CHAPTER 1

INTRODUCTION

1.1 E-WASTE: AN INTRODUCTION

E-waste, ordinarily, is that portion of wastes which constitutes almost all types of discarded electrical and electronic equipments (EEE). There is no specific definition acceptable globally, which clearly defines E-waste, as every country has its own definition for the E-waste. Some of them are given below:

- E-waste refers to the electrical and electronic products which have reached the end of their useful life and are ready for recycling". [1]
- Electrically powered appliances that no longer satisfy the current owner for its original purpose. [2]

The most widely accepted definition as per the EU directive and Basel Convention are as:

"Electrical and electronic equipment which is dependent on electric current and electromagnetic field in order to work properly and equipment for the generation, transfer and measurement of such current and fields falling under the category set out in Annex IA to Directive 2002/96/EC (WEEE) and designed for use with a voltage rating not exceeding 1000 Volt for direct current". [3] E-waste includes discarded computers, Televisions (LCD/LED/PLASMA), calculators, refrigerators, mobile phones, air conditioners, batteries, and office electronic equipments.

E-waste is increasing at a rate three times of average municipal waste and to be a significant contributor to future environmental contamination. [4] Rapid changes in technology and falling prices of electrical and electronic equipments, resulted in a fast-growing surplus of electronic waste (E-waste) around the world. Obsolete computers pose the most significant environmental and health hazard among the E-wastes. General reasons of recycling E-waste are environmental concern energy saving and resource efficiency. Recycling of E-waste will reduce the burden mining ores for primary metals. According to WEEE directive the components in WEEE are:

1. IT and telecom equipments
2. Large house hold appliances
3. Small house hold appliances
4. Consumer and lighting
5. Electrical and electronic tools
6. Toys, Leisure and sport equipment
7. Medical device
8. Monitoring and control device

Figure 1: Types of E-waste

(**Source:** www.technavio.com**)**

All discarded electrical and electronic appliances consist printed circuit boards. These waste PCBs contribute a significant role in E-waste stream and composed of different metal. The average percentage availability of metals in printed circuit board shown in table1.

Table 1: Composition of PCB

S. No.	Metals	% Availability
1.	Copper	17-19
2.	Aluminum	07-08
3.	Lead	04.00
4.	Tin	03.25
5.	Iron	02.90
6.	Zinc	00.10
7.	Nickel	00.05

(**Source:** Vijyaram R., et.al, Research journal of engineering science, Vol. 2, 2013, 11-14)

These metals are being hazardous for human health and enviornment if left in open fields. So this waste needs proper recycling to reduce hazards to human health and enviornmrnt. There are two major factors, Cheap processing cost and easy availability of labor, which leads the continuous dumping of E-waste in India from developed countries. Hence a big opportunity exists in recycling business in Indian market, so E-waste recycling is important from the economic point of view.

1.1.1 Why E-waste Recycling is important?

Old and discarded electronic appliances which have reached their end of useful life need proper recycling. The following points also show the needs of recycling of E-waste.

- ***Rich Source of Raw Materials***: E-waste is a rich source of metals like copper and gold. Globally, only 10-15 % of the gold in E-waste is successfully recovered while the 85 % is lost due to informal recycling technique. Ironically, E-waste contains deposits of precious metal estimated to be between 40 and 50 times richer than ores mined from the earth, according to the United Nations University Japan.

- ***Solid Waste Management***: Rapid growth in the electronics industry combined with short product life cycle has led to generation of E-waste. It is expected that electronic waste is 5-10 % of the municipal waste. [4]
- ***Toxic Materials***: E-waste contain toxic substances such as copper, lead, mercury, cobalt, cadmium, chromium chemical flame retardants and so on, proper processing is essential to make sure that these materials are not released into the environment.
- **Transboundary Movement of E-Waste**: The uncontrolled movement of E-waste to countries where cheap labor and primitive approaches to recycling (Developing countries) is used resulted in health hazards to human health due to release of toxins in environment.

E-waste treatment is being carried out in an unregulated environment, hence there is no control on emission of hazardous heavy metals. Open burning of E-waste is a big problem, which is a curse for the civilization. This informal recycling is much harmful due to its dangerous chemical releases into the local atmosphere. These harmful releases have dangerous effects on the health of indigenous populations. Most notably of these chemical releases from the burning of waste are unintentional persistent organic pollutants (POPs), including dioxins and furans. These persistent organic pollutants are generally regarded as harmful to human health as they are associated with DNA interference and increased free radical production in humans. E-waste workers specially engaged in informal recycling, suffers health through skin contact and inhabitation, while the other community suffered through smoke, dust, drinking water and food. It is important that POPs released from the burning of E-waste produces dioxins, furans, and other toxic chemicals into a large scale.

Figure 2: E-waste (PCBs) being incinerated in open environment

(**Source:** www.bonn.unu.edu)

It is estimated that more than 2000 numbers of non formal recycling companies are involved in the recycle business, and approximately 10,000 numbers of unskilled workers are involved in non-formal sector alone in Delhi. [6]

1.1.2 What is being done to do manage E-waste?

First of all to reduce the huge generation of E-waste uses the key of three R's concepts. These three R's are:

- Reduce: Reduce the consumption of electronic devices to use the electronic device as long as possible.
- Reuse: Reuse the second hand devices after repairing
- Recycling: Recycling the E-waste to get rare earth metal

The waste electrical and electronics equipment will adversely affect the environment if they are not designed based on the environmental consideration. Therefore, manufacturers of EEE and component needs to incorporate sustainable design principle in the early design stage, such as design for recycle (DFR) and design for environment (DFE).

The following guidelines or design criteria can help to mitigate the environmental impact of WEEE:

- Hazardous substances that may be environmentally unsafe and not easily recyclable or disposable must be reduced or eliminated.
- Mixed material assemblies must be avoided and/or optimum number of materials must be used.
- Recycled material, wherever available and cost effective, must be used.
- At first instance, one should refrain from generating huge piles of E-wastes in order to avoid its harmful effects on human health and environment. This could be done by resorting to more and more natural alternatives of the existing technologies.
- Improve the collection effort of E-wastes by collection centers for more judicious collection of relevant elements.
- To promote the Extended Producer Responsibility (EPR) among all electronic companies.
- To promote more Recycle Friendly designs (DFR) among all electronic companies.
- Promoting more Eco-Friendly processes for recovering metals from E-wastes.

Incineration and land filling was the two methods adopted by Indian recyclers. Land filling has a big problem because of the contamination of water and native land, but in case of incineration process the most hazardous substances converted into low hazardous substances. The only disadvantage of the incineration process is the air pollution. Pyrometallurgical process is one of the economical process if hazard emissions are controlled adequately.

1.1.3 Scope of the E-waste

E-waste is a fastest growing problem of the world. Throughout the world, united state and Europe are the largest producers of E-waste. Due to the low processing cost, these developed countries dump their 80% of E-waste in Asian countries like India or China for the processing activity. India is also a large producer of E-waste and need recycling of this electronic waste. So from the economic point of view E-waste processing is very important for the economy of the country.

Recycling of E-waste is especially attractive if one could:

- Use the fuel value in the plastics as extra energy resource
- Create substance produces less impact on environment and human health
- Reclaim the metals, especially the precious metals, as extra material resources

1.2 INTERNATIONAL SCENARIO OF E-WASTE

Waste of electrical and electronic equipment (WEEE) is a global concern. E-waste has been escalating with the rise of Information and Telecommunication industry. According to the Live science report 2013, China produced 12.2 million tons of E-waste after that U.K. 11.1 million ton and Europeans countries 10.4 million tons. The weight of E-waste generated in EU countries was 10.4 MT (million tons) in 2013 and the estimated figure for 2020 will be 12.3 MT (million tons), which shows a tremendous growth in E-waste generation. Developed countries like USA, UK, France and Germany generate 10 to 12 MT (Million Ton) of E-waste annually and are among the largest generators of E-waste. But these countries also have standardized E-waste managed processes. The amount of E-waste produced increase continuously, in 2008 Sweden collects 16.7 kg/capita of WEEE, Britain 8.2 kg/capita, Australia 6.5 kg/capita. [7] In the United States alone, 130,000 computers and more than 300,000 cell phones are disposed each day, and an estimated 80% of the generated E-waste is sent to less-developed countries. A large amount of E-waste was imported for recycling by India from developed countries like U.S. , Japan, Korea and other European countries. About 315 Million obsolete computers were dumped by United State of America in between 1997- 2004. [8] The data of imported personal computer (unit) and active mobile phone into the ***Iran*** per year and the amount of mobile phone (unit) worked per year are given in the table 2. [9]

Table 2: Year wise distribution of PCs and Mobile phone in ***Iran***

S. No.	Year	Personnel computer	Mobile phone (Active)
1.	1999	3,390	1,00,504
2.	2000	20,323	4,72,117
3.	2001	42,712	11,24,758
4.	2002	3,03,864	9,62,595
5.	2003	4,73,695	3,99,928
6.	2004	6,66,237	16,25,802
7.	2005	10,08,169	34,34,835
8.	2006	12,36,542	42,50,062
9.	2007	16,86,542	48,02,561
10.	2008	26,59,390	52,36,517
11.	2009	33,90,271	40,03,997
12.	2010	42,33,797	65,72,899
13.	2011	46,93,288	60,00,000

(**Source**: Mahdi Rahmani et al, Resource Conservation and Recycling, 87 (2014), 21-29)

The above data shows the rapid generation of E-waste in Iran. This huge E-waste needs recycling for recovery of valuable metals as well as to protect environment from heavy metal contamination.

A look at the Generation and recycling statistics of E-waste in U.S. and U.K...

- U.S. consumers bought 3.3 million HD televisions just in time for the Super Bowl in 2010.
- From the 2.25 million tones obsolete electronics in 2007, 82% were discarded into landfill. This figure had reached 3.16 million tons up to 2008, but the recycling rate was still 13.6%.
- About 25 million televisions become obsolete every year.
- 68% of American's have unwanted televisions or computers stored in their home. It was estimated 235 million electrical items, including televisions, computers and monitors, are being stored by consumers, because there's nothing else to do with them.
- 26.8 million Televisions (LCD/LED/PLASMA) were sold in the US in 2008; this figure was predicted to rise to 34.5 million in 2009.
- Recycling one million laptops would save enough energy to power more than 3, 500 homes in America for a year.
- 90% of E-waste in the US was exported to China and Nigeria – this is not yet illegal due to the fact that America has yet to ratify the Basel Convention.
- E-waste is the fastest growing waste stream in the UK.
- It was estimated that 1.2 million tones of electronic waste produced each year in the UK.
- In the last 5 years (2007-2012), 12.5 million computers have been thrown into UK landfills.
- 25% of British people take their PC to the dump rather than a recycling facility.
- UK households produce 900,000 tons of electronic waste each year from domestic appliances, such as washing machines, fridges and computers. 80% of all E-waste created, are actually household items.

- It was estimated 2.5 million fridges and 5 million television sets are thrown away each year.
- The British only recycled 17% of their waste – some of their European counterparts recycle up to 60% of theirs.
- E-waste is estimated to be growing at a rate of 80,000 tons a year.

(**Source**: www.e-waste.com.au)

Poland has no infrastructure to recycle the printed circuit board, that is why most of it is being transported to western European countries. In these countries WEEE was being recycled, and valuable metals are recovered. [11] Most developed countries, find it financially profitable to send E-waste for reuse and recycling in developing countries like India, china etc.. It is because the cost of recycling of a single computer in the United State is 20$ while the same could be in India for only 2$, a gross saving of US $ 18 if the computer exported to India. [12]

Switzerland is the first county in the world to develop and implement the well organized and formal E-waste management system for collection, transportation, recycling/treatment and disposal of E-waste.

Figure 3: Printed Circuit Boards Waste

(**Source:** www.climatetechwiki.com**)**

1.3 INDIAN SCENARIO OF E-WASTE

Production and use of electrical and electronic equipment (EEE) have significantly increased during the last three decades due to technological innovations and new applications of electrical & electronics equipments. There is no official data exist on how much E-waste is generated in India or how much is disposed off every year, there are estimations based on independent studies conducted by the NGOs or government agencies. There is an urgent need to decide a strategy for E-waste problem in developing countries like India. The UNEP report (2010) predicted that by 2020 E-waste from old computers in India was jumped by 500% from discarded mobile phones would be about 18 times, from televisions will be 1.5 to 2 times higher from discarded refrigerators will double or triple, than its respective 2007 levels.

All over the world, the quantity of electrical and electronic waste generated each year, especially computer, television and mobiles has assumed alarming proportions. According to Greenpeace Report (2008), India has generated 380,000 tones of E-waste which is growing at the rate of 15% annually and is expected to cross 800,000 ton mark by 2012. According to the estimates made by Manufacturers Association of Information Technology (MAIT) the Indian PCs industries is growing at a 25% compound annual growth rate annually. [8] India is expected to have an 11% share in the global consumer electronic market by 2015 and 600 million mobile subscribers 60 million PCs and 143 millions TVs up to 2012. [13] The year wise contribution of mobile, televisions and PCs in units is shown in the following graphs. The given graph shows the impact of the electronic gadgets on Indian market and show a tremendous growth in Indian electronic market. In last 10 year Indian market shows a strong demand for the electronic gadgets. Information technology (IT) sector played an important role in the growth of Indian electronic industry.

