Feasibilities of Aluminium Recovery from Combined Packaging Waste

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Abstract
This research aimed to evaluate the different possibility of recovery Aluminium from combined packaging. Increasing consumer demand and maintaining the quality of various products led to the development of multifunctional food packaging. In many cases, the functionality of the packaging increases with the increase of the various materials used for combined packaging. Aluminium foil, various polymer, paper, and cardboard are the most common materials used in the combined packaging. Although the combined package provides adequate protection of the product from various external factors, it has a negative side, recycling of these types of waste is rather complicated, for this reason, combined packaging waste is disposed in landfills or burned. For recovery of aluminium from this type of packaging waste, we selected wet separation process method. There were chosen three different separating reagents, three types of combined packaging waste samples, and condition was: temperature 60-100oC, 300 rpm. Mixing and 1 g / 200 ml of the sample, time was different, for organic solvent it was approximately 8 minutes, for acid reagent it was 30 minutes.

Keywords — *Aluminium, packaging waste, Recycling, Metal recovery, polymers*

I. INTRODUCTION

The packaging is the main and important part of many products. Increasing consumption of the product leads to growth generation of packaging waste. However, compared with previous decades, the current management of packaging waste is much better and is constantly being improved. [1], [2].

Packaging waste forms a significant part of municipal solid waste and as such has caused increasing environmental concerns, resulting in the strengthening of EU Regulations to reduce amounts of packaging waste [3], [4], [5]; Accounting for the fastest-growing segments of the packaging industry, combined (flexible) packaging provides an economical method to package, preserve and distribute food, beverages, other consumables, pharmaceuticals and other products that need extended shelf life. [6], [7].

Strengthening environmental requirements and strengthening the impact of sustainable consumption and circular economies on national policies, the recovery of aluminium from similar types of waste is becoming increasingly important. [8]

In the scientific literature several methods are indicated for recovery of Al from combined packaging waste (further CPW): pyrolysis [9], plasma [10], hydrometallurgical method [11], this method was employed for recycling waste pharmaceutical blisters (WPBs) by using hydrochloric acid; wet separation [12], [13]; and cleaner and profitable industrial technology, by using switchable hydrophilicity solvents [14] this method was for full recovery of metallic and non-metallic fraction of waste pharmaceutical blisters.

In recent years, the focus has been on the wet separation method, which is based on the selection of various solvents (reagents). The suitability of solvents such as formic acid, acetic acid, hydrochloric acid and the mixed benzene-ethanol-water organic solvent, which are used for aluminium recovery, was analysed. The performed investigations showed that aluminium recovery depends not only on the selection of the solvent but also for other factors which affect the process: temperature, mixing rate, sample size, the sample-reactant ratio in the stirrer, concentration of reagents, separation time. [15], [16];

By optimizing the maintenance of important parameters for the process, it is possible to develop a relatively good scheme of the process. However, there is no wider analysis of process applications for different types of combined packaging in the literature, also, there are no methods for assessing the potential impact on the environment and cost-effective analysis, depending on the divergent reagent chosen.

Based on the published experimental data and the generating streams of CPW, it becomes clear that further research is needed to ensure the most efficient and environmentally friendly treatment processing of CPW. Today, still a large part of the combined packaging waste is disposed in landfills or incinerated (with or without energy recovery) since such treatment methods are economically more profitable for the industry. Also, the recycling of CPW is not regulated by legislation, which enables companies instead of cheaper disposal methods to choose to recycle. Further CPW investigations are needed not only because of access to landfills or incineration plants, but also because of a lack of resources, the most important of which is aluminium. Although aluminium is a fairly common metal in the earth's crust, it is worth taking the opportunity to restore this metal to less environmentally hazardous ways, thereby avoiding mining, which does not correspond to the concepts of sustainable development, circular economy, and conservation of resources. Therefore, the search for more effective ways of recycling the CPW should be the same priority at the national and global levels as the reduction of other environmental problems. [17], [18].

The aim of this study was an objective assessment of the possibilities of aluminium recovery from CPW while considering these main tasks:

- To determine the aluminium amount in different types of CPW;
- To test several methods for aluminium separation by chemical reagents from polymer matrices in CPW;
- To select the optimal method for aluminium recovering from CPW and to evaluate its cost-effectiveness and environmental impact.

In order to achieve this goal, experimental studies have been carried out to recover aluminium from CPW, which corresponds to a comparison of the results described in the scientific literature, and the efficiency of recovering aluminium from CPW from an environmental point of view has been determined.

