Comparative End-of-Life Study of Polymer and Paper Based Radio Frequency Devices

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Abstract- In this work end-of-life (EOL) analysis of polymer and paper based radio frequency devices have been carried out. Polymer and paper based RFID antenna has been chosen as a radio frequency device. An attempt has been made to investigate and evaluate the environmental emissions at end-of-life-cycle stage and to explore type and quantity of emissions at their disposal. The Gabi's balance calculation methodology has been employed to determine amount of environmental emissions at the end-of-life cycle stage. Each significant component of the antenna and their corresponding emissions has been investigated in this paper. We have also compared the corresponding emissions to air and fresh water in both the technologies i.e. incineration and land-filling at EOL stage.

Keywords- Paper and Polymer Substrate; End-of-Life (EOL); LCA Software; Sustainability; Printed RFID Antenna

I. INTRODUCTION

People around the world are voicing about the state of the physical environment, global warming and growing adverse environmental effects. The rapid increases in products manufacturing around the globe undoubtedly affect the natural environmental conditions. With the rapid manufacturing technology, one should also consider the quantity and type of emissions in the process of raw material preparation, production and end-of-life stages. Beside this, there is a need to explore environmental assessment, sustainability aspects and disposing methodologies of the manufactured products. The study of End-of-Life (EOL) of a product has been demanded among the people due to increased concerns of the environment [1]-[5].

Based on the above facts, we have been motivated to investigate the environmental assessment, to analyze the emissions into the air and fresh water and to explore the disposal methodologies of the fabricated RFID antenna [6]. We have developed an efficient flexible UHF RFID tag antenna operating at 866-868 MHz based on polymer and paper substrate as shown its layout in Fig. 1 [6]. This is a novel antenna design for passive UHF RFID tags using polymer or paper substrate with aluminum metal for antenna trace.

We have presented the sustainability evaluation, environmental assessment and hazardous emissions during raw material and production processes in our earlier papers [7]-[9]. This work is a continuation of the earlier works. In this paper[1] we are going to examine the following research questions. What are the emissions to the air and fresh water at the end-of-life of paper, polymer and aluminum substrates? What are the comparative amount of emissions in incineration and land filling EOL technologies?

The paper is structured as follows. The next two sections provide descriptions about the related work and proposed methodologies respectively. Section IV describes the achieved results and their analysis. We will also present the tabular explanation about the emissions in the process of incineration and land-filling in Section IV. Discussion and future works have been presented in Section V.

II. RELATED WORKS

Substantial research has been conducted on several key areas related to end-of-life of the electronic products. Some of them are methods of estimating end-of-life electronics exports [10], prioritizing material recovery for end of life printed circuit board [11] and tracking the material, energy and value of end of life of lithium ion batteries [12]. In our previous work, we focused on life cycle assessment of printed antennas particularly on raw material and production processes [8] and gave insight into quantitative environmental analysis of printed circuit board [9]. The present academic literature has not focused on analysis of end-of-life of RFID based antennas. Hence here our work is to quantify the environmental emissions in particular to the air and fresh water, and to explore the quantities of emissions in the process of incineration and land-filling at the end-of-life stage of RFID based antennas.

III. PROPOSED PLAN

A process is defined by its input and output flows. The plan comprises of different manufacturing processes. Usually manufacturing process of printed antenna requires two major substances i.e. paper or poly vinyl chloride (PVC; here also named as polymer) as a substrate and aluminum ingot mix as an antenna trace. These are the input parameters for life cycle assessment (LCA). During the process interpretation one has to consider quantity, amount and particular unit of the materials. The output results of LCA depend on how input parameters and their magnitudes are considered during the process. The real composition and magnitudes of the printed RFID antenna can be obtained after life cycle inventory analysis (LCIA).

TABLE I PROCESS INTERPRETATION OF PAPER/POLYMER RFID ANTENNA

S.N.	Flows	Amount(kg)	Unit
1.	Paper Coated/PVC	5000	kg
2.	Aluminum ingot	1300	kg
3.	Total Production (No. of Pieces)		6.3 Million

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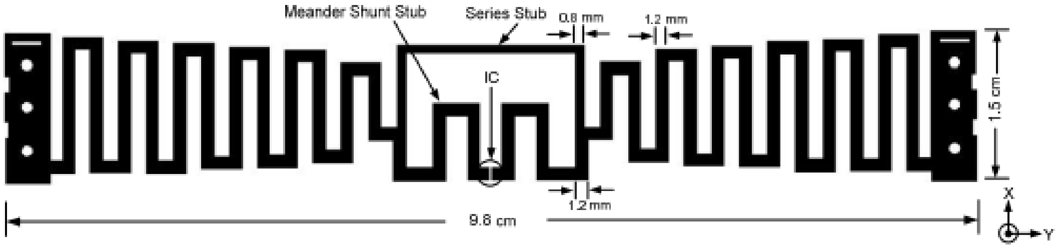