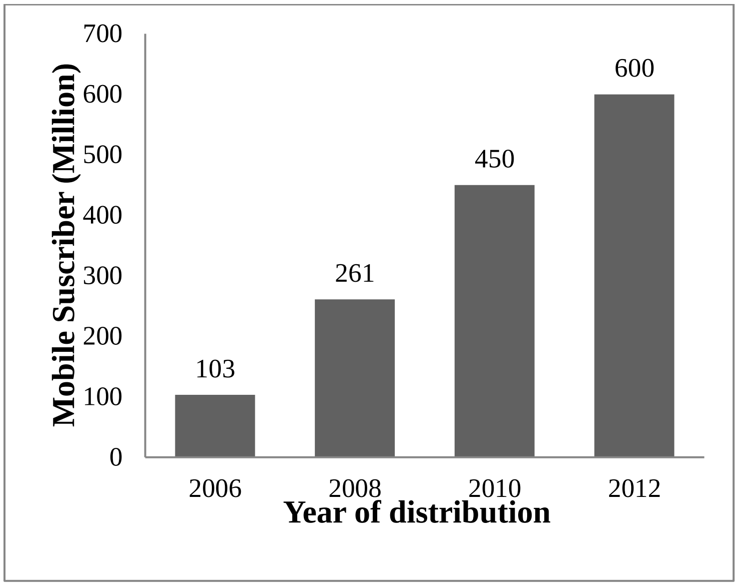


Figure 4: Year wise distribution of mobile subscribers in India

(**Source**: Tata Strategic Analysis, Tata Strategic Management Group)

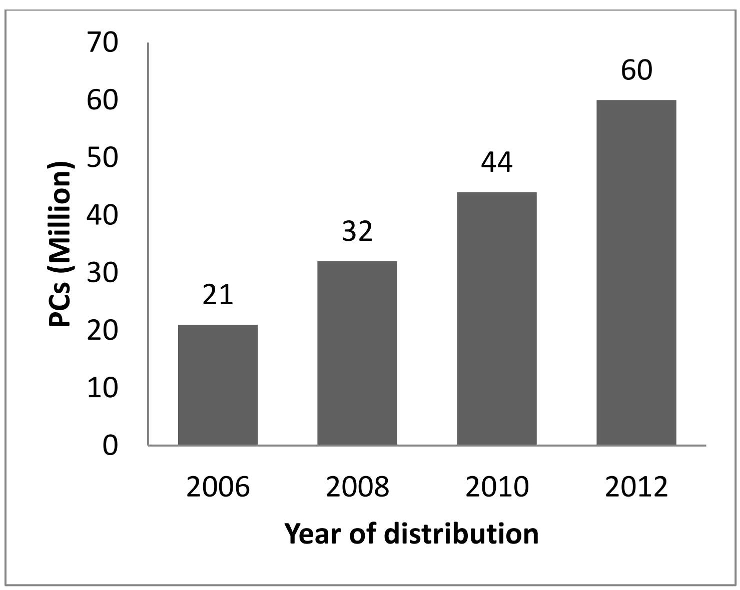


Figure 5: Year wise distribution of PCs in India

(**Source**: Tata strategic Analysis Report, Tata Strategic Management Group)

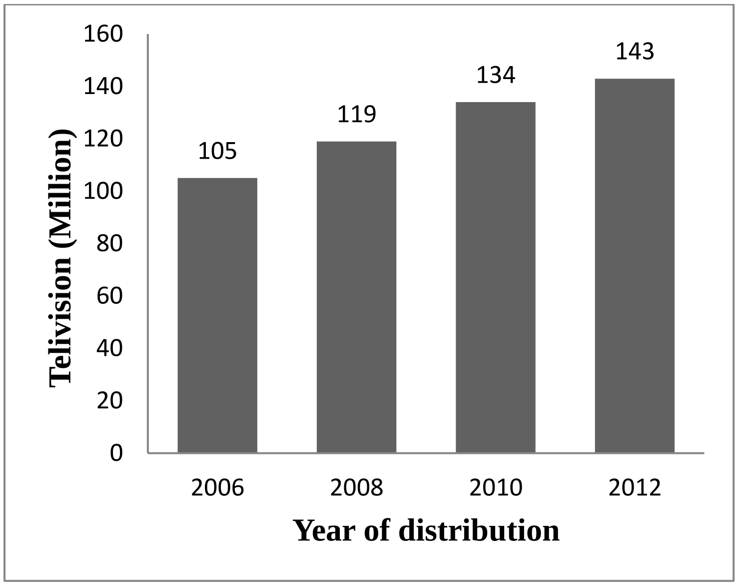


Figure 6: Year wise distribution of Televisions in India

(**Source**: Tata strategic Analysis Report, Tata Strategic Management Group)

The fraction including iron, copper, aluminum, gold and other metals in E-waste is over 60%, plastic accounts for 30% while pollutants comprise 2.7%. [14] The sources of E-waste in India are the government, public and private (Industrial) sectors, which account for almost 70 per cent of total electronic waste generation. The contribution of individual households is relatively small at about 15 per cent, the rest being contributed by manufacturers. The report by ***Toxic Link***, a New Delhi based NGO, estimated that in India and business and individual households make approximately 1.38 million personnel computer obsolete every year. E-waste generation in India is 0.4 per kg per capita. [12] It is expected that India imports 50,000 to 70,000 tons of E-waste from developed countries. [15]

In 2005, the Central Pollution Control Board (CPCB) estimated India's e-waste at 1.47 lakh tones or 0.573 MT per day. [11] In 2006, International Association of Electronics Recyclers (IAER) estimated that 3 billion electronic and electrical appliances would become e-waste by 2010, and according to the Comptroller and Auditor- General's (CAG) report in 2008, four lakh tons of electronic waste was generated in the country annually.[17] Not only developed countries, India is also a big source of E-waste. Ten Indian states contribute to 70 per cent of the total E-waste generated in the country, while 65 cities generate more than 60 per cent of the total E-waste.[12] Among the top ten cities generating E-waste, **Mumbai** ranks first followed by Delhi, Bangaluru, Chennai, Kolkata, Ahmadabad, Hyderabad, Pune, Surat and Nagpur. [12] Table 3 shows the E-waste generated by Indian sates per year (tones).

Table 3: Quantity of WEEE generated in Indian states

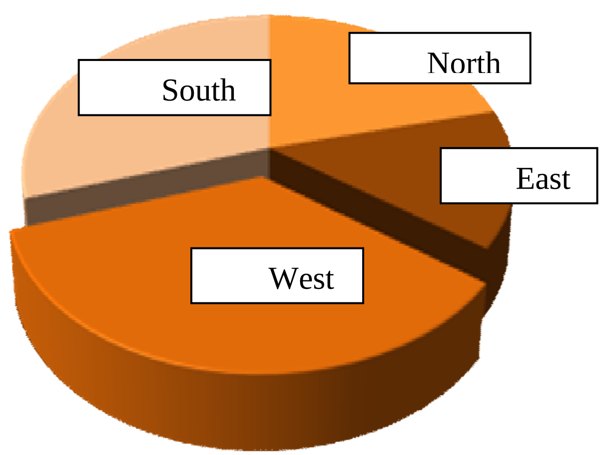
S. No.	State/UT	WEEE(tones)
1.	Andaman and Nicobar Islands	110
2.	Andhra Pradesh	15465
3.	Arunachal Pradesh	176
4.	Assam	2890
5.	Bihar	4070
6.	Chandigarh	480
7.	Chhattisgarh	2860
8.	Dadra and Nagar Haveli	40
9.	Daman and Diu	55
10.	New Delhi	1295
11.	Goa	550

12.	Gujarat	11970
13.	Haryana	6000
14.	Himachal Pradesh	1930
15.	Jammu and Kashmir	2125
16.	Jharkhand	2690
17.	Karnataka	12150
18.	Kerala	8215
19.	Lakshadweep	10
20.	Madhya Pradesh	10380
21.	Maharashtra	26700
22.	Manipur	310
23.	Meghalaya	280
24.	Mizoram	110
25.	Nagaland	192
26.	Orissa	3910
27.	Pondicherry	3920
28.	Punjab	9262

29.	Rajasthan	8068
30.	Sikkim	105
31.	Tripura	500
32.	Utter Pradesh	13822
33.	Uttarakhand	2184
34.	West Bengal	13390
	Total	**191404**

The State of Maharashtra tops the list generating 26,700 tones of E-waste annually. The other States leading in the generation of E-waste are Tamil Nadu, Andhra Pradesh, Uttar Pradesh and West Bengal. Total E-waste generation in India west, south, north and east zone wise are shown in figure 7.

Figure 7: Zone wise distribution of E-waste



(**Sources**: www.ecoreco.com)

The west zone produces a maximum amount of electronic waste as shown in figure after that south north and east zone respectively.

1.4 POLLUTANTS I N E-WASTE

Waste electrical and electronic equipment contain valuable as well as toxic materials. Pollutants or toxic substances in E-waste are typically concentrated in capacitors, batteries, plastics, Monitors, circuit boards and in LCDs (liquid crystal displays). When electronic devices reach to their end of useful life they become discarded and leave as waste in an open environment. This discarded E-waste pollutes the environment and soil fertility badly. In order to avoid environmental contamination and accumulation of hazardous substances in the human body this waste requires a special treatment for their proper disposal. Various type of toxic materials present in the E-waste given in the table 4.

Table 4: Pollutants and their occurrence in E-waste (WEEE)

S. No.	Pollutants	Occurrence
1.	Arsenic	Semiconductors, diodes, microwaves, LEDs (Light-emitting diodes), solar cell
2.	Barium	Electron tubes, filler for plastic and rubber, lubricant additives
3.	Brominated Flame	Circuit board (Plastic), cable proofing agent and PVC cables
4.	Cadmium	Batteries, pigments, solder, alloys, circuit boards, computer batteries, monitors

5.	Cobalt	Insulators
6.	Copper	Conducted in cables, copper ribbons, coils, circuitry, pigments
7.	Lead	Lead rechargeable batteries, lithium batteries
8.	Lithium	Mobile phones, photographic equipments, video equipments
9.	Mercury	Components in copper machines and steam irons, batteries in clock & pocket calculators, LCDs
10.	Nickel	Batteries, relays, semiconductor photocopier, fax machine
11.	Silver	Capacitors, contact switches, batteries, resistors
12.	Zinc	Disposable and rechargeable batteries, luminous substances

1.5 PROBLEMS ASSOCIATED WITH E-WASTE

The main problem associated with E-waste is that it contains toxic and heavy metals such as cadmium, lead, mercury, polychlorinated biphenyls and brominated flame retardants. These toxic substances affect the human health and environment badly. [1] Heavy metals presents in the electronic waste affect the different human organs and produces different deices. These toxic substances are responsible for the different deices produced within the human body which is listed given in table 5.

Table 5: Impact of hazardous substances on health & environment

S. No.	Metal	Danger
1.	Lead	Lead is a neurotoxin that affects the kidneys and the reproductive system. High quantities can be fatal. It affects mental development in children. Mechanical breaking of CRTs (cathode ray tubes) and removing solder from microchips release lead as powder and fumes.
2.	Plastic	Plastic is found in circuit boards, cabinets and cables, they contain carcinogens. Brominated flame retardants (BFRs) give out carcinogenic brominated dioxins and furans. Dioxins can harm reproductive and immune systems. Burning PVC, a component of plastics, also produces dioxins. BFR can leach into landfills. Even the dust on computer cabinets contains BFR.
3.	Chromium	Chromium is used to protect metal housing and plates in a computer from corrosion. Inhaling hexavalent chromium or chromium 6 can damage liver and kidneys and cause bronchial maladies including asthmatic bronchitis and lung cancer.
4.	Mercury	Mercury affects the central nervous system, kidneys and immune system. It impairs fetus growth and harms infants through mother’s milk. It is released while breaking and burning of circuit boards and witches. Mercury in water bodies can form methylated mercury through microbial activity. Methylated mercury is toxic and can enter the human

		food chain through aquatic.
5.	Beryllium	Beryllium is found in switch boards and printed circuit boards. It is carcinogenic and causes lung diseases.
6.	Cadmium	Cadmium is a carcinogen. Long-term exposure causes *Itai-itai* disease, which causes severe pain in the joints and spine. It affects the kidneys and softens bones. Cadmium is released into the environment as powder while crushing and milling of plastics, CRTs and circuit boards. Cadmium may be released with dust, entering surface water and groundwater.
7.	Acid	Sulphuric and hydrochloric acids are used to separate metals from circuit boards. Fumes contain chlorine and sulphur dioxide, which cause respiratory problems. They are corrosive to the eye and skin.

Electronic waste contains a complex combination of hazardous substances. A small amount of this waste entering the residual waste will introduce a high amount of heavy metals and halogenated substance. Such harmful substances leach into the surrounding soil, water and air during waste treatment or when they are dumped in landfills or left to lie around near it. Sooner or later they would adversely affect human health and ecology. There is no doubt that these substances have been definitely responsible for various debilitating health conditions, including cancer, neurological and respiratory disorders, and birth defects. This impact was found to be worse in developing countries like India, where people engaged in recycling E-waste are mostly in the unorganized sector, living in close proximity to dumps or landfills of untreated E-waste and working without any protection or safeguards.

Some of the Indian companies are already in operation and some are yet to start their operation for processes of electronic waste are:

1. E- Parisara Pvt. Ltd. [Bangalore]
2. SIMS Recycling Solutions [Bangalore, Chennai, Delhi]

3. TESSAM Recyclers [Bangalore]
4. AER Worldwide [Tamilnadu]
5. Attero Recycling [Roorkee]
6. Waste Re-Energy [Hyderabad]
7. Earth Sense recycling [Telagana]
8. MGA & Associates [Gujarat]
9. Tic Group [Karnataka]
10. Ramky Group [Hyderabad]
11. Navrachna recycling Pvt. Limited [Chhattisgarh]
12. ECS Environment Ltd. [Gujarat]
13. A2Z E-waste management Ltd. [Haryana]
14. Halcyon Electrotech Pvt. Ltd. [Uttar Pradesh]
15. M/s J.S. Pigments Pvt. Ltd [West Bengal]

According to a list of registered recyclers, 138 units are engaged in E-waste recycling business with a total capacity of **349154.6** MTA (Metric Ton Per Annum). [www.cpcb.nic.in]

CHAPTER 2
LITRATURE REVIEW

The first Honorable Prime Minister Pandit Jawaharlal Nehru had said in 1961 that the pace of change in the world was greater due to new avenues opening out with the application of electronics and atomic energy. [11] The Electronics Industry in India took off with an orientation towards space and defence technologies with the establishment of DRDO (1958) and ISRO (1969). It was followed developments in consumer electronics with transistor radios, black & white televisions, calculators and other audio products. It was the Prime Minister Rajiv Gandhi's tenures in which electronics received much more attention. The period 1984 to 1990 called golden period, the electronic industries rises up to peak level.

The electronics market in India jumped from US$ 11.5 billion in 2004 to US$ 32 billion in 2009 making it one of the fastest growing electronics market worldwide with the potential to reach US$150 billion by 2010. [11] India's low manufacturing cost, raw material, skilled labor, availability of engineering skills and opportunity to meet demands in the Indian market have contributed significantly to facilitate the growth of the electronics industry.

The Indian IT industry has been one of the major drivers to change the economy in the last two decades. In that digital revolution period IT industries generate bulk of e-waste in the country. In this digital revolution period India has also been vastly influenced by the culture of consumerism. The application of electronics related technology has been spread in all sectors. The Environmental Protection Agency (EPA) estimated that in 2005 alone, roughly 1.5 to 1.8 million tons of E-Waste was disposed in landfills. [18] This E-waste needs proper disposal otherwise it is would be a curse to the society.

A large number of literature and theories are available for recovery of metal from the printed circuit board. Different theories are available to recover the metals from the printed circuit board (PCBs).

R. Vetri Murugan [19] used the milling process to recover metal (Copper) from the E-waste (PCBc). In this mechanical method first the waste printed circuit boards cut into a size of 2*2 cm^2 using a hand cutter. These printed circuit board crushed in an impact hammer mill by the impact of the swinging hammers into a size of 125μm. The product obtained from the hammer mill sent to an elutriation column (size 7 mm diameter) for separation here the metal and nonmetal separated by a vertical flow of air. The metal recovery efficiency of the cursed material depends upon the following parameters like feed rate, velocity of air and particle size. As the particle size decreased the metal recovery efficiency increased. The maximum efficiency obtained at a particle size of 1000 μm at an air flow rate of 130 m^3/h with a batch feed of 393.6 gm.