II. RESEARCH PROCESS AND USED METHODOLOGY

Three types of CPW have been selected for experimental research – Tetra Pak Packages (T), pharmaceuticals blister (B) packaging and aluminate film (F) packaging. Performing the first research task - to determine the aluminium amount in different types of CPW – The samples of the packages were solved in "aqua regia" and the Al concentration in the solution was measured.

According to the relevant literature, it is available to presented possible methods for aluminium recovering from CPW, wet process separation method has been selected for experimental studies, using three separating reagents: organic solvent mixture and two acids of different strengths and other chemical and physical properties [13], [19], [20], [21]. In order to objectively compare the efficiency of separation of aluminium with different separation agents, differences in the mass of the sample before and after treatment were determined. Also, the chemical analysis of Al in solutions was measured to determine the possible loss of Al mass. Each experiment was performed three times and average values were calculated.

A. Determination of a Aluminium content in CPW

Al content in the analysed CPW after dissolution in the aqua regia was determined by spectrophotometric analysis of UV absorption with Chromazuroli S (chromogenic reagent) according to Wang C., Wang H. and Liu Y. [19]. This method is chosen because of the relatively fast and simple analysis, and because of the authors conducted their experiments on packaging pharmaceutical blisters (B), which, because of the structural similarity of this type of package with the analysed other packages, allows to make assumptions that this method is the most suitable for the investigation.

As mentioned above, in the study of Wang C., Wang H, and Liu Y, samples (B) were dissolved in hydrochloric acid (HCl). After complete dissolution of Al, the resulting solution was analysed using a UV spectrometer with Chromazuroli S (CAS). However, when trying to repeat the described method in our study, it was found that the samples are not completely soluble in HCl acid, and the aluminium residues in the package are fixed visually. Therefore, the method was modified and samples of all three types of packages were treated with stronger acid media - aqua regia (ratio of HNO3 nitric acid to hydrochloric acid HCl 1: 3).

In addition, the analysis was carried out as follows: 5 ml 0.1% CAS, 5 ml pH 4.6 acetic acid/sodium acetate buffer and 0.1 ml of the test sample were added to a 100 ml volumetric flask, and then diluted with distilled water to the full volume of the flask. After 5 minutes, a chromogenic (colour) reaction of the sample and intensity of light absorption ($\lambda = 574$ nm) are measured in a 5 cm cuvette.

The Al content in the solution is calculated according to the calibration curve. A series of solutions with known Al concentration was prepared for the calibration curve and the optical density of these solutions was measured.

B. Aluminium recovering from CPW

Samples of three types of CPW: Tetra Pak (T) packages, pharmaceutical blister packaging (B) and aluminium-coated film (F) packaging were analysed experimentally. Samples of packaging were collected from consumers when they consumed products, so the samples actually correspond to the object of research - combined packaging waste. All remnants of food, beverages, and drugs are removed by washing with water before testing.

The components of the Tetra Pak package are paper/cardboard and polyethylene/aluminium laminate (Al-PE). Since the paper/paperboard layer is unlikely to interfere with the analysis and will not interfere with the processes occurring in the sample to make all samples more similar in composition and the Tetra Pak sample is poured into the water and the paper/paperboard layer is removed mechanically before the experiments begin. The remaining Al-PE layer is well dried to remove moisture before analysis. The prepared Al-PE layer is cut into a 1 cm by 1 cm section and weighed in 1 g of the cut sample for each experiment.

Samples of a pharmaceutical blister packaging and aluminized films were prepared, respectively, by cutting the sample into a 1 cm x 1 cm portion and weighed in 1 g of the cut sample for each experiment. Samples cut according to the recommendations given in the scientific literature. The liquid-solid phase relation was selected in accordance with the recommendations of the scientists - 1 g sample and 200 ml reagent [12], [13], [19], [21].

Under appropriate conditions, the reagent separates the aluminium and plastic layers in the laminate, so if the experiment succeeds, two products are obtained- an aluminium foil layer and a plastic layer. The experiments were carried out using three different reagents under the same conditions to determine the most suitable reagent for the analysed samples and in accordance with the recommendations of scientific articles on the choice of reagents. The following reagents were used:

- 4 mol/l formic acid (F);
- 4 mol/l acetic acid (A);
- The mixed organic solvent (O): benzene – ethanol–water, the volume ratio of 30-20-50 respectively.

Each sample (T, B, and F) was exposed to each of the reagents (F, A, and O) so that 9 experiments were performed, each of them was repeated three times, thus 27 experiments were carried out. Each experiment has an identification number in accordance with the principle: type of sample + type of separation reagent + test number, such as AT1, where A is 4 mole/l of acetic acid separation reagent, T is Tetra Pak sample, and 1 is the serial number of the test.

