separation of valuable minerals from associated gangues are based on differences in physical properties of materials such as density, magnetic susceptibility, electrical conductivity, surface property etc. are conveniently utilized to achieve the desired separation.

Similar methods can be applied to process the Electronics waste as these are relatively simple and economical. Particle size, shape and degree of liberation play an important role in separation of different constituents of WEEE by physical methods and development of optimum flow-sheet for its recycling. As there is a considerable difference in physical and physico-chemical properties of plastics and metallic components associated with WEEE, they can be effectively separated using the techniques of physical beneficiation and the metal enriched concentrate so obtained can be subjected to hydrometallurgical processing to recover the metals in desired form. The preceding part would remain far from use unless the efforts are multiplied manifold at the earliest. The development of economically viable technologies is often associated with the constraints in the light of non-availability of uniform waste material stock i.e. supply from multiple sources, large volume and large number of valuable constituents, lack of processing methodology for recovery of all the major constituents and at times the prohibitive cost of the processes developed (Venugopal, 2010, Kumar et. al., 2010, 2014, 2015). The proposed flow-sheet does not warrant any use of sophisticated machineries and relies on the tested equipments with reasonably good efficiency involving eco-friendly physical processing scheme.

III. CLASSIFICATION OF ELECTRONICS WASTE

Typical composition of Electronics waste is comprised of 90-95% by weight contains composite metals, plastics, cables, wires and glasses, which can easily be dissembled and separated without damaging environment. Rest 5-10% by weight of electronic waste actually consist of printed circuit boards and there is a need of environment friendly recycling technique for the recovery of valuable metals from waste PCBs. Electronic waste is the fastest growing waste stream in the industrialized and urbanized societies due to their rapid technology change, low initial cost and even planned obsolescence. Of all the Electronics waste, the computer wastes are the most significant owing to their fast generation rate coupled with the difficult recycling process. The composition of electronic waste varies and largely depends on the type of appliances. An average composition of electronic waste is given below in Table 1 while an average material constituent of consumer electronics which forms a significant component of municipal solid waste stream is presented below in Table 2.

Table 1: Average composition of WEEE (Gramatyka et.al. 2007)

Constituents	Refractory oxides	Plastics	Copper	Iron	Tin	Nickel	Lead	Zinc	Silver	Gold	Palladium
Wt %	30.23	30.23	20.12	8.10	4.0	2.0	2.	1.00	0.2	0.10	0.01

Table 2: Material constituents of consumer electronics in the municipal waste (in % of total) :(Venugopal,2010)

Type of electronics	Steel	Copper	Aluminum	Lead	Other metals	Glass	Wood	Plastic
Video products	22	3	0	7	10	27	20	11
Audio products	20	0	0	0	30	0	3	47
Information products	27	5	4	3	4	8	0	42

Substances found in large quantities include epoxy resins, fiber glass, polychlorinated biphenyls, polyvinyl chloride and thermosetting plastics; lead, tin, copper, silicon, beryllium, carbon, iron and aluminum. Elements found in small amounts include cadmium, mercury and thallium. On an average when one tone of WEEE is shredded and undergoes other separation steps during mechanical recycling, approximately 40 kg of dust like material is generated containing precious metals, which are otherwise toxic if they exist in nature in such a high concentration (Venugopal, 2010, Kumar et.al. 2010, 2024, 2015). It clearly shows that a hidden treasure lies beneath this huge ever-growing mountain of WEEE.

IV. RECYCLING METHODS

Treating the waste PCBs in a way that does not harm the environment is a complex process due to the heterogeneous composition of the obsolete equipment. Technologies used in the recycling of WEEE include thermal processes consisting of Pyrometallurgy and paralysis, hydrometallurgical techniques, biometallurgy and mechanical-physical processing.

Pyrometallurgy is a traditional technology for recovery of ferrous and non-ferrous metals by incineration, smelting in a plasma arc furnace or blast furnace reactions in a gas phase at high temperatures (Cui and Zhang, 2008). Incineration is a common way of getting rid of plastic material and other organics to further concentrate the metals. The crushed scrap can be burned in a furnace or in a molten bath to remove plastics, leaving a molten metallic residue. The main part of WEEE is processed pyrometallurgically in a copper smelter which includes steps such as reduction and smelting of material, blister or raw copper production in the converter, fire refining, electrolytic refining and processing of the anode mud. The anode composition and the quality of the dust and slag fluctuate significantly due to heterogeneity of the input materials. This is also the case with the anode slime which results from electro-refining. Pyrolysis is a process where the material is heated up in an inert gas atmosphere. At certain temperature the organic fractions (plastics, rubber, paper wood etc.) decompose and form volatile substances which can be used in the chemical industry or for generation of energy by combustion of the gases or oils. At the present there exist no process which uses this method in industrial scale (Gramatyka et.al. 2007).

Disadvantages of this method are the waste gases and flue dusts. The halogen content can lead to dioxins and furans problem, and the off-gas system has to be adopted. Noble metals stay for a long time in the metallurgical process and are obtained at the very end of the process. Less noble metal (e.g. aluminum) cannot be regained with this method. Large-scale recovery of metals from waste PCBs by Pyrometallurgy do not appear in developing countries and method discouraged due to its high-energy requirement. Although a primary copper-smelting plant is ideal for PCBs recycling, such facilities are not well established in most part of the world. Thus, it is reasonable to look after an economically viable process to remove the non-recyclable material (i.e., epoxy resin and fiber glass) from the PCBs to increase the value of the recyclable material.