Qingjie Guo [20] studied that printed circuit boards recycled on a fluidized bed reactor. This reactor made of steel with a diameter of 27 mm and a length of 1600 mm and heated with an electric furnace. The fluidized bed (particle size 200 mm – 300 mm) heated up to 600°C at a rate of 10°C/min under nitrogen flow rate of 19-48 m/s. The products obtained copper, benzene, char and fiberglass.

E. Kantarelis [21] did the thermal cracking of small household appliances (computer and refrigerator) under preheated nitrogen. These products after segregation crushed into a size of 0.42 mm and dried using a stream of dried air of 25°C for 30 days, after that a mixture of methane and nitrogen flow to make a 10 KW gas burner for running the experiment. When enough temperature (1100K) achieved supply of methane stopped and nitrogen introduced in the reactor. The reactor continuously cooled by nitrogen gas and after completion of process metal and ash content collected.

Yanhua Zhang [22] worked on the leaching process to recover the precious metals from the waste printed circuit board. In the process first the printed circuit board crushed into small pieces. After that the solution (Nitric acid or Sulfuric acid) of concentration 2.73 mol/liter used for reaction with the crushed material. The metal copper precipitated and rest of all material dissolved within the solution. Cyanide leaching, Thiosalphate leaching, Halide leaching and Thiourea leaching used to recover the Gold from the waste printed circuit board.

Mingfei Xing [23] focused on the separation of Brominated Flame Retardants present in the waste printed circuit board. The most common material of the waste printed circuit board is FR-4 which using glass fiber as reinforcement material and Brominated Epoxy Resin as a binder. In this study supercritical water used to recover the organic polymer. First of all the waste is broken into pieces of size 100 mm* 15 mm. After that the pieces dried at 105°C for 24 hours. Now apply the super critical (High pressure and temperature) water approach to decompose the Brominates Epoxy Resin. The optimum temperature and holding time were 400°C and 30-120 minute.

Jie Guan [24] stated that printed circuit board is the important part of the waste electrical and electronics equipment. The main part of printed circuit board is thermoplastic and metals. Thermoplastic contains flame retardants like bromide and antimony. Bromide is the source of acid gas (HBr) which corroded the equipment under thermal treatment. Firstly the PCBs are crushed into small pieces of size 5.0 cm* 5.0 cm. Pyrolysis of PCBs carried out in a tubular reactor of diameter 0.06 meter and length 1.2 meter. The carrier gas nitrogen flow at the rate of 1.5 L/m. When the final temperature reached, the process holds for 30 minutes and the metal and calcium rich slag separated.

Jissica Hanafi [25] developed the magnetic separation method to separate the metal and organic substances. In this study the collected PCBs disassembled, pulverized and separated by using density and magnetic separation method. In density separation method, once the collected PCBs crushed into a size of 20 mm* 10 mm, after that it pulverized down to a size of 100 micron. The aim of this method to separate the metals from the nonmetals by using an organic solution Tetra bromoethane (TBE). Tetra bromoethane (TBE) chosen for its high density, 2.967 g/ml and mixed with acetone to make complete reactive solution. In this organic solution light substance float on the solution and heavy metal settled down within the solution. The light and heavy fraction extracted from the test tube, filtered and then dried. In magnetic separation method neodymium magnet used to separate metal from the nonmetal. The chemical recycling method conducted by dissolving 10 grams of heavy fraction sample of 149 μm mobile phone PCBs in a mixture of 25 ml H_2O, 25 ml of concentrated H_2SO_4, and 10 ml of concentrated HNO_3. Then the solution heated on a heating plate. After all the gaseous substance evaporate, the heater turned off and the solution kept still for 5 minutes until no more vapor and a bright green solution produced. The process continued to cementation process.

Viraja Bhatt [26] proposed a novel approach which combined the Hydrometallurgical and Biometallurgical process for recovery of precious metals like gold and silver from the waste printed circuit board. In hydrometallurgical process the cyanide solution used to recover gold and silver from the waste printed circuit board. The mechanism of gold and silver dissolution in cyanide solution an electrochemical process. The process involves the reaction between gold, oxygen, cyanide and water. Maximum dissolution of gold and silver occurs at a ph value above 10. In Bioleaching process, the living microorganism (Bacteria, fungi, algae) used to recovered metal. Biosorption process combined electrostatic interaction, ion exchange complexion, formation of ionic bond, precipitation nucleation etc. Biosorption process affected by the ph value of the solution.

Ping Jiang [27] developed a novel method to recover the precious metal from the waste printed circuit board. Author study state that the process based on green chemistry and green engineering methodology. After rinsing the boards to remove dirt and dust so on, all chips and components chemically desoldered. This process takes 20 minutes in an acidic solution at a temperature of 30°C to 40°C. Now solder free boards subjected to gold leaching chemistry at a temperature of 30°C for 5-10 minutes, which selectively remove all the precious metal. After collecting the precious metal, the left residue sends for the next operation (copper collection).

Deepak Pant [28] presented a hybrid technique for the largest metal recovery efficiency. This hybrid technology joined the chemical and mechanical process. Many fungi like Niger and penicillium bilaiae secretes the various organic acids like citric, tartaric and oxalic acids which can act as a chelating agent, hence employed for extraction of metals like Co, Cd, Zn and Pb. This technique comparatively less time-consuming than the bioleaching alone. By using some specific ligands and microbes it possible to achieve metal specific extraction.

Ravindra Rajaro [29] developed a novel approach to recover precious metals from waste printed circuit boards. In this technique a pyrolysis process done at a temperature of 750-1550°C in an organ atmosphere for a time period of 20 minute in a horizontal tubular furnace. Temperature above the 1350°C were required to completely remove the lead and other metals from the printed circuit boards waste. After thermal treatment the metallic part could be easily separated from the non metallic residue.

A. Vijaydhar [30] proposed froth floatation technique to extract the valuable metal and removing the non metallic constituents from the crushed printed circuit board. The printed circuit boards first crushed into a size of 3-5 mm, after drying the waste boards used a ball mill to cut the board’s size up to 1 mm. Now the board’s material crushed in a ball mill which produces a size of 1000*500 μm and 500*35 µm. Now this crushed powder steered in an experimental box filled with experimental solution (mixture of Bromoform and benzene with specific gravity 2.0), where metal and non-metal separated. Metals settled down within the solution and non metals were afloat on the top of the solution. The maximum speed to steer the solution 1200 rpm and flow rate of air 12 liter/hour.

Pia Tanskanen [31] suggested that the environment friendly recycling process and said about the reuse of valuable metals collected from the recycling process. He proposed to set up the robust models and infrastructures for collection and recycling as well as to raise awareness and facility changes in the behavior of the consumer. He also suggests that; legislation restricted the use of hazardous substances in the electrical and electronic equipment. He states that pre treatment (Sorting and Disassembly) of E-waste is very helpful to reduce the hazardous waste. Recycling campaigns are necessary for collection of this hazardous waste and to aware the society.

Cui Quan [32] proposed the thermo gravimetric analysis to investigate the thermal cracking of keyboards, printed circuit boards and telephone wires. The first process carried out transformation of raw material into fine powder. Thermo gravimetric analysis done in a thermo balance into two different environments (Nitrogen and Oxidation atmosphere). Thermo gravimetric analysis carried out in a STA449C thermo balance. In each run 10 mg of sample heated from room temperature to 700°C at a heating rate of 10°C/min. Nitrogen used as carrier gas because of its inertia with a flow of 30 ml/min during pyrolysis. The air used as oxidant during combustion at the same flow rate as in nitrogen environment reaction. The result obtained from the experiment indicates that the thermal stability sequence was in order of keyboard> printed circuit board > telephone wire.

R. Khanna [33] studied an environmentally sustainable solution to e-waste management and reducing associated pollution during recycling. In this theory, waste PCBs heat-treated in the temperature range 1150-1350°C for periods of up to 20 minutes in an Argon atmosphere. Pyrolysis of E-waste occurs in to an alumina crucible of diameter 5 cm and length 1 meter. The size of the PCBs is $1cm^2$; put the crushed pieces into the furnace at a temperature range 250°C-350°C for 10-20 minute to avoid thermal shock. High purity argon is continuously flowing at a rate of 1 L/min. Inert conditions led to formation of carbonaceous slag. Combustion of raw material occurs at a temperature of 1150°C-1350°C. At the end of the process the metal and nonmetal are easily separated and a carbonaceous/slag residue also obtained.

N. N. Adhapure [34] suggested that, in leaching process use large pieces of waste printed circuit board as compared to fine powder, because the fine powder did not separate from the non metallic substances. Large pieces of PCBs restricted due to the chemical coating present on the PCBs and the problem sold by the use of chemical treatment of PCBs earlior to the bioleaching with the help of 10M solution. The size of pieces of printed circuit board should 4 cm * 2.5 cm. Natural ph of the solution shown that the coating removal process complete. PCBs pieces (size 4 cm*2.5 cm) subjected to bioleaching by MMC (Mixed Microbial Consortium) in a conical flask rotated at 120 rpm at 30° C for 2-10 days and metal concentration in leach ate determined by atomic absorption spectroscopy (AAS) method. The use of large size pieces of printed circuit boards reduced the cost of the powder formation.

Wenhong Li [35] proposed proper disposal of non metallic substance obtained during E-waste recycling. Printed circuit boards sent to the metal smelter for deep processing or electrolytic purification, but produced a lot of tons non metallic powder annually. This powder is generally used for land filling, but the author proposed the different technique to use the non metallic powder. Asphalt widely used as viscoelastic material in paving and bridge construction, non metallic powder used as modifier in asphalt production. Non-metallic powders of WPCBs, which to make environmentally friendly cement mortar. The use of WPCB nonmetallic powders, non-metallic powders improved FRP (Fiber Reinforced Plastic) mechanical and physical performance, especially bending strength much improved, and products met the requirements of the technical, economic and green.

S. Roy [36] stated about the copper collection from waste printed circuit boards by stripping technique. The process carried out at room temperature using copper in nitrate solutions, copper and nitrate solutions with iron/tin, as well as real waste solutions. The electrochemical measurements performed by using a Pine Instruments rotating ring disc electrode (RRDE). A gold disc of diameter 7mm (surface area of 0.384cm2) the working electrode and a platinised titanium sheet of area 20mm×25mm used as a counter electrode. Initially, copper deposited from solution on the gold electrode in the H-cell, which rotated at 800 rpm. The deposition carried out for a certain time period. The copper deposit then washed with deionised water and the used water transferred into 0.5M HCl. Copper stripped from the disc at constant potential and the current recorded. The disc rotation speed maintained at 800 rpm during the stripping period.

Shigeki Koyanaka [37] proposed grinding technique to make a perfect size of PCBs powder for their recycling. In his study, the destruction behavior of PCBs investigated with a high-speed video camera from the perspective of separating metallic components. The effect of control of impact velocity enhancement of selective grinding related to the destruction behavior of PCBs recorded on the high-speed video images.. The size of the metal particle large as compared to nonmetallic particles because PCBs have more strength than the other board (Key board or TV board). The speed of the grinder 10-40 m/s for better operation. The metallic parts easily separated due to density differences (Metallic $\rho > 3$ g/cm^3 and Non metallic $\rho < 3$ g/cm^3) from the non metallic part by a heavy medium separation using a heavy polytungstate solution of specific gravity 3.0.

Lu Hongzhou [38] focused on the size and shape of the crushed printed circuit board. He suggested three types of shapes of the particle size Spherical, cylindrical and flake. A corona electrostatic separator, connected to direct current high voltage supply and a grounded rotated electrode, used for separation of metals and nonmetals part of waste printed circuit board. He suggested that the flake type shape was given the better result as compared to spherical or cylindrical type.

Yuemin Zhao [39] proposed the high voltage electrical pulse crushing method. In this method a high voltage (80-100 KV, Frequency 1-5 Hz) applied to the circuit boards after that which crushed into small pieces. As the pulse process breaks down the waste printed circuit boards, the copper foil and glass cloth laminated boards separated from the user interface between them. The process produces copper foil monomers and ring plate-glass cloth particles. Most of the copper foil monomers crushed into a particle size below 2 mm. Crushed copper and slag separated from processed circuit boards.

O. A. Fouad [40] experimented that, the recovery of copper from the waste printed circuit board powder of nano size by cementation on helical-form iron scrap chips from the spent etching solution. The solution ammoniacal copper solution containing 135g/l copper with minor impurity. The cementation process carried out in a 250-ml beaker, 50 ml of copper sulphate solution introduced into the beaker and a certain weight of iron chips rolled on a magnetic rod. The reactor placed on a hot plate with magnetic stirrer at 200 rpm for an electrochemical reaction (Reaction time 20 minutes). The mechanical friction between the iron chips and the bottom wall of the beaker resulted in removing the precipitated copper layer on the chip. The precipitated copper powders filtered as soon as the experiment finished.

2.1 RESEARCH GAP

After a comprehensive study of the existing literature, a number of gaps observed in the research work done on the processing of waste electronic printed circuit boards.

1. A lot of work done on the recovery of metals from the fine powder of electronic waste. No work done on using complete circuit boards; this reduces the cost of making fine powder of electronic waste.
2. Literature study shows that slag as a waste, but it can used for used for different engineering purposes like fabrication of frames.
3. There is very less literature available on low-cost E-waste processing technique.

2.2 MOTIVATION AND OBJECTIVE

Motivation of this project was to make a model for small-scale industries and enhance the efficiency of metal recovery by Plasma pyrolysis process techniques.

The main aim of this project is:

1. To design and make a model for small-scale industries.
2. To enhance the efficiency of metal recovery.
3. To reduce the hazardous gases and fumes emanating from the process used.
4. To promote the pyrolysis process in small-scale industries because of its inherent benefit in saving the health of workers and protection of environment.

2.3 STATEMENT OF THE PROBLEM

"E-waste management (Design and Modeling of Plasma Pyrolysis Reactor)"

At present, industries don't have a mechanism to handle e-wastes at small-scale and low capital investment like at the city level or an individual factory. The research work describes the design and development of the plasma pyrolaysis reactor, for small-scale industries (Formal recycling), for processing of E-waste and increase metal recovery efficiency and to reduce hazardous of heavy metals on human health and environment.

2.4 PLAN OF INVESTIGATION

The research work was planned to carried out in the following steps:

1. Identification of local and Authorized company collection center of E-waste.
2. Segregation of different types of E-Waste. Ex. Printed circuit board, CFLs, Cables/wires etc.
3. Separate transformers and capacitors from the printed circuit board.
4. Finding the effect of variables on metal recovery efficiency.
5. Plotting the conclusions on charts and graphs.
6. Discussion of result and its effect on process variables.