After separation, the acid-treated samples were washed with distilled water and dropped out for twenty-four hours to dry at room temperature. Meanwhile, the samples treated with an organic solvent were thoroughly washed with ethyl alcohol and distilled water before the drying, so that the organic solvent residues were removed from the products obtained [12]. In addition, the samples were dried at room temperature. Completely dried samples are sorted to separated aluminium and plastic parts and undiluted layers of packaging, each fraction (products and by-products) are weighed.

To determine the possible loss of the experimental yield, i.e., the conversion of Al into a soluble form, depending on the selected separation reagent, after the experiments, the remaining solutions are analysed in accordance with the procedure described in Chapter A.

The duration of the experiment and the scheme of the process were adapted in accordance with Yan D. et al. (Figure 1.) [13]. Experiments are conducted in such constant conditions:

- 60-100°C temperature;
- mechanical stirring speed ~ 300 rpm;
- sample size ~ 1 cm x 1 cm;
- 1 g mass of investigated sample;
- 200 ml separation reagent volume;
- 30 minutes of maximum time spent on the sample in the stirrer.

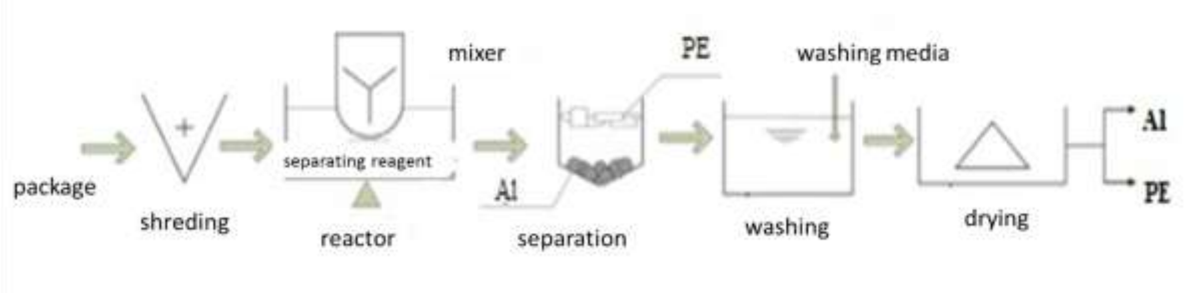

Fig 1: For experimentation adapted process scheme according to Yan D. et. al. [13]

After creating a mass of products and by-products, the experimental results were processed by the MS Excel software.

C. Life cycle assessment

In order to determine the potential impact of the studied methods on the environment, a life-cycle assessment was conducted to evaluate and compare the potential environmental effects of the three separation reagents used in the recovery of Al from the combined packaging waste.

a) Definition of purpose and scope

The purpose of this study is to compare the extraction of aluminium from combined packaging waste by a wet method using three different divergent reagents from an environmental point of view. Life cycle assessment is performed for the aluminium recovery process from the packages described in Subsection 2.3. One kilogram of waste from an Al-PE laminate Tetra Pak packaging is defined as a functional unit in this study. The functional unit consists of polyethylene and aluminium composite materials, where their mass ratio is 70-80% and 20-30% respectively. All incoming and outgoing process flows are normalized to this function unit.

b) Boundaries of the system

In this study, the boundaries of the system include the technological part of the extraction of aluminium from the packaging process. The study does not include the resources needed to transport materials, waste, and products at any stage of the life cycle, nor does it include the resources needed to produce the packaging. The focus is on the technological process of recovering aluminium from the packaging, taking into account the consumption of materials and energy, emissions into the environment and the disposal of by-products. Inventory data are presented in Figure 2. And Table 1.

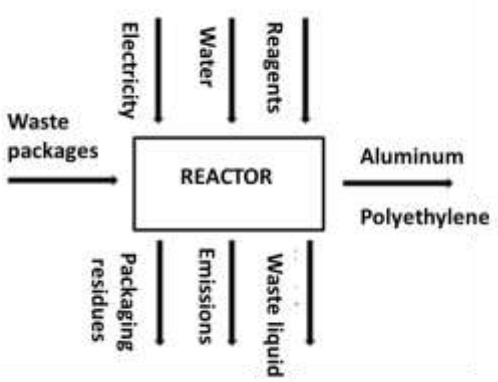

Fig. 2. Process scheme for life cycle assessment

C. Inventory analysis

Data for input and output materials and energy flows were needed for life-cycle assessment, it was compiled from the experimental studies described above (Table 1) and data that should be indicated in the scientific literature [27]. The relevant processes and materials related to these data from the Eco-invent database.