Fig. 1 Layout of UHF RFID tag antenna for European frequency band

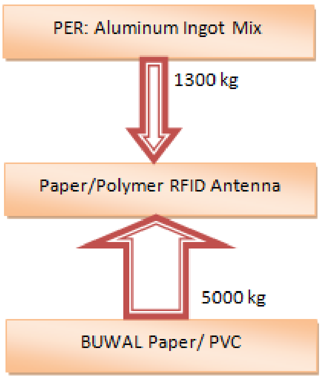

Fig. 2 Modeling plan for EOL of printed antenna

Table I shows the process interpretation for manufacturing printed paper and polymer substrate RFID antennas. The masses of materials are chosen as per the knowledge of materials and devices employed for fabrication of antennas [14]-[21]. The plan for paper/polymer substrate printed RFID antenna is shown in Fig 2. It comprises of a plan 'paper/polymer RFID antenna' along with two connected processes 'aluminum ingot mix' and 'paper wood free coated/PVC'. We have generated the model such that the production of 6.3 million printed RFID antennas require 5000kg of wood free coated paper/PVC and 1300kg of aluminum ingot mix. The total number of products (printed RFID antennas) is scalable with the masses of substrate and antenna trace material.

IV. RESULTS ANALYSIS

A number of useful outcomes have been generated which explicitly describes the theme of this paper. Initially we have considered unit mass(kg) of paper, PVC and aluminum to figure out the quantities of emissions at end-of-life stage. We have achieved the quantities of emissions for each significant component of the polymer and paper based RFID antennas after several iterations of simulation. In our next attempt we configure the proposed plan with the specified amount of components to constitute two separate antennas, one is made from paper substrate and the other is from polymer substrate. These results have been illustrated in the following sub-sections.

A. Emissions: Significant Components

We have computed the quantity of emissions for both EOL processes i.e. incineration and land-filling. The concerned outputs for both the processes have been exemplified in the following paragraphs. Paper, polymer and aluminum have been considered as the significant components for polymer and paper based RFID antennas. Fig. 3 and Fig. 4 show the numerical assessment for the amount of emissions to each significant component (paper, PVC and aluminum) in the process of incineration and land-filling respectively.

The incineration of paper produces less polluting emissions to the air and fresh water compared to polymer and aluminum. The exact figures for these emissions have been shown in Table II.

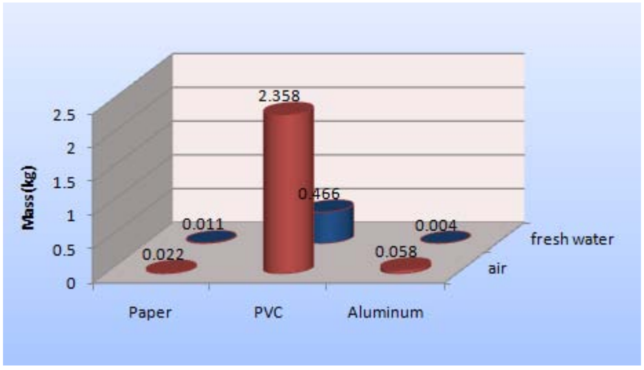

Fig. 3 Amount of emissions in incineration process

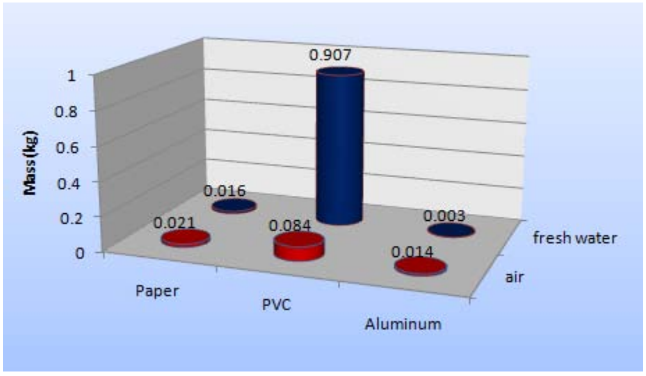

Fig. 4 Amount of emissions in land-filling process

TABLE II EMISSIONS FROM SIGNIFICANT COMPONENTS

1. Incineration				
S.N.	Unit Mass(kg)	To air	To fresh water	Unit
1.1	Paper	0.022	0.011	kg
1.2	Polymer	2.358	0.466	kg
1.3	Aluminum	0.058	0.004	kg

2. Land-filling				
S.N.	Unit Mass(kg)	To air	To fresh water	Unit
2.1	Paper	0.021	0.016	kg
2.2	Polymer	0.084	0.907	kg
2.3	Aluminum	0.014	0.003	kg

B. Comparative EOL Emissions: RFID Antenna

The comparative end-of-life emissions have been computed for both the processes of incineration and land-filling. Fig. 5 demonstrates the comparative analysis for amount of emissions to the air where as Fig. 6 exemplifies the amount of emissions to the fresh water. The essential elements and their proportions causing emissions to the air and fresh water in process of incineration and land-filling have been illustrated in Table III. Heavy metals, Inorganic, Organic and particles are the common forms of emissions to the air and fresh water. The results depict that the polymer based RFID antenna causes more polluting emissions to the air and to the fresh water compared to the paper based antenna in both EOL technologies.