CHAPTER 3
RESEARCH AND METHODLOGY

At present a lot of E-waste processing techniques are present in the world like pyrometallurgical processing, Hydrometallurgical processing and Bio technological technique. But here we are discussing only those methods which used generally for recovery of metals from waste electrical and electronic equipment (WEEE). These methods are:

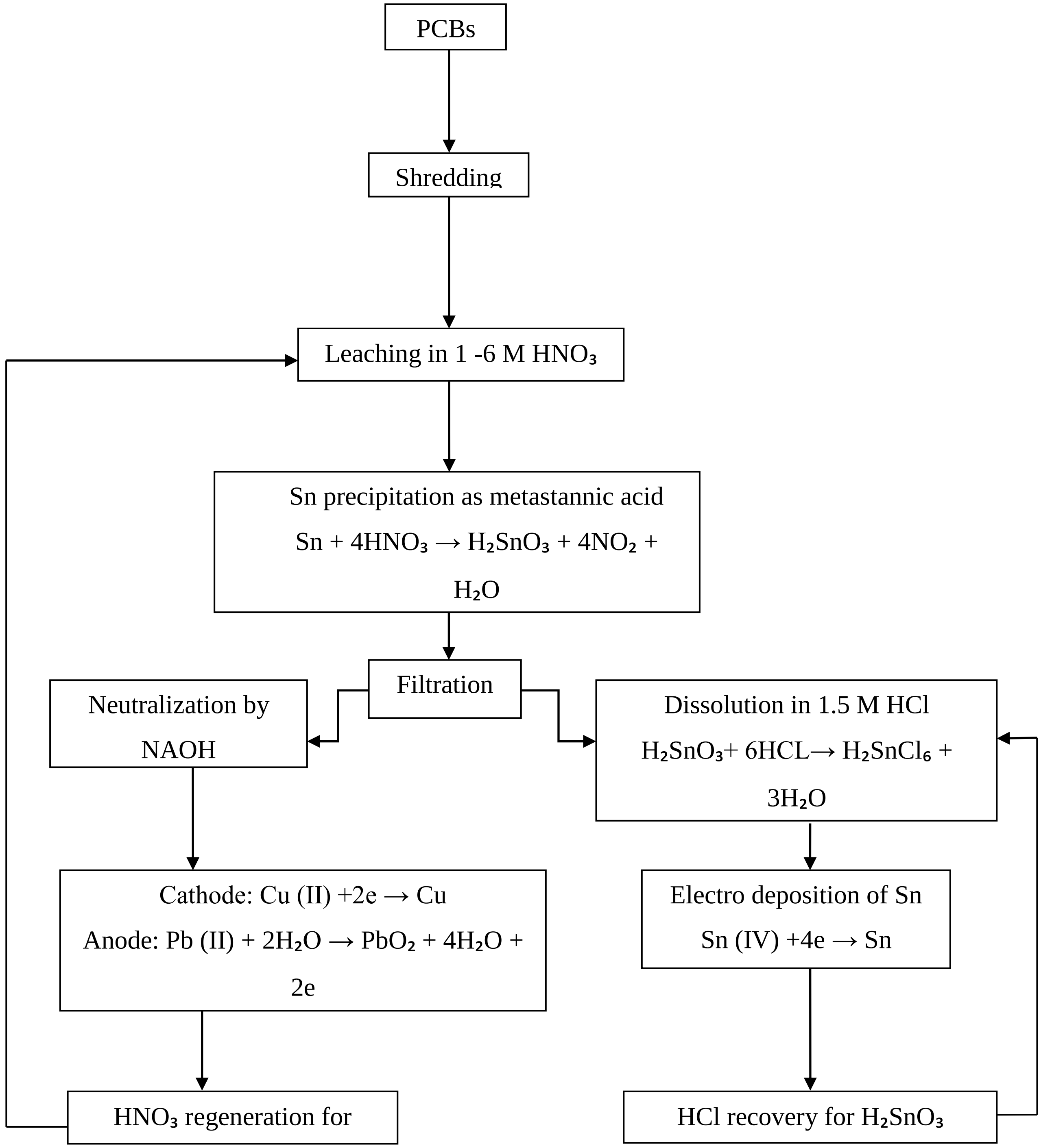
1. **CHEMICAL PROCESS**
2. **MECHANICAL PROCESS**
3. **BIO PROCESSING**
4. **PYROLYSIS PROCESSES**

3.1 CHEMICAL PROCESS

Chemical process is a clean and environment friendly technology as compared to incineration process. Chemical recycling refers to decomposition of waste polymer into their monomer or some useful chemicals by reactions. To start chemical recycling process, first the printed circuit board crushed into a ball mill up to a size of 0.20 mm. [41] Reduction of the PCBs scraps is essential because multilayered board restricts access of the stripping solution to the internal layers of printed circuit boards. After that powder obtained from the ball mill leached by solution of HNO_3 to remove dirt and dust from the waste scrap. The efficient recovery metal was highly dependent upon pH value of the solution used.

Mecucci used nitric acid of 1 - 6 mol/L to extract copper and lead from PCBs. Precipitation of tin as H2SnO3 (Metastannic acid) occurred at acid concentrations above 4 mol/L. [42] After filtration of precipetate, neutralization occurred by NAOH, Cu and lead collected at cathode and anode respectively, left solution of HNO3 reused for further process.

The chemical process of metal (copper) recovery using solution of nitric acid shown in figure.



FLOW DIAGRAM 1: PROCESS FLOW CHART FOR METAL RECOVERY FROM WEEE

(**Source**: Mecucci et.al, Journal of chemical technology and biotechnology, 77(2002), 449-457.)

3.2 MECHANICAL PROCESS

The recycling process for a product is deside based on the how the product extractd. There are two methods for recycling first one is plasma pyrolysis of WEEE material and second is milling process.

- **Plasma pyrolysis** is a refining process in which WEEE (PCB) is crushed and feed into plasma reactor. After required time and temperature, the molten metal and slag extracts from the bottom of reactor and slag hole.
- **Milling process** is another process of extracting process of metal from the WEEE. In this process metal extracted by milling (mechanical process). But some waste material is also stick with the extracted metal during the machining process. So it requires further treatment for pure form of metal.

Based on the above discussion, we will choose another method which has the advantages of both the above discussed processes.

In this method following steps are as:

- Extract the metal rich waste with the help of milling process.
- Metal rich waste is now pyrolysised with the help of plasma reactor.

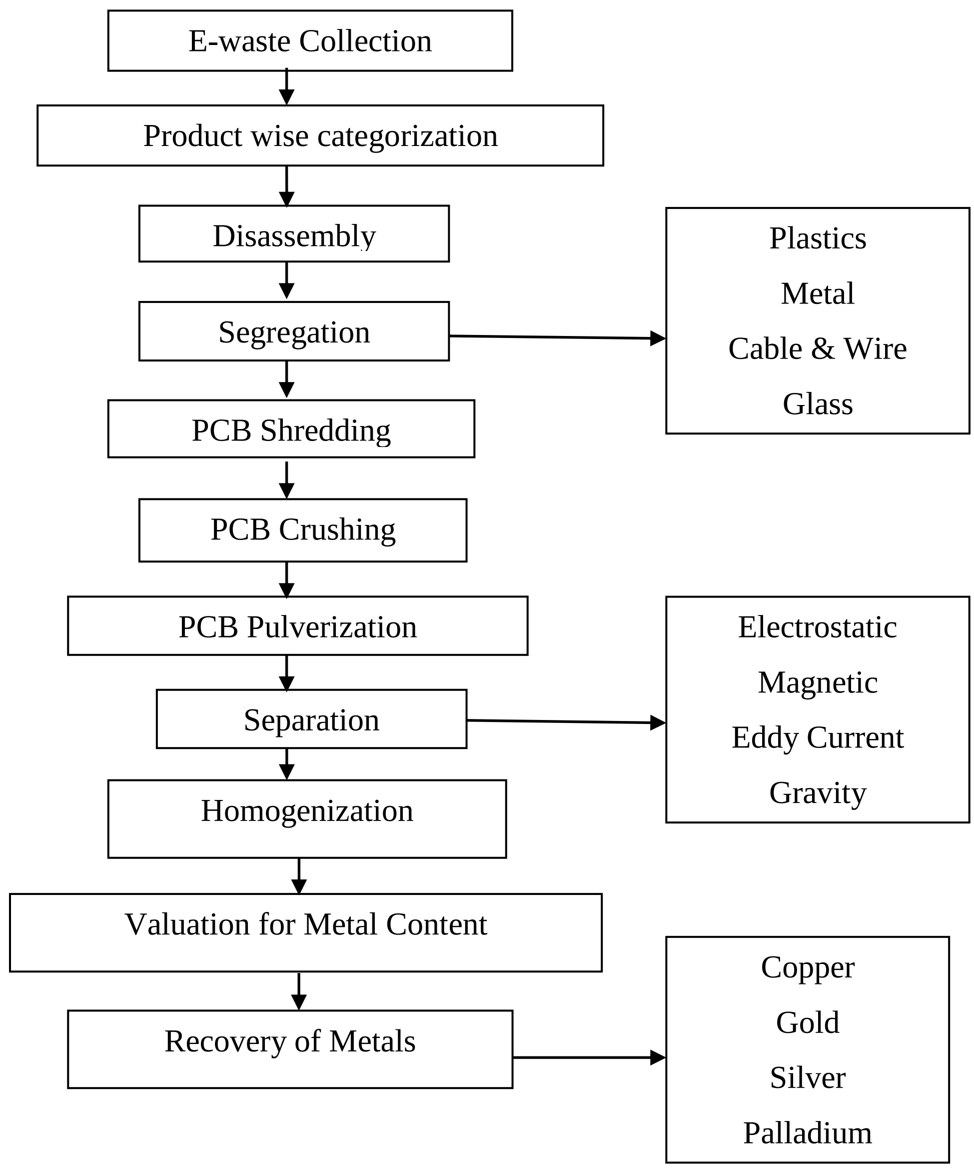
Mechanical process is cheap and economical because it saves the time and cost included with metal recovery process. Material for printed circuit board (PCB) should dielectric. Mechanical methods used in Poland and other countries applied to process WEEE and recover from it Al, Fe, Cu, plastics, and printed circuit boards. Then, those resources sold to companies that process them and purify to form of pure metal products.

Currently, recycling of E-waste can broadly divided into three major steps:

1. **Disassembly**: Selective disassembly, targeting on singling out hazardous or valuable components for special treatment, is an indispensable process in recycling of E-waste.

2. **Upgrading:** Using mechanical processing and/or metallurgical processes to upgrade desirable material content, i.e. preparing materials for refining processes.

3. **Refining:** In the last step, recovered materials are retreated or purified by using different processing technique to be acceptable for their original using.



FLOW DIAGRAM 2: Process Flow Chart for recovery of valuable material from e-waste (**Source**: S. Chatterjee, American Journal of Environmental Engineering 2012, 2(1), 23-33.)

3.3 BIO LEACHING PROCESS

Bio leaching recycling is a process of extraction of metal from the waste printed circuit board with the use of living organism. Bio leaching is the branch of bio-hydro-metallurgy and use to recover metals like Copper, Zinc, lead, arsenic, antimony, nickel, gold, silver and cobalt. This process base on the use of acidophilic strains of mesosphilic and thermophilic bacteria. This bacteria converts Fe^{2+} in to Fe^{3+} under suitable environment.

$$2FeSO_4 + \frac{1}{2} H_2O + H_2SO_4 \rightarrow Fe_2 (SO_4)_3 + H_2O \qquad (1)$$

The kinetics of bioleaching of copper is:

$$Cu^{\circ} + 2 Fe^{3+} \rightarrow Cu^{2+} + 2Fe^{2+} \qquad (2)$$

(Source: www.acdmeia.com)

The microbe metal interaction mechanism is shown in figure 8.

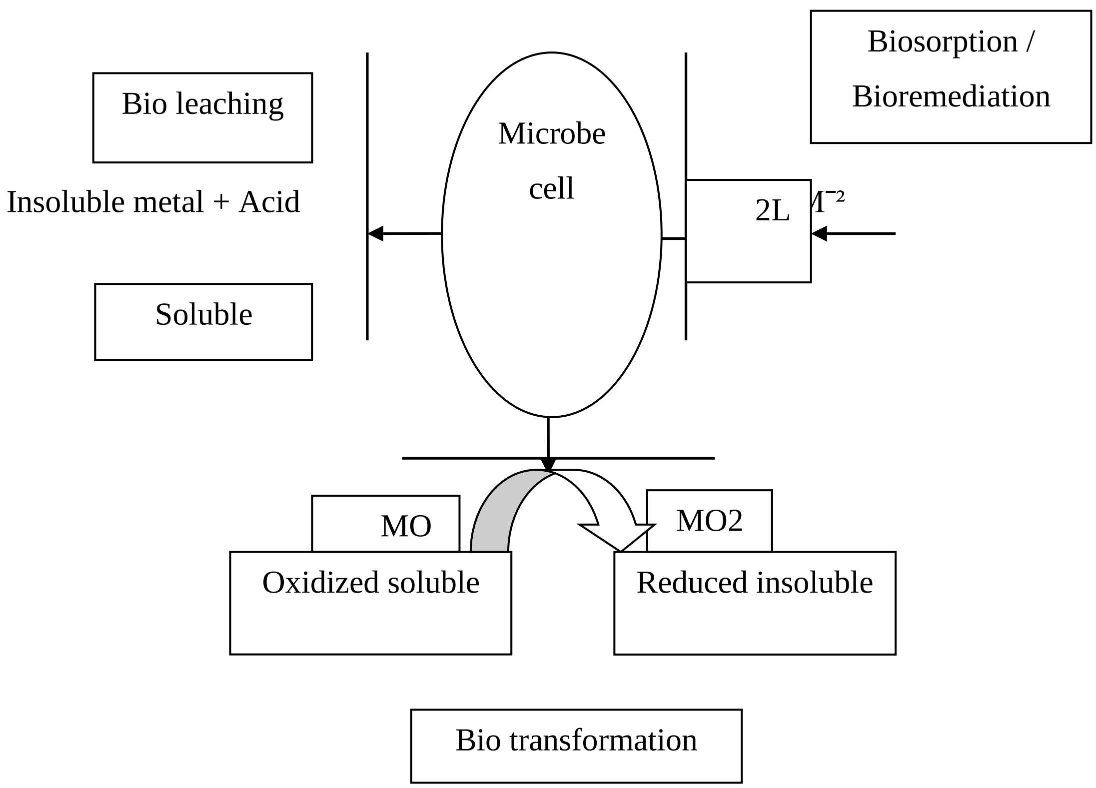


Figure 8: Microbe-Metal interaction mechanism

(**Source**: Dabaraj Mishra et.al, Chungnam National University, Daejeon 305-764, South Korea)

Different types of microbes used to recover different metals like cooper, lead and zinc. Mesophilic microbes are work at a slow rate and at a moderate temperature about 28-35°C, and thermophilic bacteria is work faster than the mesophilic microbes and works at a temperature near 50°C. [43] Now a day's major industrial waste retreated with bioleaching process and this technology used as green technology. Various types of industrial waste and used microbes for the recovery of valuable metal are show in table 6.