Table 1. Inventory data for life cycle assessment

Input	**Output with Acetic Acid** ($C_2H_4O_2$)	**Output with Formic Acid** (CH_2O_2)	**Output with C_6H_6-C_3H_6O-H_2O mixture**
Waste packaging: 1 kg	Aluminium: 0.18 kg	Aluminium: 0.20 kg	Aluminium: 0.32, kg
Reagent: 200 ml	Polyethylene: 0.78 kg	Polyethylene : 0.75 kg	Polietilene:0.67 kg
Electricity: 700 kWh	Waste liquid:200 ml	Waste liquid: 200 ml	Waste liquid: 200 ml
-	Unseparated Al-PE:0.01 kg	Unseparated Al-PE: 0.04 kg	Unseparated Al-PE: - 0
-	Emissions: 0.63 g/s m^2	Emissions: 0.83 g/s m^2	Emissions(**C_6H_6**):4.71 g/s m^2
-	Washing media[1]:10 ml	Washing media [1]:10 ml	Emissions (**C_3H_6O**): 1.91 g/s m^2
-	-	-	Washing media [1]: 10 ml
-	-	-	Washing media [2]: 10 l

1 – Washing media for products - water;

2 – Washing media for products - ethanol.

d) Calculation of emissions

Evaporation of volatile organic and inorganic compounds per unit time from the liquid phase or solvents is calculated as follows [Nafas, 2000]:

$$P = \frac{MD}{RT} F \frac{P_{soc.} - P_{dal.}}{l} \quad (1)$$

Where:

A - by a coefficient depending on the Reynolds criterion;

M - The molar mass of the evaporated material;

D - The diffusion coefficient of the evaporated material in air under current temperature conditions;

R - The gas constant;

T - The absolute temperature, equal to the arithmetic mean for the liquid surface and the ambient temperature;

F - The evaporation surface area, m2;

Psat .. - The saturated vapor pressure of the evaporated compound under the conditions of liquid temperature, Pa;

Pparc. – The partial pressure of the evaporated compound in atmospheric air, Pa;

l - The length of the airflow path above the evaporation surface, m.

Such emission calculations were performed for each separation reagent, and the results presented in the calculations in Appendix 1 are included in SimaPro simulation software for environmental impact modelling.

e) Characteristics of the impact

The results of the life cycle assessment were analysed taking into account the environmental impact of each separation agent. In the light of M. Xie et. And others 2016, which is similar to this analysis, the Eco-indicator 99 method was used at the stage of environmental impact assessment. The assessment was carried out in 10 impact categories: carcinogenic effects on human health, ozone layer depletion, climate change, acidification/eutrophication, ecotoxicity, land use, depletion of resources - minerals, ionizing radiation, and health effects through the respiratory system. The life cycle assessment was carried out using the SimaPro software.

III. Results and Discussion

A. Aluminum content in the packages

Tetra Pak Packages (T), pharmaceutical blister packaging (B) and aluminum-coated film (F). The amount of aluminum content in the various packages was determined by dissolving the Tetra Pak, the blister packaging and the aluminum-coated film in the "aqua regia". These results showed that the Petra Pak contains 32% of aluminum after removing a layer of cardboard-paper, and the remaining 68% - polyethylene. The blister contains almost 23% aluminum. Meanwhile, the smallest share of aluminum is in the package with an aluminum coating - 0.13% (Figure 3).

