



# Research of Condensers Recyclability

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## Summary

Nowadays, electric and electronic equipment (EEE) are an integral part of every household and office and it could be said that EEE entered into every pore of modern society. Rapid technological development in the modern world brings as much advantages as it brings bigger amount of waste and this especially refers to the waste electrical and electronic equipment (WEEE). Condensers or capacitors are an integral part of every electronic device. There are many types of capacitors. Aluminium electrolytic capacitors are the most common because their inexpensive electrolytic. The electrolytic capacitors are composed of about 50 % of aluminium by mass and because that they could be a good source of aluminium. This paper presents research of possibility of aluminium recycling from electrolytic capacitors using gravity concentration. Separation of aluminium from the cylindrical shape capacitors in size from 7 to 80 mm was carried out using wet shaking table. Four different grain sizes were tested in plant scale (+8 mm, 8/4 mm, 4/2 mm and -2 mm), while only grain size 4/2 mm were tested in a laboratory scale. The separation efficiency was evaluated on the basis of three parameters: mass yield, aluminium recovery and grade of concentrate. The results obtained in plant scale showed that aluminium recovery and grade of aluminium concentrate increases with decreasing grain size. The best results of recovery of 95.19% and grade of 99.98% were obtained in grain size 4/2 mm, while mass yield was constant at level about 23%. Grain size of 4/2 mm was also tested in laboratory scale and the results showed that small capacitors are more suitable for separation than the larger one. The results showed that it is possible to separate aluminium from capacitors into high quality concentrate.

**Keywords:** e-waste, condensers, recycling, aluminium, gravity concentration

## Introduction

Safe and adequate waste management is one of the greatest challenges of modern society. Waste electric and electronic equipment (WEEE) is one of the largest growing waste streams globally (Tanskanen, 2013). In 2006, the yearly world's e-waste production was estimated between 20 and 50 million tons (UNEP, 2006) and today estimate is about 50 million tons (Wang et al., 2013). Recycling is an integral part of modern waste management system, known as 3R principle (Reduce, Reuse, Recycling) which purpose is to obtain secondary raw material while at the same time brings numerous benefits such as saving of natural resources and energy and reduced pollution. This article presents research of aluminium recyclability from waste electrolytic condensers. Generally, every electronic device contains capacitors. Capacitor is a container of static electricity and energy of the electric field that occurs in the space (filled with dielectric material) between two electrically conductive body (electrodes). There are many types of capacitors, which usually refers to the material used for the electrodes, dielectric and the packaging or sealing method: disk ceramic capacitors, monolithic ceramic capacitors, polyester film capacitors, polypropylene film capacitors, silver mica capacitors, polycarbonate film capacitors, electrolytic capacitors, tantalum capacitors, capacitors with radial leads and capacitors with axial leads.

Aluminium electrolytic capacitors are the most common because their inexpensive electrolytic. They are made using aluminium foil electrodes and dielectric material rolled into layers to increase the effective plate area and

form high capacity in small packages (Figure 1). The aluminium foil is "wetted" with an electrolyte to assist in conduction and increase of the dielectric properties. The electrolyte is a substance (solution, melt or solid) which is electrically conductive due to the movement of free ions, i.e., it has a characteristic of ion conductivity. The basic characteristic of electrolytic capacitors is a high capacity, particularly pronounced at low operating voltages. The composition and material densities of the electrolytic capacitors are shown in Table 1.

## Materials and methods

Material used in the tests were electrolytic capacitors. Size of cylindrical shape capacitors varied from 7 to 80mm (figure 2), in diameter up to 30mm. Capacitors composition is shown in table 1. From table 1 it could be seen that aluminium content in capacitors is 49% by mass and also that its density differs from the other materials in capacitor. Therefore it was decided to conduct the study using gravity concentration based on the difference in density of components to be separated. Testing procedures included comminution of capacitors, classification and separation by shaking table. Separation testing was conducted in laboratory and plant scale. Samples preparation procedure was as follow. Due to the size of inlet of crusher and mill, capacitors were divided into two fractions: "small" capacitors up to 25mm and "large" capacitors, larger than 25mm. In primary comminution stage, small capacitors were comminuted in disc mill, while large capacitors were crushed in jaw crusher. Further procedures were identical for both

fractions. In secondary comminution stage hammer mill was used. Comminuted capacitors were classified into four fraction of different grain sizes: +8mm, 8/4mm, 4/2mm and -2mm.

All four fraction were tested on industrial shaking table and only grain size class 4/2mm were tested on laboratory shaking table. A result of thin film concentration on flat part of table and vertical stratification into layers according to the density between the riffles is typical product arrangement on a partially riffled shaking table (figure 3). Heavier particles (particles of higher density) have the longest path and exits as concentrate diagonally form feed point. Lighter particles (particles of lower density) have shorter path and exits as tailing. Fine particles have the shortest path leaving table in form of slime opposite to the feed point.