Table 6: Types of industrial waste and used microbes

S. NO.	Types of waste	Metal value	Micro organism
1.	Fly ash	Al, Zn, Cu, Cd	Acidithiobacillus sp., Aspergillus niger
2.	Sewage sludge	Cu, Mn, Zn, Ni	At. Thiooxidans
3.	Sediment	Cr, Cu, Zn	At. Thiooxidan
4.	Tannery sludge	Cr	At. Thiooxidans
5.	Electronic scrap	Cu, Ni, Sn, Al, Zn	Acidithiobacillus sp., Sulfobacillus, Aspergillus niger
6.	Spent battery	Co, Li, Ni, Cd	Acidithiobacillus sp.
7.	Spent refinery catalyst	Co, Ni	Acidithiobacillus sp.
8.	Spent petroleum catalyst	V, Ni, Mo	Acidithiobacillus sp.
9.	Spent fluid cracking catalyst	Al, Mo, V	Aspergillus niger
10.	Waste electric device	Au	Chromobacterium violaceum
11.	Jewelry waste/Automobile catalyst	Ag, Pt, Au	Chromobacterium violaceum, Pseudomonas

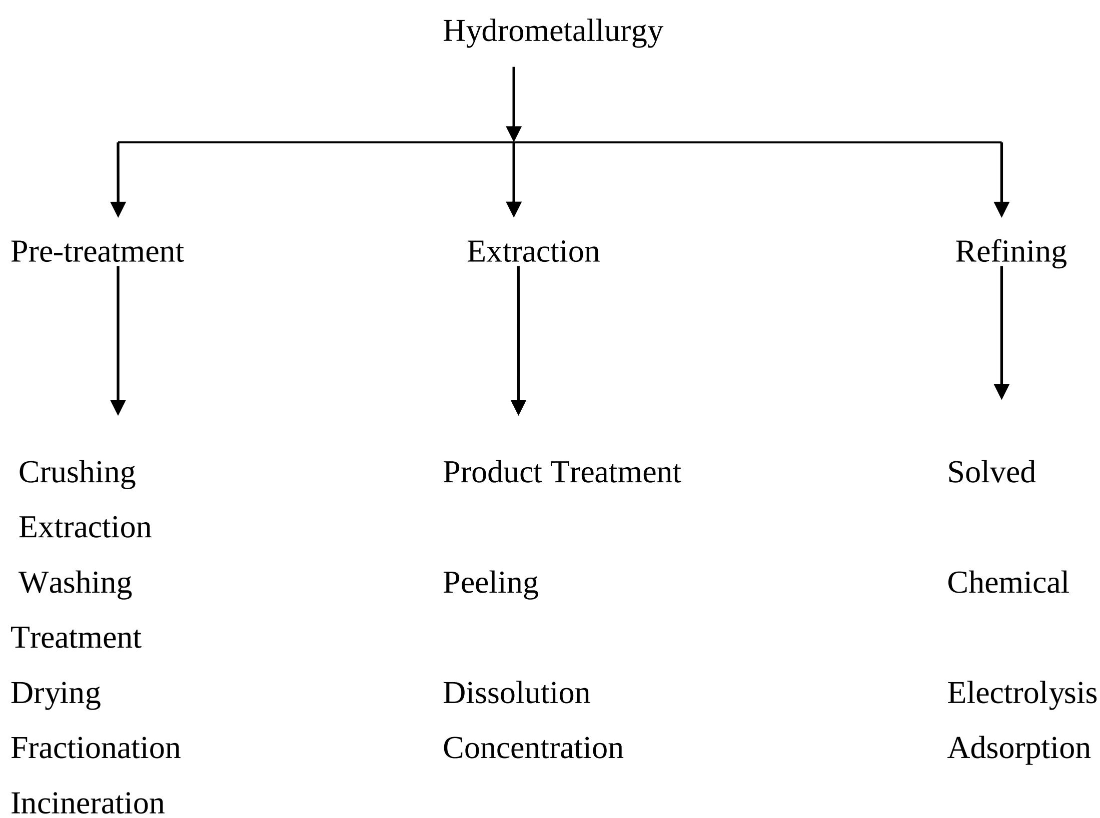
fluorescens, Bacillus megaterium

(**Source**: Dabaraj Mishra et al, Chungnam National University, Daejeon 305-764, South Korea)

Hydrometallurgical process is a branch of chemical recycling process and it can divided in to three steps:

1. Leaching
2. Solution concentration and purification
3. Metal recovery

Leaching solution are mainly aqua regia, hydrogen peroxide, sulphuric acid, thiourea, nitric acid, cyanide leach solution, hydrochloric acid, sodium hydroxide and so on. Hydrometallurgical process occurs in to three steps are as:



Gold cyanidation is a metallurgical technique for extracting gold from low-grade ore by converting the gold to water-soluble coordination complex. Production of reagents for mineral processing to recover gold, copper, zinc and silver respectively represents approximately 13% of cyanide consumption globally. The remaining 87% of cyanide used for another industrial processes such as plastic, adhesives and pesticides.

The chemical reaction for the dissolution of gold is as:

$$4Au + 8NaCN + O^2 + 2H_2O \rightarrow 4Na\,[Au\,(CN)_2] + 4NaOH \qquad (3)$$

In this process, oxygen removed via two-step reaction, one electron from each gold atom to form the complex Au (CN_2^-) ion. The main drawback of cyanidation is water pollution. Human drinking water and rivers polluted as well as killing everything for several times downstream.

As the environmental problems become serious, Thiosulphate leaching is another option for the recovery of valuable metal from the waste printed circuit board. It is non toxic and has a faster reaction rate than conventional cyanidation. Thiosulphate stabilizing gold in solution and copper and ammonia accelerate the leaching reaction.

Theiourea leaching is more effective than the thiosulphate leaching but less efficient, because of high consumption of theiourea and low reaction rate.

Leaching combined with electro winning is also another chemical recycling process. This is an extractive metallurgical technique which converts metals into soluble salts in aqueous media. Leaching is less harmful because of no gaseous pollution occurs. Leaching done in a long cylinder may vertical or horizontal known as autoclaves. Leaching with electro winning is an example of chemical leaching method of recovery of copper from the waste printed circuit boards. This process completes into two steps first is leaching and second is electro winning. In leaching process pretreated printed circuit board powder is dissolved in leaching solution at ambient temperature and pressure.

The leaching solution has required amount of Cu_2Cl_2, HCl and NaCl. And in electro winning process graphite plated connected 5A, 10V DC supply used for the reaction. Copper collected at cathode, washed with acetone and weighted. [44]

The reactions of the given process are given as:

Reactions in solution

$$Cu^{+} + Cu^{2+} \rightarrow 2Cu^{+} \quad (4)$$

$$Cu^{+} + Cl^{-} \rightarrow CuCl \quad (5)$$

$$CuCl + Cl^{-} \rightarrow CuCl^{-} \quad (6)$$

Reactions at cathode:

$$Cu^{2+} + 2e \rightarrow Cu \quad (7)$$

$$Cu^{2+} + e \rightarrow 2\,Cu^{+} \quad (8)$$

$$Cu^{+} + e \rightarrow Cu \quad (9)$$

Reactions at anode:

$$CuCl^{-}2 \rightarrow Cu^{2+} + 2Cl^{-} + e \quad (10)$$

$$2Cl^{-} \rightarrow Cl2 + e \quad (11)$$

(**Source**: M. Somasundaram et. al., Powder Technology 266 (2014), 1–6)

The main drawback of this leaching process is high acidic and sometimes it's toxic residual effluents and its lower efficiency caused by low temperature of the operation, which dramatically affect the chemical reaction rate.

The conventional methods of electronic waste management have provided to an environmental burden. Using micro organism and weed extracts for the bioremediation of the hazardous electronic waste and obtaining valuable metal from the same proves to a remarkably economical and eco-friendly approach.[43]

3.4 PYROLYSIS PROCESS

Pyrolysis of polymers leads to formation of gases, oils and chars which can used as chemical fed stocks or fuels. Pyrolysis process degrades the organic part of the PCBs wastes, making the process of separating the organic, metallic and glass fiber fraction of PCBs much easier and recycling of each fraction more practial. The removal of soldered part decreases the pollution level and increases the metal recovery efficiency.

Vacuum pyrolysis is the new term in the E-waste recycling literature. This technique reduced organic vapor residence time in the reactor and decreases decomposition temperature, reducing the occurrence and intensity of secondary reactions. The residue of vacuum pyrolysis at 550 °C of PCBs scrap (25 cm2) crushed and size classified; about 99% of original copper confined in particles > 0.4 mm, fibers remained in the smaller particles recovered after calcinations. [45] The pyrolysis process shown in figure 9.

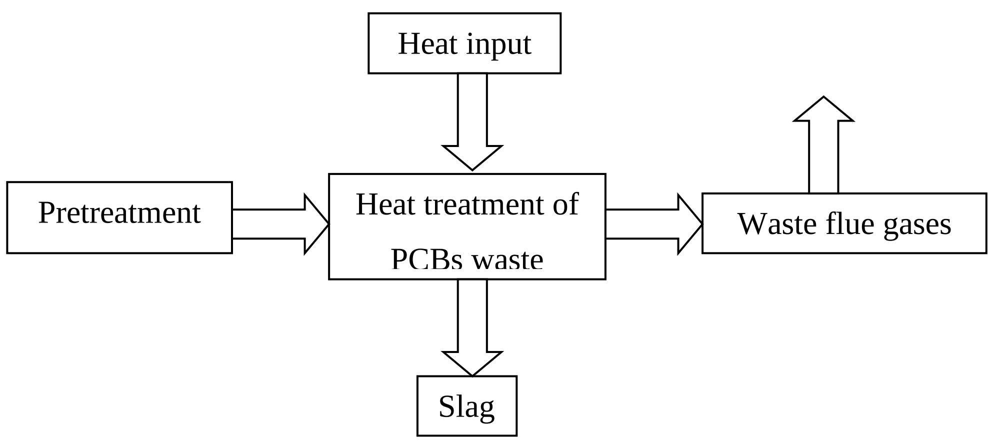


Figure 9: Block diagram of pyrolysis process

(**Source:** M. Puncochar et.al, Procedia engineering, 42(2012), 420-430)

Mechanical process and disassembly are mainly used for the pre treatment of E-waste for upgrading the valuable material content. In the pyrometallurgical process raw material (Crushed printed circuit boards) feed into the pyrometallurgical reactor and heating done by hot inert gases, but from the economic point of view we use the compressed air. High temperature plasma technology recycles the printed circuit board without need of its preprocessing. For processing crushed circuit boards feed to the reactor after reaching 1250^0C temperature in the reactor chamber and hold the furnace for 20 minutes. Then raw material melted and metal due to heavy density settled down and slug floating on the metal due to low density. Here metal and slag are separate. The slag consists of metal oxides like aluminum, silica, iron and lead oxide and formed during operation of metal in the reactor. That is why slag mass is higher than the mass of metal in the input waste, and thus the mass balance is affected by oxidation of metals that increase the slag mass.

Approximate 90% mass of copper gained and rest of copper evaporated due such high temperature and can collected in a scrubber during neutralization and cooling of the fumes. Metal recovered easily by adding 12% NAOH by weight of charge. [46]

CHAPTER 4

DESIGN AND MODELING OF THE REACTOR

4.1 INTRODUCTION

Modeling is a scientific activity the aim of which is to make a particular part easier to understand, define, quantify, visualize, or simulate. Different types of models are Conceptual Model to better understand, operational model to Operationalize, Mathematical model to quantify, or graphical model to visualize the subject.

The Industrial Research Institute for Automation and Measurement designed and constructed the plasma reactor to investigate plasma processing of waste of electronic and electrical equipment for recovery of metal and its neutralization. Figure shows the various components of plasma reactor are:

Figure10: Various component of a laboratory set up

(**Source**: Jakub et.al, Procedia Engineering, 57(2013), 1100-1108)

Components of the setup are as:

1. Plasma reactor
2. Plasmatron
3. Molten product Collection
4. Fume-Exhaust (chimney)
5. Waste package transporter
6. Plasmatron power supply
7. PLC- automation and data collection apparatus cabin
8. Automatic waste package feeder

The key component of a test setup is the plasma reactor, equipped with three plasmatron– plasma sources, each in 120^0 around the reactor chamber. The test position is equip with peripheral systems, measurement and control apparatus for data acquisition and control of the process during research. The high temperature plasmatron plasma reactor is the key component of laboratory setup for research over high temperature use of waste of printed circuit boards, for metal recovery. Block diagram of laboratory setup shown as:

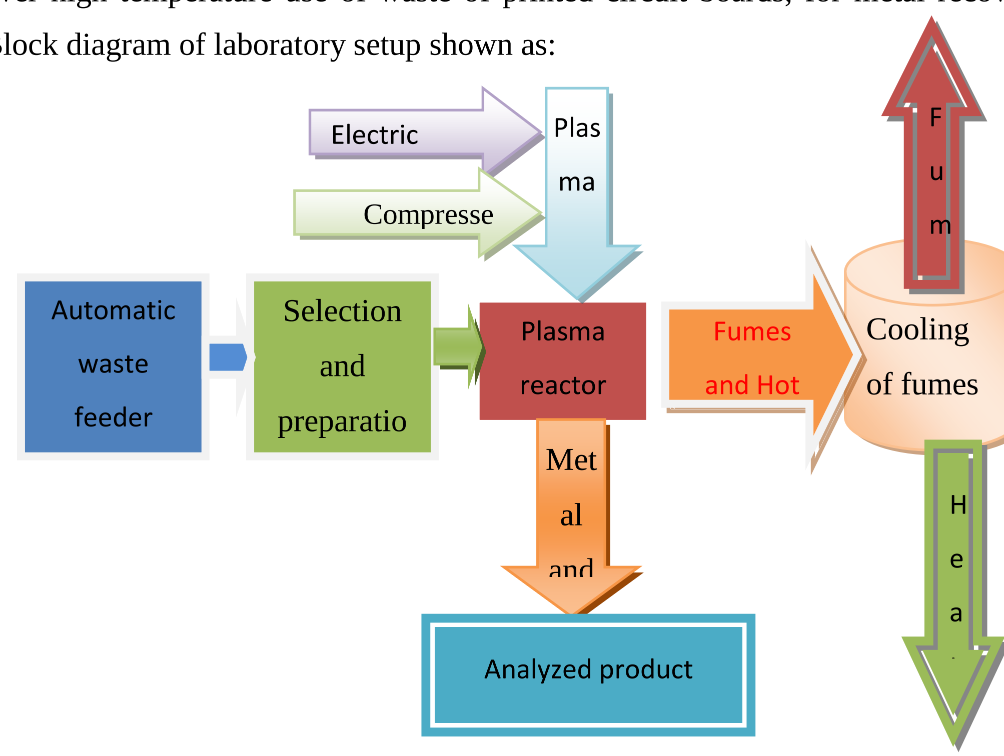


Figure 11: Block diagram of pyrolysis process

(**Source**: Jakub et.al, Procedia Engineering, 57(2013), 1100-1108)

Designed plasma process carried out by the following setup presented in figure 11. Prepared electronic waste transport through automatic feeder to the plasma reactor chamber. In the reactor chamber, the waste is incinerate and melt by three hot plasma streams. Metal recover after 20 minutes of completion of incineration process.