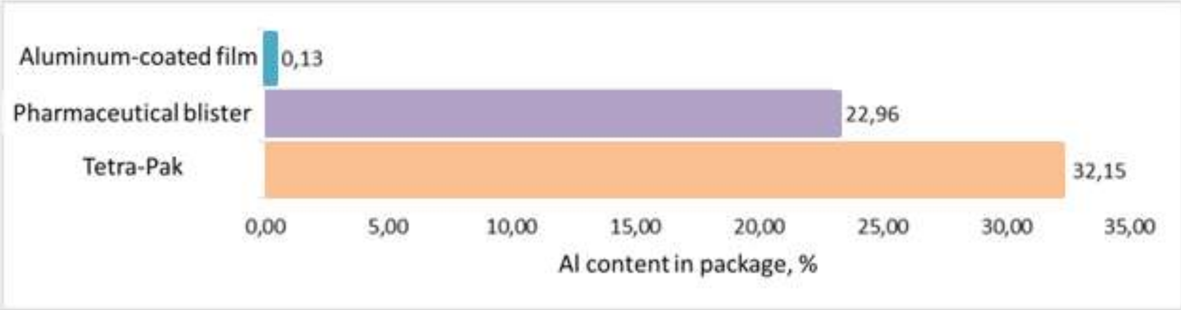

Fig. 3. Al content in different combined packages

In the scientific literature under analysis, the amount of aluminium for different types of packaging varies. For example, it is usually indicated that the Al content in a Tetra Pak is 5% of the total package [28], [29]. However, in aluminium and plastic laminates, the aluminium/polyethylene ratio is 20-30% -70-80%, respectively, after removing a layer of cardboard-paper [27], as shown by the results of the spectrometric analysis. According to the sources of scientific literature, the content of aluminium in pharmaceutical blister packs ranges from 15% to 20% by weight [15], [11] ; [12]. A similar result was obtained during our experiments - Al was 23% by weight of the Packaging. Nevertheless, it is most difficult to estimate the amount of aluminium in packages with an aluminium coating. In this type of packaging, the aluminium layer varies in the range of several micrometres and nanometres, depending on the technology used during production [15], [22], which determines the amount of aluminium in the package. The study analysed that not all aluminate film contains the same amount of metal and plastic. For example the packaging of food products from a film covered with aluminium, labelled with a number of 90 packs, which contains a relatively small amount of aluminium, just 0.13% of aluminium from the packaging weight.

B. Aluminium losses during the separation process

Further, after the separation experiments, the aluminum concentration was measured spectrometric method in the remaining solutions to determine the possible loss of aluminum during the experiment. The results are shown in Figure 4. In this analysis, it is clear that during the wet separation with acid reagents, all three packages (Tetra Pak, blisters, and aluminum coating film) are characterized by loss of aluminum. Theoretically, the organic solvent should not dissolve aluminum, and this is confirmed by spectrometric analysis - there are no traces of aluminum in such solutions, therefore it means that the separation of packaging waste with an organic solvent does not cause loss of aluminum yield.

The largest loss of aluminum was in the separation of Tetra Pak with a reactive formic acid - 0.08% (FT). The use of acetic acid reagent is also accompanied by an inevitable reduction in the weight of aluminum - aluminum loss is about 0.02% (Figure 4).

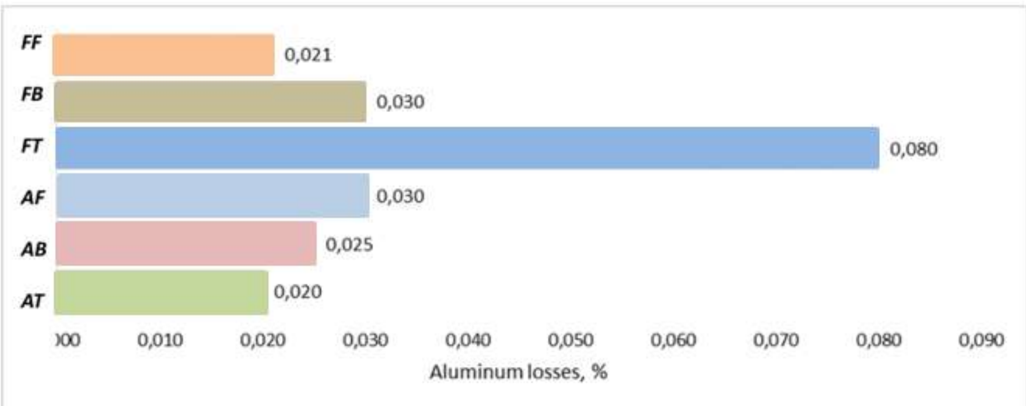

Fig. 4. Al losses during the separation process

(FF – formic acid and Al coated film, FB – formic acid and blisters, FT – formic acid and Tetra Pak, AF – acetic acid and Al coated film, AB – acetic acid and blisters, AT – acetic acid and Tetra Pak)

Compared with the loss of aluminum for Tetra Pak during separation by formic acid, the corresponding loss of aluminum for blisters was lower. However, the loss of aluminum when the reagent is separated by formic acid remains higher than in the separation with acetic acid (Figure 4).

For processing of aluminum-coated film, the largest losses were obtained using an acetic acid reagent, i.e. 0.03%. And for the corresponding treatment with formic acid, aluminum losses were slightly lower - 0.02% (Figure 4).

The results obtained show that the greatest losses of aluminum are due to the use of formic acid - two of the three cases. However, the amount of aluminum found in solutions is relatively small - it is lost from 0.02% to 0.08% of aluminum. Therefore, considering the possible extraction of aluminum from the corresponding type of packaging, it can be argued that such aluminum mass losses can be acceptable in the processing of industrial packaging.