V. HYDROMETALLURGY

Hydrometallurgy is another technology for the recovery of valuable metals from waste PCBs. This technique is based on the dissolution of metal contents into leaching solutions such as acids or alkalis and then the desired metals are recovered by electro-refining. This process normally requires a small grain size to increase the metal yield. Hydrometallurgical methods also lead to high purity of the metals with the possibility to a selective leaching of the metals in various steps using different solvents. This technique has the advantage of being flexible and energy saving (Lee and Kim, 2004, Lee, et al., 1997). The main steps in hydrometallurgy consist of a series of acid or caustic leaches (cyanide leaching, halide leaching, thiourea leaching, and thiosulphate leaching, etc.) of solid materials (Hang et. al., 2009). From the solutions the metals of interest are then isolated and concentrated via processes such as solvent extraction, precipitation, cementation, ion exchange, filtration and distillation. The Cyanide leaching is associated with certain shortcomings such as toxicity and long leaching times. Halide leaching involves chlorine for leaching of precious metals to form their metal complex favorably at low pH and high temperature with enhanced level of chlorine (Pilone and Kelsall, 2006). Ammoniacal thiosuphate leaching is another suitable method for dissolution of metals to form stable thiosulphate complex at high pH and ambient temperature. However the process is yet to come at commercial stage because of its high consumption which makes it uneconomical. Thiourea is non-hazardous, non-toxic lixiviant to dissolve the metals at faster rate either in acidic or alkaline solution (Zheng et.al. 2006, Murthy et. al., 2003, Murthy and Kumar, 2002).

Biometallurgy has been used for recovery of precious metals and copper from ore for many years, but for recycling waste PCBs is still in its infancy in the developing countries. There are two main areas of biometallurgy for metals recovery, namely bioleaching and biosorption. Compared with other methods, biometallurgy offers a number of advantages including low operating costs, less pollution, minimization of the volume of chemical and/or biological sludge to be handled and high efficiency in detoxifying effluents. However, the known bacterium which is suitable for the treatment for waste PCBs is seldom and hard to culture, and the cycle for biometallurgy in recovery of precious metals is too long. Therefore, extensive research work required for seeking and modifying a biomass to have a high uptake capacity and good biosorption characteristics.

Mechanical recycling process for waste PCBs is based on the differences of materials in physical characteristics (including density, magnetic susceptibilities, electric conductivity, etc.). Due to its better environmental property (such as less waste water), high efficiency and easier operability, mechanical-physical recycling process is drawing more attention by the researchers in recent year. In this type of integrated recycling process for waste PCBs, the materials coming out of separators are metallic and nonmetallic. There are about 30 % by weight are metallic materials after separation. The recyclable materials have less volume and higher metal concentration after separation. The enriched metal content can then be sold and transported to an appropriate recycling facility for further treatment. Generally, this type of separation plant consists of a series of physical treatment units devoted to processes such as shredding, crushing, grinding, screening, magnetic separation, air classification, gravity separation, eddy-current separation, electrical-conductivity separation, etc. The range of devices in usage depends strongly on the composition of scraps. Depending on the separation units used in this method, several metal fragments of various size and content are obtained. The enriched metal fractions have to be further processed using hydrometallurgical treatment methods for the selective extraction of metals for their specific end use. Since no chemical additive is associated with physical separation method, there is least pollution problem in this type of operation. The capital and operational costs of a physical separation plant for PCBs recycling are much less than those for a copper-smelting plant.

VI. DISCUSSION

An indicative process flow chart for recovery of metals/ precious metals from the populated PCBs is represented .The shredding, crushing and pulverization is carried out to make homogenous mixture of populated PCBs. The powder mixture can be segregated into various fractions containing copper, iron, aluminum, lead and other mixed metal. The magnetic separation is used for separating iron and aluminum can be separated by eddy current separation. The electrostatic separation is used for separating plastic and metals and various embedded plastic and metal clusters are separated by gravity separation. Nowadays, the pyrometallurgical treatment in the copper smelters is the common process for the recycling of WEEE. But the treatment of WEEE especially material with high contaminations or amount of plastic needs always a combination of different steps i.e. mechanical and hydrometallurgical, whereas the environmental regulations have to be considered.

VII. CONCLUSIONS

Based on the literature available as mentioned in the reference it may be mentioned here that in developing countries like ours the problem is far away from solution and more acute. For example, in India and China, the problem has attained an alarming dimension today because of a rudimentary disposal, classification and collection system of WEEE as well as lack of cost-effective technology for processing them. Moreover, conventional mineral processing equipment and circuits may be used to obtain the concentrate in a large scale with relatively low expenditure. Novelty lies in the processing approach that involves application of inexpensive, chemical free and eco-friendly physical beneficiation unit operations and further processing for individual metal extraction using hydrometallurgical techniques. Fines generation would be avoided in a closed circuit grinding operation and enhanced gravity separation techniques with higher '*g*' forces may be used to make the proposed flow-sheet industrially and economically feasible.

The proposed methods also have the advantages to minimize pollution as the process remove most of the plastics and harmful component in close circuit operation to convert them as useful product. A continuous operation with recycling of streams at plant level will be able to minimize the loss of metal values to a negligible level. For sustainable development there is a need of implementation of an integrated WEEE recycling process involving collection, dismantling, mechanical separation, selective extraction of metals.

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