Next, the incineration fumes transport to the scrubber where they neutralized, cooled and then released to the atmosphere. As the metal and slag in molten state they flow out from the reactor and set in casts, from which they can recover and recycled.

4.2 MODELING OF PLASMA ARC REACTOR

I have visited many plants in my vicinity to collect information's regarding metal recovery and found:

- They resort to obsolete traditional ways like directly heating PCBs on kerosene stove, which is highly insecure and inefficient in matter of metal recovery.
- Some of the factories were employing state of the art, imported technologies. Though these technologies were more efficient in respect of number and measure of extracting metal, but these secure a big amount of money.

Hence proposed method could be more helpful to secure workers health with better efficiency and reduced cost.

This method has few limitations such as:

- The method is truly relevant for the metals which have considerably higher proportions among other available coexisting metals.
- Another problem with this method is that at a time only one metal could be extracted.

Reactor chamber construction consists three layers, first is the fire-proof concrete, next is the thermal insulation, and last is the external metal shell. Reactor chamber is hexagonal and its construction is present in figure 12.

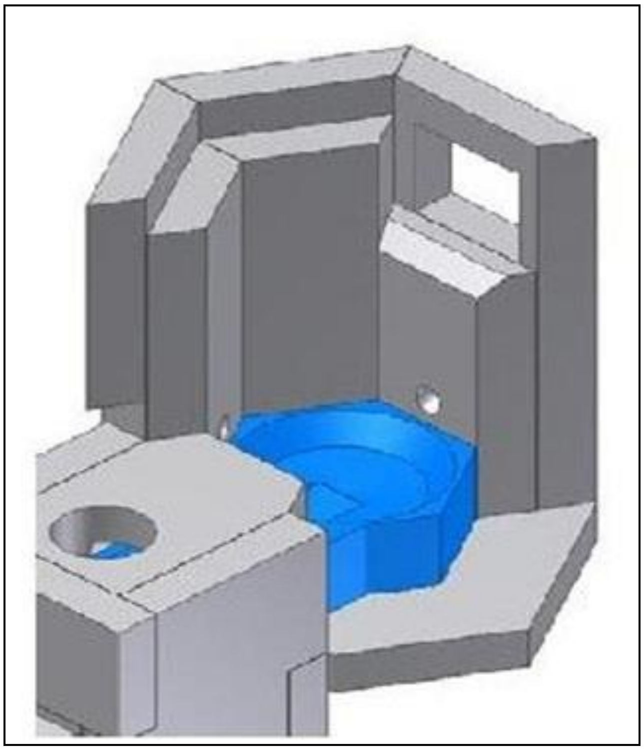


Figure 12: Internal construction of plasma reactor

(**Source**: Jakub et al, Procedia Engineering, 57(2013), 1100-1108)

The reactor construction has bear a temperature up to 1500 ^{0}C. However the area where the plasma has direct effect the wastes, the temperature exceeds the given temperature range. The plasmatron plasma reactor has three sources of heat, which are 20KW arc plasmatrons from three sides of reactor wall. Copper has a melting temperature at 1085°C, so for perfect recovery of copper metal suitable reactor temperature is 1250^{0}C. Plasmatron efficiency reaches up to 75% of energy to plasma heat efficiency. After calculating the plasmatron efficiency, including efficiency of power source, the overall efficiency decrease up to 70%. Each plasmatron generates a stream of plasma that flow out from the bottom of the reactor chamber. The plasma produce from a compressed air, which used as plasmatron working gas. Three plasmatron consume 11 Nm^3/h of air during normal operation. [47]

4.3 DESIGN OF PLASMATRON PIPE

To design a plasma pyrolysis reactor, first we design heat pipe. To design plasmatron heat pipe we use two basic heat transfer equation.

Equation of heat transfer through a cylinder is:

$Q = 2\Pi KL\Delta T/\ln(r_2/r_1)$ ……………………………………Equation 12.

Q = Heat flow (watt)

L = length of pipe (m)

K = Thermal conductivity (W/m k) 17-50W/m k

r_2 = outer radius of cylinder (m)

r_1 = inner radius of cylinder (m)

t_2 = outer surface temperature (^{o}c)

t_1 = inner radius temperature in (^{o}c)

To design a one kilowatt plasmatron pipe

Let us consider the following data to design plasmatron pipe:

A minimum temperature difference across the cylindrical pipe wall is 10^{o}c.

For a barrel design there is difference of 30-40 % in radius of cylinder. [48]

The outer and inner radiuses of the cylindrical pipe wall are:

r_2 = 0.0125 m (outer)

r_1 = 0.0075 m (inner)

Thermal conductivity of is steel 30W/m k (Average). [48]

Length of pipe is:

$1 = 2*\Pi*0.030*l*10/\ln(1.33)$

L = 0.15 cm.

Basic heat transfer equation for required temperature of the reactor.

$Q = m\ c\ \Delta t$ ………………………………………….…..Equation 13.

Q = Heat flow (k Joule/s)

M = mass of air kg/s

Cp = specific heat at constant pressure (kJ/kg k)

Δt = temperature difference of air b/w outlet and inlet of pipe.

t_1 = inlet air temperature 30°c (Assume)

$1 = 4.3959*10^{-3} *1.468*\Delta t$

Δt = 220°c

t_2 = 250°c

4.4 MINIMUM VELOCITY OF AIR FOR BETTER HEAT TRANSFER

Pressure of air is atmospheric. (Assume)

We know that the Reynolds no. **(Re) = ρ υ d / μ**……………………Equation 14.

Reynolds Number for turbulent flow of air should be less than 4000.

Where ρ = Density of air (kg/m³)

V = Velocity (m/s)

d = Diameter of pipe (m)

μ = kinematic viscosity (Ns/m²)

Take kinematic viscosity of air is $15.11*10^{-6}$ m²/s. [48]

Diameter of pipe = 0.15 m

Let us consider the Reynolds no. is 4000.

Put the value in the above eq. and get the velocity v =2.32 m/s.

Now take Re = 4500.

Put the value in the above eq. and get the velocity v= 2.71 m/s.

Now take Re = 5000.

Put the value in the above eq. and get the velocity v=2.90 m/s.

Now take the Re = 6000

Put the value in the above eq. and get the velocity v = 3.48 m/s.

Now take the Re = 7000

Put the value in the above eq. and get the velocity v = 4.06 m/s.

Now take the Re = 8000

Put the value in the above eq. and get the velocity v = 4.64 m/s.

Based in the above discussion we can see the Reynolds No. increases the velocity also increase, but at high velocity there is a By Pass Factor work and high speed air is not transfer heat to the reactor.

So we choose minimum Reynolds No. 8000 and chose velocity at 4.64 m/s for better heat transfer for a small diameter pipe.

4.5 MASS FLOW RATE OF AIR

Mass flow rate of air Q = ρ A v m^3/s. ……………………………..…Equation 15.

Take ρ = 1.21 kg/m^3. [45]

Take ρ = 1.21 *2*3.14*0.0075*0.15*4.64

Q = 0.0396 m^3/s'

4.6 VOLUME OF THE REACTOR

Volume of the reactor is $\Pi r^2 L$………………………………………..Equation 16.

Where, r = Internal radius of cemented cylindrical cell.

L = Length of the cemented cylindrical cell.

L = Π *0.09*0.09*0.375

Volume of the reactor of 5 kg/hr is 9.53775 *10^{-3} m^3.

4.7 MATERIALS REQUIRED CONSTRUCTING PLASMA REACTOR (FLOW RATE OF 5 KG/HR) WITH THEIR PRICES:

The following materials are required to construct the plasma pyrolysis reactor shown in table 7. Their required weight and their price are given in the following table.

Table 7: Materials with Weights and their Prices

S. No.	Material	Weight	Price(Rupees)
1.	Badarpur	50 Kg	50
2.	Cement	15 Kg	150

3.	Saria (8 mm)	3 Kg	120
4.	Refractory Cement (FH-70R)	25 Kg	625
5.	Heat Pipe	3 Piece	2600
6.	Heaters	3 Piece	2800
7.	Gas Pipe	2 Piece	240
8.	Elbow	4 Piece	180
9.	Electrical Wire	8 Meter	360
10.	Ammeter	1 Piece	40
11.	Plug 3 Pin	1 Piece	40
12.	Wall Putty	2 Kg	50
13.	Paint	50 gm	40
14.	Paint Brush	2 Piece	50
15.	Elbow Extension	7 Piece	175
16.	Labor Charge	-	500 Rupees
17.	Transportation charge	-	1000 Rupees
	Total Cost	**-**	**9020 /- Rupees**

Total cost of Plasma Reactor is 9,020 Rupees. All Prices are in Retail.

Total cost of Plasma Reactor for a Flow rate of 10 kg/hr is 18,020 Rupees.

Total cost of Plasma Reactor for a Flow rate of 15 kg/hr is 27,060 Rupees. Cost of the reactor is taken in lump-sum, it may vary.

Note: The process limited up to 10 kg/hr for better operational condition because of the strength of the plasma arc.

4.8 PROCEDURE FOR MAKING PLASMA REACTOR IS AS:

Following step are required to build the plasma pyrolysis reactor.

1. Prepare foundational frame of plasma reactor with the help of iron rod (Saria) for reinforcement.
2. Prepare a mixture of badarpur and cement in a ratio of 4:1 for good strength.
3. Applying the mixture to the ready foundational frame.
4. Leaving the concrete structure for 3-4 days.
5. Now applying a layer of Refractory cement of 3 cm thickness on the inner surface of the concrete structure.
6. Leaving the structure for 1 day to dried-up and solidify.
7. Assembly of elbow, elbow extension to heat pipe.
8. Assembly of heaters and heat pipes.
9. Make electrical connections of heaters.
10. Connecting Ammeter to main line.
11. Connect gas pipes to heat pipe and compressor.
12. Fit heaters to concrete structure at place of 120°.

Now model is ready to use.

Note: If base component is replaced by making it with refectory cement then we could reduce the overall cost by 15%.

Figure 13 shows the metal holding component (Base component) of the plasma pyrolysis reactor, which can be eliminated by use of parent metal layer to reduce overall cost of the reactor.

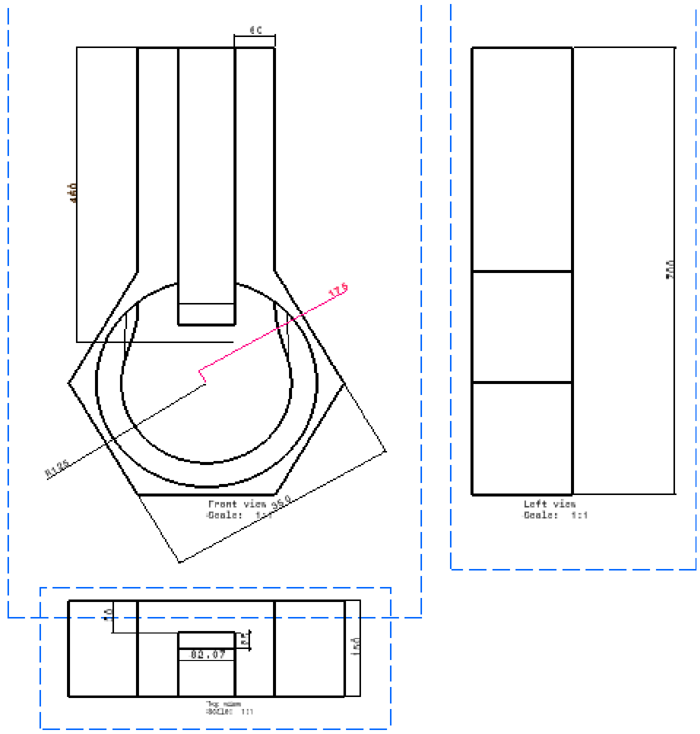


Figure 13: Two dimensional view of Reactor base

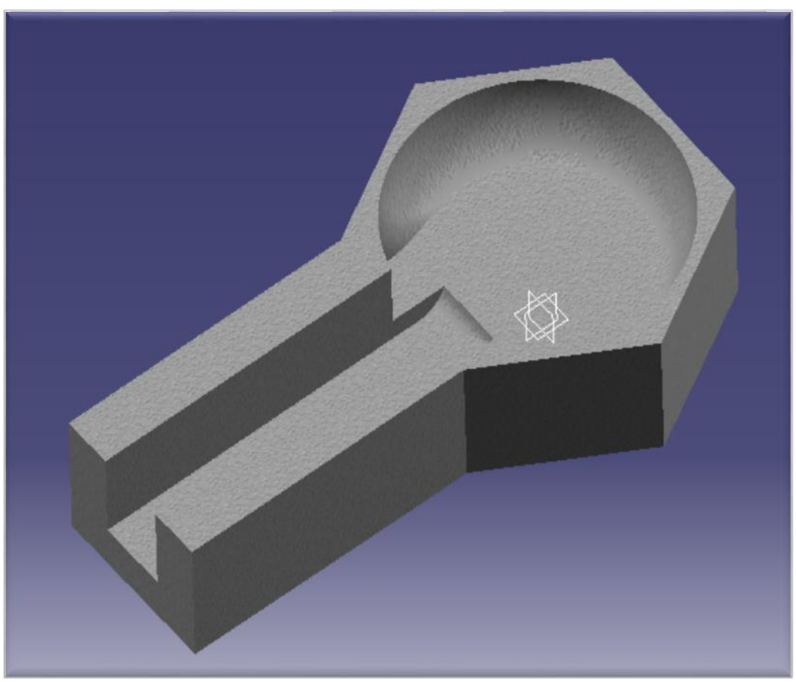


Figure 14: Three dimensional view of Reactor Base (Metal holding component)

Figure 14 shows the three-dimensional view the metal holding part of the reactor, which made of steel and requires a big amount of money. But with the use of FR-70 refractory cement, it is possible to eliminate the holding part. Elimination of this holding part reduces the overall cost of the reactor. After the first use of reactor a metal layer deposited on cemented wall of reactor, which reacts as a surface of holding part of the reactor.

Intermittent removal of molted metal is taken from the reactor.

Alumina is the main constituent of the used refractory cement (FR-70). The main property of cement FR-70 is better heat resistant and minimum setting time. Approximate 24 hours is sufficient to use the newly constructed structure of the rector. Other key properties of alumina are as follows:

- Hard, wear resistant
- Excellent die electric properties
- Resist strong acid and alkali attacks at higher temperature (1500°C)
- High strength and stiffness

All desirable properties of alumina are because of strong ionic interatomic bonding. The drawing made by the catia software.

Figure 15 shows the constructed reactor chamber. Generally it consists of three layers, fire-proof concrete, insulation, external concrete shell. But with the use of refractory cement the insulation layer eliminated permanently. This reduces the overall cost of the reactor and the second concrete layer worked as heat resisting layer.

The three plasmatron pipes connected at the base of the reactor and at 120°C as shown in figure 13. These plasmatron are responsible for generation of plasma stream, which is use for the melting waste printed circuit board. Strength of the plasma stream can regulated with variation of size and frequency of current.