C. Results for aluminium recovering from Tetra Pak by wet separation

Studies with Tetra Pak showed that the best experimental yield was obtained using an acetic acid reagent. During the separation, two products were obtained: aluminum foil (19%) and polyethylene (78%), and determined Al3+ concentration in the separation solution was 0.02%. However, the separation is incomplete, since, at the end of the process, 1.19% of the Al-PE laminate remains undivided, so the total loss of separation with the acetic acid reagent is 1.21% (Table 2).

When the Tetra Pak is separated by formic acid, the higher weight loss due to incomplete separation is 3.59% Al-PE-laminate, and 0.08% aluminum is dissolved in the separation reagent. Nevertheless, the best output aluminum foil was 20%, but after separation, there remained a little less polyethylene - 75% (Table 2).

When using a mixed reagent with an organic solvent, a 100% separation of Tetra Pak - 31% aluminum foil and 69% polyethylene - was achieved (Table 2). There remain undivided or incompletely separated residues, also the insolubility of aluminum in the separation reagent reduces the loss of yield. In addition, experiments have shown that separation with this reagent occurs faster than separation using acidic reagents. Complete separation with a mixture of organic solvents takes place within 10-15 minutes, which reduces the separation time required for dosing, thereby reducing the amount of energy required for separation. According to Zhang S. et. al., such separation also requires a lower reagent-sample ratio, i.e. 100 ml-1 g of sample, so it can be argued that separation with an organic solvent is more effective in this respect [12].

According to Yan D. et. al., and Zhang J.F. et al., the effect of the reagent-sample ratio on research results is very important. These authors investigated the different ratios of reagents and samples in their work, they found that the optimum ratio is 60 l / kg, but in the conclusions they indicate that the reagents/samples ratio is lower, the greater the risk that not the whole sample surface will enter contact with the reagent, which will inevitably adversely affect the effectiveness of separation efficiency. It is also observed that, at a very high reagent-sample ratio, this can lead to higher aluminum losses, that is, most of the aluminum will react with the reagent and go into a soluble form. Therefore, it is proposed to select the reagent to sample ratio based on the desired result of the results [13], [21].

A photo of the products of the separation of Tetra Pak obtained by formic acid is shown in Fig. 5. Aluminum foil does not visually differ from conventional foil, and polyethylene is completely transparent and visually looks intact. The results for acetic acid and the mixed organic solvent were not visually distinct, that is, we had similar products with the same visually perceptible characteristics.

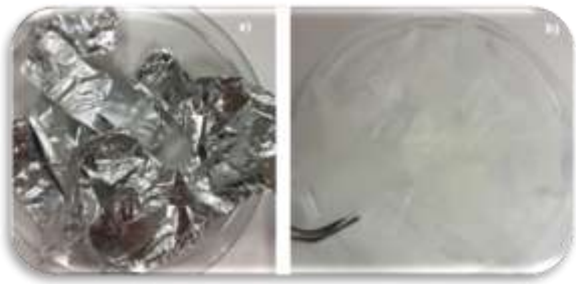

Fig. 5. Tetra Pak separation by formic acid results: a) aluminum foil layer, b) polyethylene layer

According to Yan et al. Thus, recovered aluminum and polyethylene meet the requirements for processed products and is suitable for further processing - aluminum smelting for aluminum ingots and recycling of polyethylene [13].

D. Results for aluminum recovering from pharmaceutical blisters by wet separation

Pharmaceutical blisters contain aluminum and polyvinyl chloride laminate (Al-PVC), so it is assumed that this type of packaging can also be recycled using the wet method. The separation of this package into hydrochloric acid is described, but then aluminum completely reacts with the acid to a soluble state [20]. Therefore, it was proposed to separate the blister packs with formic acid, acetic acid and mixed reagents with an organic solvent. However, the desired separation result i.e. completely separated layers of Al-PVC laminate (14% and 86%, respectively) is achieved only using a mixed organic solvent (Table 2).

When the pharmaceutical blisters were separated with a mixed organic solvent, it was found that the separation time could be shortened, since a complete separation occurred within 8-10 minutes, which was three times less than when the Tetra Pak was separated by acidic reagents. In addition, as already mentioned in the case of Tetra Pak, the amount of reagent used can be reduced, which will further increase the efficiency of separation in terms of energy (due to shorter separation times) and resource costs. Nevertheless, as can be seen in Fig. 5. The separated layers differ in appearance from the results obtained during the separation of the Tetra Pak laminate.