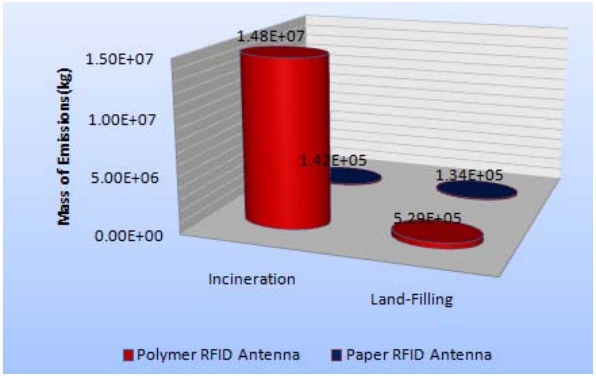

Fig. 5 Comparative emissions to air

V. DISCUSSION AND FUTURE WORKS

This research work offers several essential contributions. Obvious practical implications of our results show that incineration and land-filling of paper causes polluting emissions to the air and fresh water. The emissions to the air contain key toxic components such as carbon dioxide, carbon mono oxide, and hydrogen chloride, and ammonia. A smaller proportion of emissions to the industrial soil have been observed additionally in the process of land-filling of paper in spite of emanating identical emissions to the air and fresh water in both EOL technologies of incineration and land-filling.

Another imperative outcome clearly demonstrates that the incineration and land-filling process of unit mass(kg) of aluminum release 56.1 gram and 13.5 gram of carbon dioxide respectively. The amount of carbon foot print deposition in both EOL technologies suggests that land-filling is an environment friendly technique for disposing aluminum metals. The polymer shows a remarkable characteristic among

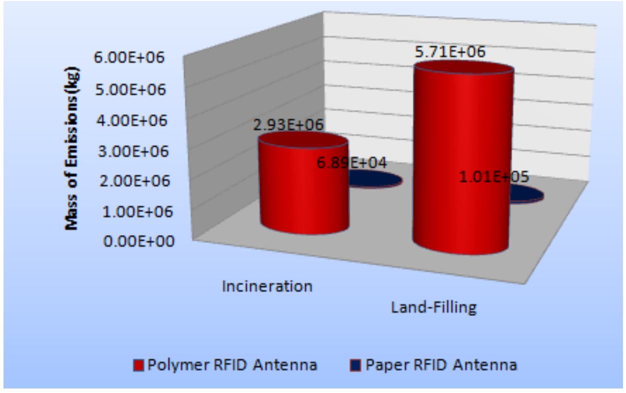

Fig. 6 Comparative emissions to fresh water

several fabricating components of RFID antenna. The polymer needs to be disposed with substantial care as incineration of unit mass (kg) produces 2.358 kg emissions to the air and 0.466 kg emissions to the fresh water.

The comparative study on end-of-life of polymer and paper based RFID antennas concludes two important facts. The selection of substrates during manufacturing an RIFD antenna plays an important role in EOL stage. With the similar performance (Gain, Bandwidth and Resonant Frequency) obtained using polymer or paper material, the paper substrate RFID antenna would be advantageous in terms of environmental emissions in all the stages of its life cycle. Secondly landfilling process causes lesser harmful emissions to the environment for both polymer and paper based RFID antenna.

The important future work is to figure out amount of toxic emissions especially carbon dioxide, carbon mono oxide and nitrous oxide in the manufacturing process of polymer and paper RFID devices.

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TABLE III ENVIRONMENTAL IMAPCTS AT END-OF-LIFE STAGE

S.N	Environmental Impact	Incin.: Polymer	Incin.: Paper	Land-Filling: Polymer	Land-Filling: Paper	Unit
1	**Emission to Air**	**14854140**	**141567**	**529962**	**134013**	**kg**
1.1	Heavy Metals	4.65	1.75	1.10	1.36	kg
1.2	Inorganic Emissions	14796810	140074	479864	132967	kg
1.3	Organic Emissions	6591	1024	50016	831	kg
1.4	Particlesto Air	50922	467	79	215	kg
2	**Emission to Fresh Water**	**2935359**	**68890**	**5715864**	**100705**	**kg**
2.1	Heavy Metals	192	136	85	63	kg
2.2	Inorganic Emissions	2931768	60499	2962575	85982	kg
2.3	Organic Emissions	91	30	36	46	kg
2.4	Particlesto Fresh Water	1029	94	83	113	kg

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