Figure 15: Concrete cell of plasma payrolysis reactor

(a) Heat Pipes

(b) Plasmatron heaters

Figure 16: Plasmatrons of pyrolysis reactor

Figure 16 (a) shows the plasmatron pipes, made of non magnetic steel 304. It is austenitic steel which cannot be hardened after heat treatment. Content of the austenitic 304 grade steel shown in the table 8.

Table 8: Metal percentage in 304 grade steel

S. No.	**Name of the metal**	**% of metal**
1	Carbon	0.08 %
2.	Manganese	2 %
3.	Phosphorous	0.04 %
4.	Sulphur	0.03 %
5.	Silicon	1.00 %
6.	Chromium	18 %
7.	Nickel	8 %

(**Source:** www.lenntech.com/stainless-steel-304.htm)

The 18% minimum chromium content provides corrosion and oxidation resistance. Other elements also give their significant role to stabilize the part at elevated temperature. This steel used for various cooking appliances.

Figure 16 (b) shows the completed plasmatron heating pipe, which used for generation of hot plasma streams. The steel pipes covered by heaters, and these connected in star connection. These plasmatron generate hot plasma streams which produced required temperature (1250°C) for melting of waste printed circuit boards. These plasmatrons connected to a three phase-supply for power input.

Figure 17: Segregated Printed Circuit Board

Segregated E-Waste used as raw material. Capacitors and other accessories removed by mechanical process (Desoldering) to reduce hazardous up to an extent. After that it is crushed into a crusher to reduce the size of the waste circuit board for efficient incineration process. The sizes of the crushed printed circuit boards are less than the 1 cm^2.

CHAPTER 5
RESULTS AND DISSCUSSION

5.1 AIM OF STUDY

The major aim of the study is to improve metal recovery efficiency of copper from waste printed circuit boards which is up to 14%. This study is important in the field of extracting metal (copper) from E-waste since the available methods in India in the field of metal recovery could only recover the metal up to 10%. The study has major implications in preventing hazardous effects of E-waste on human health and soil degradation as well as reusing extracted metals in various engineering processes as input. This work is also helpful to reduce the effect of informal recycling of waste printed circuit boards on human health and environment. In this theoretical and experimental work energy balance and mass balance calculated by energy tables and mass table, which shows the energy efficiency and metal recovery efficiency of the rector.

The effect of various process parameters like temperature versus heat transfer rate, velocity versus heat transfer rate, temperature versus efficiency studied. The energy efficiency and metal recovery efficiency of the equipment or process would be tabulated.

5.2 ENERGY BALANCE TABLEGY

Energy balance table gives details of energy consumption. Energy table gives the details of energy input, energy used, energy losses and cost of the recycling process. These parameters are necessary for calculation of energy efficiency.

Energy efficiency of the process is given as:

Energy input – Energy output / Energy input

Energy audit is shown in table 9.

Table 9: Energy balance table

S. NO.	Energy input (kw)	Temperature (^oC)	Energy use (kw)	Energy loss (kw)	Cost (Rs/kwh)	Total cost (Rs.)
1.	**1**	**1000**	**0.70**	**0.30**	**6.50**	**6.50**
2.	**1.5**	**1000**	**1.05**	**0.45**	**6.50**	**9.75**
3.	**2**	**1000**	**1.40**	**0.60**	**6.50**	**13.00**

Energy efficiency of the process ═ 1-0.30/1 = 0.70*100= 70 %.

5.3 MASS BALANCE TABLE

Mass balance completed by audit of mass input, slag output and metal recovered during pyrolaysis process. It prepared by a Mass balance table, where raw material input, slag output and metal recover calculated. These parameters are responsible for the cost of material recovered.

Mass balance table for the mass balance process used is as follows:

Metal recovery efficiency of the process = Mass input – Mass output / Mass input

Table 10: Mass balance table

S.NO.	Mass input (kg)	Raw material Rs(100/kg)	Mass lost (kg)	Mass Output (kg)	Material cost (output) Rs(470/kg)
1	**2**	**200**	**1.72**	**0.28**	**131.6**
2	**3**	**300**	**2.58**	**0.42**	**197.4**

3	**4**	**400**	**3.44**	**0.56**	**263.2**

Metal recovery efficiency ═ 2-1.72/2= 0.14*100= 14 %.

5.4 EFFECT OF TEMPERATURE (t) ON HEAT TRANSFER COEFFICIENT (h)

The relationship between the temperatures (t) of plasmatron and heat transfer coefficient (h) shown in figure. Figure show that the heat transfer coefficient "h" increase linearly with increase in temperature of plasmatron. As the temperature of plasmatron increases, heat transfer rate through is also increases. Temperature increment depends on time and flow of current and thermal conductivity of metal used for making plasmatron pipe.

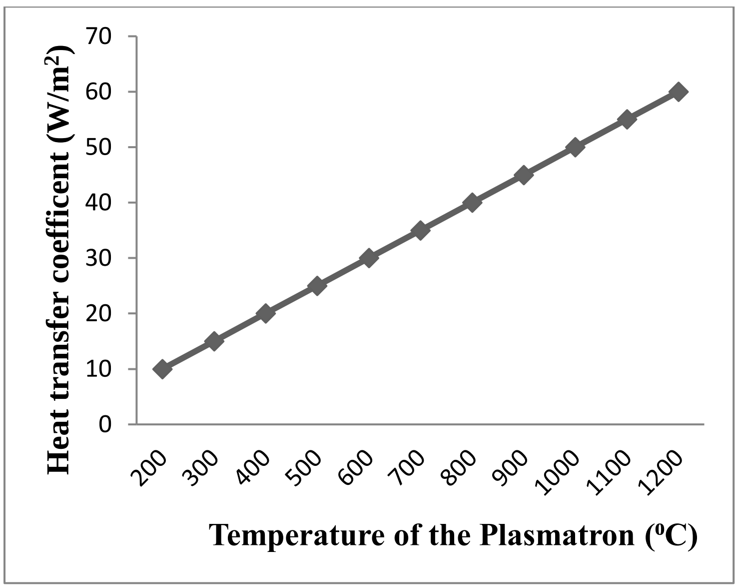


Figure 18: Effect of temperature on Heat transfer coefficient

5.5 EFFECT OF VELOCITY (v) ON HEAT TRANSFER COEFFICIENT (h)

Heat transfer coefficient also depends on velocity of air. The value of heat transfer coefficient varies from 20-200 w/m² for turbulent flow. [48] Graph shows the value of heat transfer coefficient corresponding to the different velocities. If we take higher velocities of air, the there will act a bypass factor which will decrease the heat transfer coefficient (h). Hence optimum velocity of air is 5 m/s for better heat transfer coefficient.

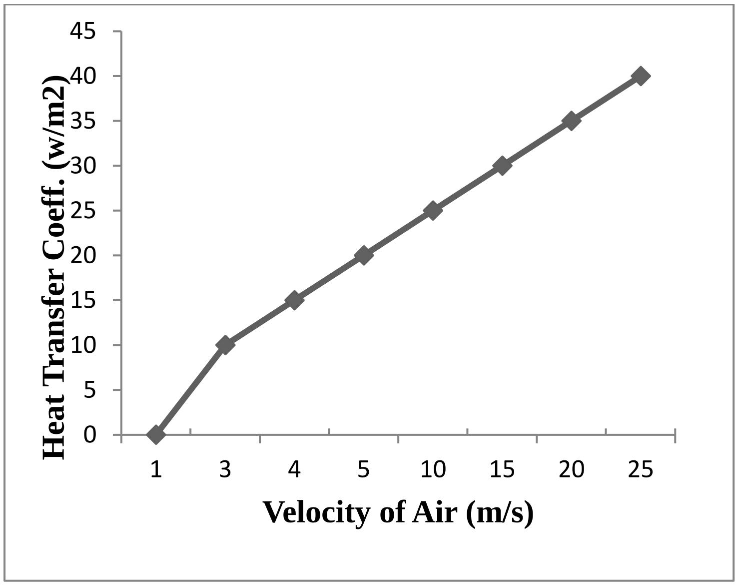


Figure 19: Effect of Velocity of Air on Heat Transfer coefficient

(**Source**: www.engineeringtoolbox.com)

5.6 EFFECT OF TEMPERATURE (t) ON EFFICIENCY (η)

Figure 20 shows that the maximum efficiency of the process is 14 %. This efficiency is achieved at a temperature of 1250ºC and holding time for the process is 20 minute, after which the efficiency decreases.

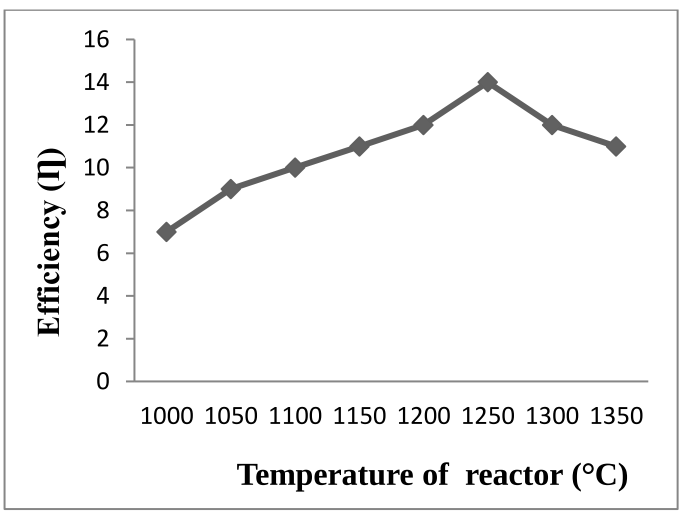


Figure 20: Effect of Temperature on Metal Recovery Efficiency.

Melting point of copper is 1085°C. At a temperature of melting point of copper the metal will start melting. After that as the temperature increases metal melting rate also increases. At a temperature of 1250°C required metal flow rate obtained. Maximum efficiency of metal (Copper) recovery obtained at a temperature of 1250ºC. After required temperature metal will starts to evaporate.

5.7 COMPARISION OF MANUAL, PYROLYSIS AND LATEST TECHNIQUE OF METAL RECOVERY FROM WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT (WEEE)

Comparison of manual, Pyrolysis and latest technique is important to compare the different parameters of the process like metal recovery efficiency, total capital investment and health hazardous etc. The comparison between the named processes shown in table 10.

TABLE 11: Comparison of Manual, Pyrolysis and Hydrometallurgical Technique.

S. N0.	MANUAL PROCESS	PYROLYSIS	HYDROMETALLURGICAL PROCESS
1.	Flow rate is very small (2 Kg/hr).	Flow rate is moderate (6Kg/hr).	More than one item is extracted in single time.
2.	Cost of the manual process is very small, but it is hazardous to human health and environment.	Less pollute environment, as compared to manual process.	Almost Pollution free.
3.	Manual process is Least expensive but the cost dearly to human health and environment.	Pyrolysis is less expensive but suits better than the manual process for a small scale industry.	Hydrometallurgical process incurs a huge amount of money.

4.	Manual process is not safe because in this process waste burning in open environment.	Pyrolysis is safe because it is processed in a close chamber.	Noiseless and free from almost all types of hazards.
5.	Manual process is used only for copper Extraction.	Pyrolysis can be used for more than one metal because it could operate at different temperatures.	Approximately 12 items can be extracted in a single filling.
6.	This process has a poor efficiency, always less than 10%.	This process has efficiency up to 14%.	Hydrometallurgical process is most efficient process.

5.8 FLOW RATE OF METAL RECOVERY IN DIFFERENT PROCESSES

Figure shows the Flow rate of different Metal Recovery Processes. Manual process has least flow rate of 2 kg/hr and Pyrolysis process has moderate flow rate of 5 kg/hr. The Latest Technology has much better than the both processes. Because of high capital investment these processes are not used for small scale.

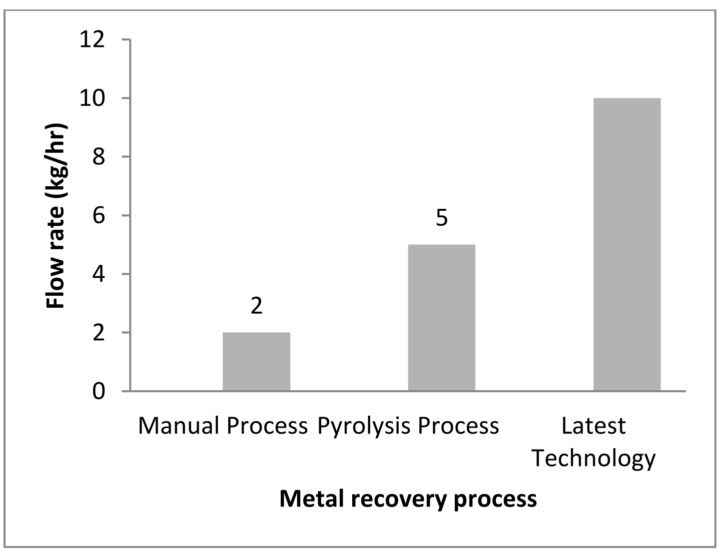


Figure 21: Flow rate (kg/hr) of different processes of metal recovery

5.9 METAL RECOVERY EFFICIENCY (η) OF DIFFERENT PROCESS

Figure 20 shows the Efficiency of different Metal Recovery Processes (Manual, Pyrolysis, Latest technology). In all discussed processes, manual process has least efficiency less than the 10%. Pyrolysis process has moderate efficiency 14% and Latest Technology has efficiency better than the both processes about 20% for copper Extraction. Latest technique is an import technique and require a big amount of money, but plasma pyrolysis reactor is very low in cost as compared to imported technology.

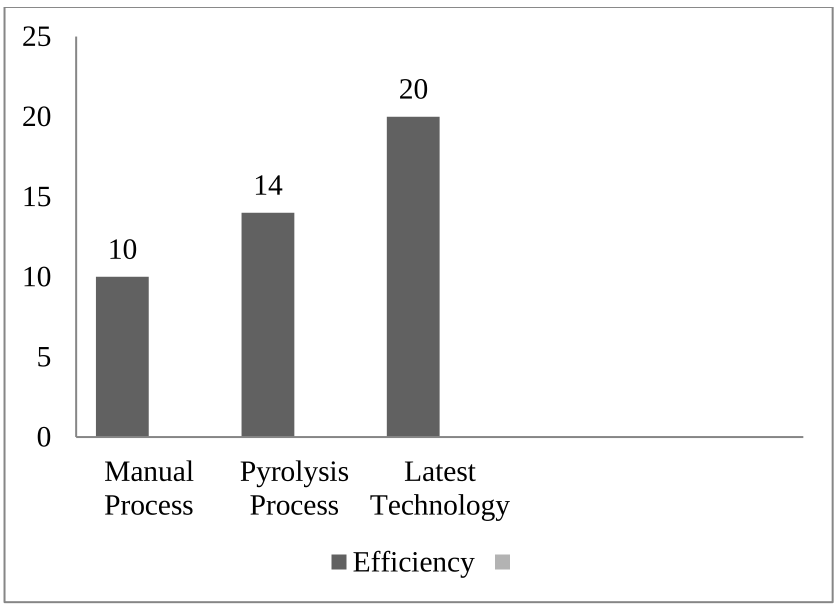


Figure 22: Efficiency (η) of different processes of metal recovered

If the gases released from the reactor are securely handled, then it is one of the economic and efficient recycling process. If this pyrolysis process used as small-scale industries, then it leads to the formal recycling method cause less harmful effect on human health and environment.