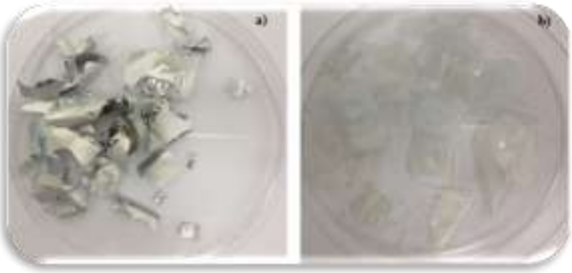

Fig. 6. Pharmaceutical blisters separation by mixed organic solvent results: a) aluminum foil layer, b) polymer layers

The resulting aluminum foil remains a layer of paint that is not eliminated even after the entire separation time (30 minutes). This is due to the fact that during the manufacturing of blisters before the thermal sealing process, in which polyvinyl chloride plastic and aluminum foils are laminated, the aluminum foil is coated with special paints that must be thermally (at least 300oC) and mechanical resistance [15], [22], [23].

Meanwhile, the resulting layer of PVC plastic has clear, visually insignificant evidence of damage, and therefore the premise that this product can meet the processing standards is complete. Wang C., Wang H and Liu Y. A qualitative study of a blister pack and hydrochloric acid in a blister pack and testing of hydrochloric acid in 2015 confirmed that the product obtained is of high quality and purity and is suitable for further processing. [20].

E. Results for wet separation of the aluminum-coated film

The wet separation of the aluminum-coated film with the three above-mentioned reagents was unsatisfactory since the desired result-different aluminum and plastic layers-were not achieved. Despite this, there are external changes to the package (see Figure 7).

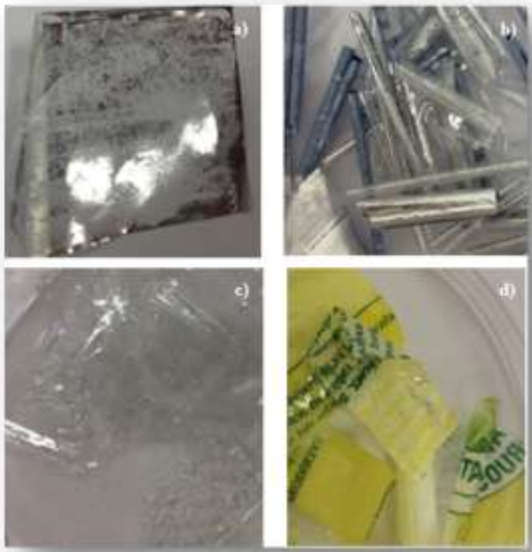

Fig 7. The changes of the aluminum-coated film after solvent separation: a) changes after acid separation; b) changes after organic solvent separation; c) layer without aluminum after acid separation; d) layer with paint after acid separation

With acid treatment, it was observed that the packaging was "divided" into three layers: a plastic layer with silvery dusty aluminum remains (Figure 7a); a transparent thin plastic layer (Figure 7c) and a plastic layer with unremoved paint (Figure 7d) and a layer of plastic with a removed paint (Figure 7b). According to Fig. 7 a, we can assume that aluminum can be slightly dissolved from the plastic. However, since aluminum is "imprisoned" among plastic layers, and the proportion of aluminum is relatively small, therefore, even with acid treatment, aluminum dissolution is difficult, this was confirmed by measuring the aluminum concentration - a certain concentration of aluminum in the solvent was from 0.02 to 0.03. The results of the separation of the organic solvent are shown in Fig. 7b, when the package is not separated from several plastic layers, however, the general physical changes are obvious (result showed physical changes).

Despite the changed appearance of the package, the separation by each of the reagents is considered to be missed. Therefore, we can conclude that wet aluminum, extracted from a film coated with aluminum, for packing potato chips, coffee beans, etc. (Marked with 90 packing labels) is impossible.

Table 2. Materials distribution for Al recovering from CPW by wet separation

CPW-reagent combination	Separated Al, %	Separated polymer, %	Solved Al, %	Non separated residue %
AT	19.38	79.58	0.02	1.02
AB	0.00	0.00	0.03	99.97
AF	0.00	0.00	0.03	99.97
FT	20.19	75.70	0.08	4.04
FB	0.00	0.00	0.03	99.97
FF	0.00	0.00	0.02	99.98
OT	31.63	68.37	0	0.00
OB	14.14	85.86	0	0.00
OF	0.00	0.00	0	100.00

F. Life cycle assessment results

The life cycle assessment to determine the potential environmental impact was carried out to recover aluminum from the combined packaging waste process using various separation reagents. According to the input and output parameters, it was found that with the wet recovering of aluminum, the greatest negative impact is typical for human health. When an organic solvent (C6H6-C3H6O-H2O) is used as the separating reagent, the greatest effect on human health is 65 points (Pt) compared to the other two reagents. A high impact on human health (63.5 Pt) is also due to the use of 4M acetic acid (C2H4O2) for separation. When using 4M formic acid (4M CH2O2), this exposure is 56.5 Pt. The least negative impact on the quality of the Ecosystem is independent of the reagent used - 0.85 Pt. Compared with the effect of reagents on resources, the most negative effect is with acetic acid (2.93 Pt), slightly less for formic acid (2.21 Pt) and the lowest for the organic solvent, only 1.7 Pt (Figure 8)

Thus, the use of an organic solvent as a separation agent in the extraction process of aluminum will have the greatest negative impact on human health. Since benzene, which is part of this reagent, is considered highly toxic, hazardous, carcinogenic and mutagenic compound [24], a similar result was expected. Meanwhile, when analysing the characteristics of acid reagents, it can be considered that acetic and formic acids, on the contrary, are not very dangerous. Acetic acid is a flammable and volatile liquid that seriously damages the skin and eyes, but it is not considered to be a carcinogen [25]. Formic acid is also classified as a flammable and evaporative liquid, toxic by inhalation, seriously damages the skin and eyes, prolonged or repeated exposure may cause allergic reactions for some susceptible persons, but it is also not considered a carcinogen [26]. However, a comparative analysis of the effects of reagents showed that the use of acidic reagents in the process of aluminum recovery is similar in weight to the use of an organic solvent.

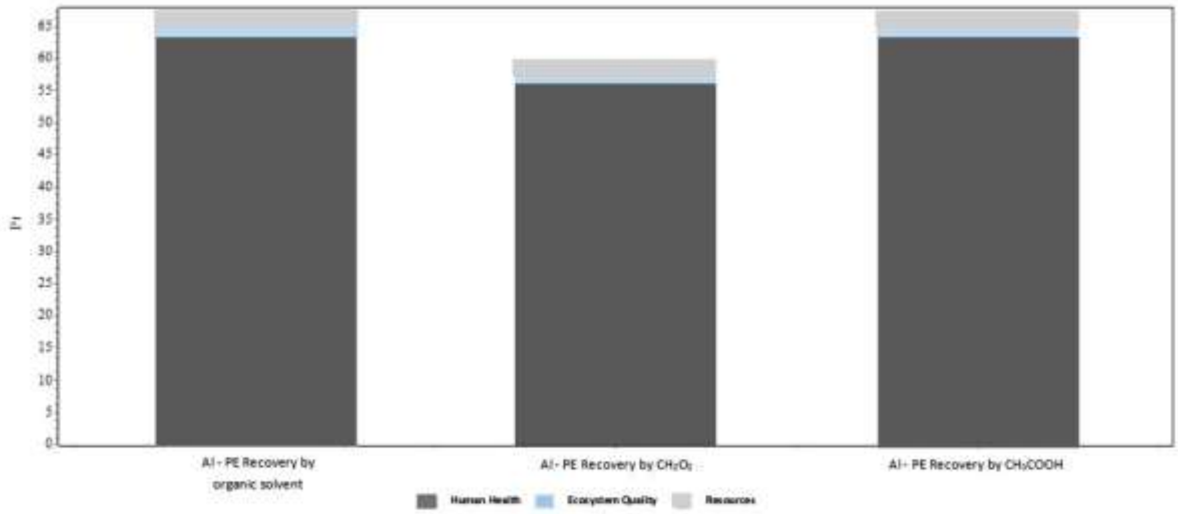

Fig 8. Potential environmental impact of wet aluminum recovering processes for different environmental impact categories

IV. Summary and Conclusion

The main purpose of this study was to investigate and evaluate the possibilities of extracting aluminum from combined packaging waste. It was concluded that:

- Aluminum content for various types of combined packages: for Tetra Pak - 32% of the total package weight, for pharmaceutical blisters about - 17%, and for the film with aluminum coating - 0.13%.

- With respect to aluminum losses, the mixed organic reagent (benzene-ethanol-water) has the best effect of separating aluminum - 30.5%. For a pharmaceutical blister, it is 14.23% of the same reagent. However, wet aluminum recovered from a film coated with aluminum using an organic solvent and acetic and formic acids is not possible.
- When estimating the separation time, the optimal method can be separated by a reagent of a mixed organic solvent - a complete separation of the substances takes place within 8 minutes, and with the use of acidic reagents it lasts about 30 minutes.
- A comparative assessment of the environmental impact on reagents used in the recovery process shows that the greatest negative impact is on human health, and the use of a mixed organic solvent is at least environmentally acceptable.
- Although the recovery of aluminum from combined packaging waste by separating wet reagents is possible, however, taking into account trends in the development of the world and European policies, especially for environmental reasons, this type of waste should be avoided.

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