CHAPTER 6
CONCLUSIONS AND FUTURE SCOPE

6.1 CONCLUSIONS

E-waste is a big issue because the rapid generation of end-of-life electronic products. This end-of-life product leads the heavy metal contamination in environment. Informal recycling is the main problem to pollute human health and environment badly. So now E-waste requires serious concern. This project work leads the formal recycling method and reduces informal recycling of E-waste (Printed circuit board). This project works extensively focused on the formal recycling process and metal recovery efficiency of the E-waste. The following points calculated from the research are as following:

- Plasma pyrolysis process enhances the **Metal Recovery Efficiency up to 14%.**
- Pyrolysis process is safe and reduces hazards to Human health and environment and is **suitable to Indian scenario.**
- By developing this innovative plasma technology for waste processing, it proved that such smelting processes can designed and the structure of the device can developed for Indian small-scale industries which could be made near the collection centers of wastes.
- It is beneficial for every region in India to find the possibilities that will allow reduction of export of valuable resources in the form of an "artificial ore" abroad, and to develop the new ways of use and production from resources we have.
- If pyrolysis process will use in small-scale industries, it will promote employment up to an extent.
- It will also check the possible soil contamination by these E-wastes.

- It will help to reduce a large amount incurred in an expensive imported machines there by leveling off the companies’ extravaganza.
- It will eliminate the need of skilled labor to run the state of the art machines.

6.2 FUTURE SCOPE

The thesis work has presented a framework for design and modeling of plasma pyrolysis reactor, modeled for small-scale industry which leads to the formal recycling. The model represents the following enhancements in the future are as:

- Plasma pyrolysis process is very useful and could be used to recover other metals like lead and tin with the same reactor.
- The recovered slag is also used for the different engineering purposes like frames, artificial windows and so on.
- Secure handling of harmful gases emanating from the reactor.
- Formal recycling is responsible to reduce emission of green house gases.
- It promotes the formal recycling and reduces the informal recycling up to a valuable extent.

REFERENCES

[1] Evaluating Electronic Waste Recycling System, Susan Fredholm, M.S. Thesis, MIT, 2008. [Doi: August/12/2014]

[2] The Management of Electric Waste (A comparative study on India and Switzerland), Deepali Sinha, Master Thesis in cooperation with EMPA, University of St. Gallen, Switzerland, [Doi: October/27/2014].

[3] E-waste Volume I: Inventory Assessment Manual, United Nations Environmental Program, [Doi: October/10/2014]

[4] The Product characteristics of calcium –basic compounds pyrolysis with waste printed circuit board, Jie Guan, Jingwei Wang, Xu Min, Wenjei Wu, Elsevier,16 (2012) 461-468.

[5] Copper extraction from the discarded printed circuit board by leaching, Vijyaram R., Nesakumar D., Chandramohan K, Reseach journal of engineering science, 2 (2013), 11-14.

[6] Effective electronic waste management and recycling process involved formal and non formal sectors, S. Chatterjee, Krishan kumar, International journal of physical science, 4 (2009), 893-905.

[7] 11th International conference on Modern Building materials, Structure & Techniques by Jakub Szalatkiewicz, Roman Szewczyk, Eugeniusz Bundy, Tadeusz Missala, Wojciech Winiarski, MBMST, 57 (2013), 433-442.

[8] Electronic waste a case study, Gupta Reena, Sangeeta and Kour Virendra, Research Journal of Chemical Science, 1 (2011), 49-56.

[9] Estimation of waste from computers and mobiles in Iran, Mehdi Rahmani, Ramin Nabizadeh, Kamyar Yaghmaeian, Amir Hossein Mahvi, Massoud Yunesian, Elsevier, Resource Conservation and Recycling, 87 (2014), 21-29.

[10] www.e-waste.com.au [Doi: August/1/2014].

[11] E-waste in India, Research unit Rajya Shaba Secretariat, New Delhi, June 2011.[Doi: August/1/2014]

[12] Generation of electronics waste in India: Current scenario, Dialammas and stake holders, Anwesha Borthakur, Kunal sinha, African Journal of Environment Science and Technology, 7 (2013), 899-910.

[13] www.tata.co.in [Doi: August/28/ 2014]

[14] Management strategies for various E-waste generators in Puducherry region- A case study, S. Pradeep Kumar, S. Govindaradjane, T. Sundararajane, International Journal of Emerging Technology and Advanced Engineering, 1 (2013), P 546-551.

[15] Effective electronic waste management and recycling process involving formal and informal sector, S. Chatterjee, Krishna Kumar, International Journal of Physical Science, 4 (2014), 893-905.

[16] Tata strategic Analysis Report, Aug, 14. [Doi: August/28/2014]

[17] Department-related parliamentary standing committee on science & technology, Environment & forests, Hundred and ninety-second report on functioning of central pollution control board, Rajya Sabha Secretariat, September, 2008.

[18] The E-waste problem, IMS electronics recycling, California. [Doi: August/28/2014]

[19] Milling and separation of multi component of printed circuit board materials and analysis of elutriation based on a single particle model, R. Vetri Murugan, S. Bharat, Abhijit P. deshpanday, Susy Varughese, Pratap Haridoss, Elsevier, Powder technology, 183 (2008), 169-176.

[20] Pyrolysis of scrap printed circuit board plastic particles in a fluidized bed, Qingjie Guo, Xuehai Yue, Minghua Wang, Yongzhuo Liu, Elsevier, Powder Technology, 198 (2010), 422-428.

[21] Thermo chemical treatment of E-waste from small house hold appliances using highly-preheated nitrogen-thermo gravimetric investigation and pyrolysis kinetics, E. Kantarelis, W. Yang, W. Blasiak, C. Forsgren, A. Zabaniotou, Elesevier, Applied Energy, 88 (2010), 922-929.

[22] Current status on leaching precious metals from waste printed circuit boards, Yanhua Zhang, Shili Liu, Henghua Xie, Xianlia Zeng, Jinhui Li, Elsevier, 7th international conference on waste management and technology, 16 (2012), 590-597.

[23] A novel process for detoxification of BERs in waste PCBs, Mingfei Xing, Fushen Zhang, Elesvier, Enviormental science, 16 (2012), 491-494.

[24] The products characteristics of calcium based compounds pyrolysis with waste printed circuit boards, Jie Guhan, Jingwei Wang, Xu Min, Wenjie Wu, Elsevier, 16 (2012), 461-468.

[25] Material recovery and characterization of PCB from electronic waste, Jessica Hanafi, Eric Jobiliong, Agustina Christiani, Dhamma C. Soeanarta, Juwan Kurniawan, Januar Irawan a, Elsevier, International conference on Asia pacific Business Innovation and Technology Management, 57 (2012), 331-338.

[26] Development of an integrated model to recover precious metals from electronic scarp- A novel strategy for E-waste management, Viraja Bhatt, Prakash Bhatt, Prakash Rao, Yogesh Patil, Elsevier, International conference on Emerging Economics, 37 (2012), 397-406 .

[27] Improving the end-of-life for electronic materials via sustainable recycling method, Ping Jiang, Megan Harnay, Yuxin Song, Ben Chen, Queenie Chen, Tianniu Chen, Gillian Lazarus, Lawrence H. Dubois, Michael B. Korzenshi, Elsevier, The 7th international conference on Waste Management and Technology, Environmental Science, 16 (2012), 484-490.

[28] Chemical and biological extraction of metals presents in E-waste: A hybrid technology, Deepak Pant, Deepika Joshi, Manoj K. Upreti, Ravindra K. Kotnala, Elsevier, Waste Management, 32 (2012), 979-990.

[29] Novel approach for processing Hazardous Electronic waste, Ravindra Rajaro, Veena Sahajwalla, Romina Cayumil, Miles Park, Rita Khanna, Elsevier, Urban Environmental Pollution, 21(2013), 33-41.

[30] Enrichment implications of forth flotation kinetics in the separation and recovery of metal values from printed circuit boards, A. Vijaydhar, A. Das, Elsevier, Separation and Purification Technology, 118 (2013), 305-312.

[31] Management and recycling of electronic waste, Pia Tanskanen, Elsevier, 61 (2013), 1001-1011.

[32] Combustion and pyrolysis of electronic waste: Thermo gravimetric analysis and kinetic analysis, Cui Quan, Aimin Li, Ningbo Gao, Elsevier, Environmental science, 18 (2013), 776-782.

[33] A novel recycling approach for transforming waste printed circuit boards in to a material resource, R. Khanna, R. Cayumil, P.S. Mukherjee, V. Sahajawalla, Elsevier, Urban environmental pollution, 21 (2014), 42-54 .

[34] Use of large pieces of printed circuit boards for bioleaching to avoid ‘precipitate contamination problem’ and to simplify overall metal recovery, N.N. Adhapure, P.K. Dhakephalkar, V.R. Tembhurkar, A.V. Rajgure, A.M. Deshmukh, Elsevier, 1(2014), 181-186.

[35] Research progress on the recycling technology for non metallic materials from waste printed circuit board, Wenhong Li, Yan Zhi, Lili Lui, Jinhui Li, Shili Lui, Henghua Xie, Elsevier, The 7th international conference on waste management and technology, 16 (2012), 569-575.

[36] The recovery of copper and tin from waste tin stripping solution Part II: Kinetic analysis of synthesis and real process waste, S. Roy, R. Buckle, Elsevier, Separation and Purification Technology, 68 (2009), 185-192.

[37] Effect of impact velocity on selective grinding of waste printed circuit boards, Shigeki Koyanaka, Shigehisa Endoh, Hitoshi Ohya, Japan, Advance Powder Technology, 17 (2006), 117-126.

[38] Movement behavior in electrostatic separation: Recycling of Metal materials from waste printed circuit board, Lu Hongzhou, Li Jia, Guo Jie, Xu Zhenming, Elesvier, Jornal of materials processing Technology, 197 (2008), 101-108.

[39] Material port fractal of fragmentation of waste printed circuit boards (WPCBs) by high voltage pulse, Yuemin zhao, Bo Zhang, Chenlong Duan, Xia Chen, Song Sun, Elsevier, Powder Technology, 269 (2014), 219-226.

[40] Cementation-induced recovery of self-assembled ultrafine copper powders from spent etching solution of printed circuit boards, O.A. fouad, S.M. Abdel Basir, Elsevier, Powder Technology, 159 (2005), 127-134.

[41] Copper extraction from the discarded printed circuit board by leaching, Vijaya ram. R., Nesakumar D., Chandramohan K., Research journal of engineering science, 2 (2013), 11-14.

[42] Leaching and electrochemical recovery of copper, lead, and tin from scrap printed circuit boards, Andrea Mecucci, Keith Scott, Journal of chemical technology and biotechnology, 77 (2002), 449-457.

[43] Waste to health: Bio leaching of nano particle from e-waste and their medical applications, Devipriya R. Majumdar, Indian journal of applied science, 3 (2013), 277-286.

[44] Recovery of copper from printed circuit board: Modeling and optimization using response surface methodology, M. Soma sunder, R. Saravanathamizhan, C. Ahmed Basha, V. Nandakumar, Elsevier, 266 (2012), 1-6.

[45] Recycling of printed circuit boards, Maria Paola Luda, Integrated waste management, University di Torino, Italy, 2 (2011), 285-298.

[46] Experimental study on metal recycling from waste Printed Circuit Board, Gongming Zhou, Zhizhu Luo, Xulu Zhai, Proceding of the International Conference on sustainable solid waste management, 5-7 (2007), 155-162.

[47] Construction aspect of plasma based technology for waste electrical and electronic equipment (WEEE) management in urban areas, Jakub, roman eugeniusz, Tedeusz, wojciech, Modern Building Materials, Structure and Technique, MBMST, Procedia Engineering, 57 (2013), 1100-1108.

[48] www.engineeringtoolbox.com [Doi: September/05/ 2014]

[49] A Roadmap for Development of Sustainable e-waste Management System in India, Sushant b. Wath, Atul n. Vaidya, p.s. Dutt, Tapan chakrabarti, Elsevier, Science of the Total Environment, 409 (2010), 19-32.

[50] Victory- India introduces E-waste law, Green peace international organization. [Doi: September/3/2014]

[51] Electronic waste in India: problems and policies, Anwesha borthakur1, Pardeep singh, Elsevier, International Journal of Environmental Science, 3 (2012), 353-362.

[52] Development of process for disposal of plastic waste using plasma pyrolysis technology and option for energy recovery, M. Puncochar, B. Raju, P. K. Chatterjee, Elsevier, Procedia Engineering, 42 (2012), 420-430.

[53] The challenges of e-waste management among institutions: a case study of UKM, John Babington Chibunna, Chamhuri Siwar, Rawshan Ara begum and Ahmad fariz Mohamed Elsevier, 59 (2011), 644-649.

[54] Overview of electronic waste (E-waste) management practices and legislations, and their poor applications in the developing countries, I.C. Nnorom, o. Osibanjo, Elsevier, Resource Conservation and Recycle, 52 (2008), 843-858.

[55] Exploring E-waste management systems in the United States, Ramzy kahhat, Junbeum kim, Ming xui, Braden allenby, Eric williams, Peng zhang, Resource conservation and recycling, Elsevier, 52 (2007), 955-964.

[56] A Matter of Electronic Waste; the government issue, Ravinder pal Singh, Journal of Business Management & Social Science Research, Elsevier, 2 (2013), 15-20.

[57] Handling e-waste in developed and developing countries: Initiatives, Practices, and Consequences, Suthipong sthiannopkao, Ming hung wong, Elsevier, Science of Total Environment, 463-464 (2013), 1147-1153.

[58] www.meche.mit.edu [Doi: September/3/2014].

[59] www.livescience.com [Doi: September/8/2014].

[60] Heat transfer through a cylinder, steady state heat transfer, P.K. Nag, TATA McGraw Hill.

[61] Global prospective on E-waste, Environmental impact review assessment, Rolf Widmer, Heidi Oswal Crapf, Deepali sinha khetripal, Elsevier, 25 (2005), 436-458.

[62] Bio-processing of solid wastes and secondary resources for metal extraction – A review, Jae-chun Lee, Banshi Dhar Pandey, Elsevier, Waste Management, 32 (2012), 3-18.

[63] Metallurgical recovery of metals from electronic waste, Jirang cui, lifeng zhang, Elsevier, Journal of hazardous material, 158 (2008), 228-256.

[64] www.cpcb.com

Figure 23: Plasma pyrolysis reactor set up

Figure 24 (a): Metal Recovered **Figure 24 (b):** Slag Recovered

Figure 24: Products of plasma pyrolysis reactor