After gravity concentration, products were dried and their composition were determined by hand sorting and weighing. Separation efficiency was estimated by three parameters: mass yield, aluminium recovery and grade of concentrate. Mass yield represents the mass of the obtained

concentrate in relation to the feed mass:

$$Y_m = 100 \cdot \frac{m_{conc.}}{m_{feed}} \quad (\%)$$

where  $Y_m$  is yield of mass in percentage,  $m_{conc.}$  is mass of concentrate in grams and  $m_{feed}$  is mass of feed material in grams. The recovery represents the percentage of the total metal contained in the feed that is recovered into the concentrate. The recovery  $R$  can be expressed by follow equation:

$$R = 100 \cdot \frac{C \cdot c}{F \cdot f} \quad (\%)$$

where  $R$  is recovery in percentage,  $C$  is a mass of the concentrate in grams,  $c$  is a mass content of aluminium in concentrate in percentage,  $F$  is a mass of feed in grams and  $f$  is a mass content of aluminium in the feed material in percentage. Grade of concentrate represents the percentage of the metal contained in the concentrate as a final product and can be expressed by follow equation:

Tab. 1 Electrolytic capacitor composition and density of materials

Tab. 1 Kondensatory elektrolityczne - skład i gęstości materiałów

Material	Mass, %	Density, g/cm <sup>3</sup>
Aluminium	49	2.7
Paper	15	0.25 – 1.5
Electrolyte (acid or alkali)	2	~ 0.961
Copper wire	11	8.96
Rubber cover	22	~ 1.1

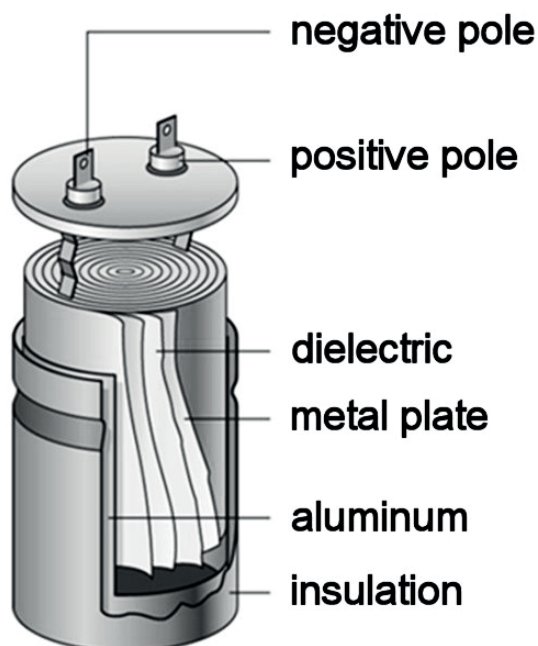


Fig. 1 Structure of electrolytic capacitor

Rys. 1 Struktura kondensatora elektrolitycznego

$$G_C = 100 \cdot \frac{m_{Al}}{m_C} \quad (\%)$$

where  $G_C$  is grade of concentrate in percentage,  $m_{Al}$  is mass of aluminium in concentrate in grams and  $m_C$  is mass of concentrate in grams.

### Results and discussion

Figure 4 shows results obtained by plant scale shaking table. Separation efficiency is evaluated on the basis of three parameters: mass yield, aluminium recovery and grade of concentrate. Mass yield varied from 20 to 42 percent and average value was about 30%. Coarser classes have had approximately equal mass yield, slightly more than 20%, while only the smallest grain size (-2 mm) had the higher

yield of 42 %. Aluminium recovery varied from 16 to 95%. The coarse grain size (+8mm) had the smallest recovery. It can be noted that recovery increased with decreasing grain size up to grain size 4/2 mm. Further reduction in grain size resulted in decreased recovery. Grade of concentrate showed the same tendency as the aluminium recovery. The coarse grain size (+8mm) had the lowest concentrate grade of 16%. Grade of concentrate have had increased up to almost 100% for grain size of 4/2 mm, and then had decreased to 71% in the smallest grain size (-2mm).

Grain size and the comminution also have had an impact on the separation results, because the liberation of different materials “locked” in one coarse particle is achieved during material comminution. Looking at the results obtained for different grain sizes, it can be said that the coars-



Fig. 2 Capacitors used in testing  
Rys. 2 Kondensatory użyte w badaniu

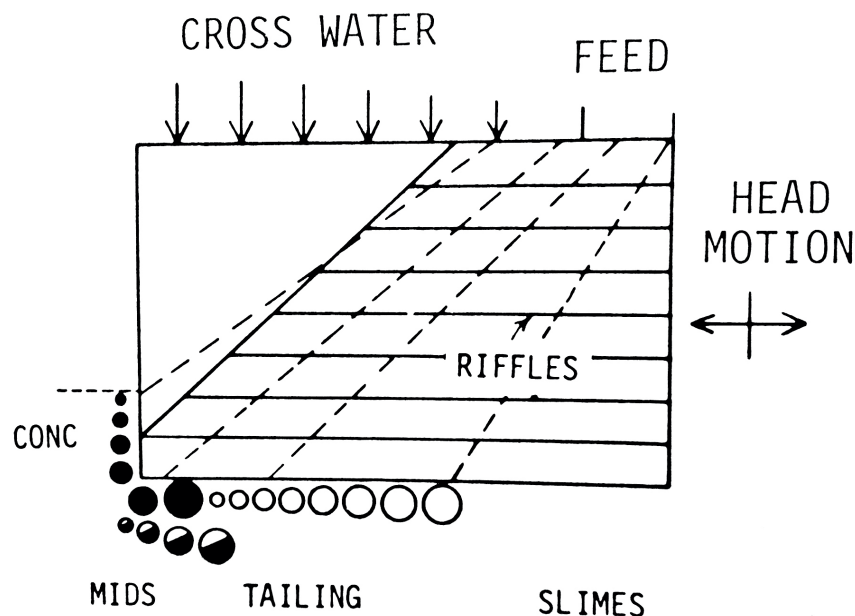


Fig. 3 Typical products arrangement on a shaking table (Burt, 1984)  
Rys. 3 Typowe produkty na stole koncentracyjnym (Burt, 1984)

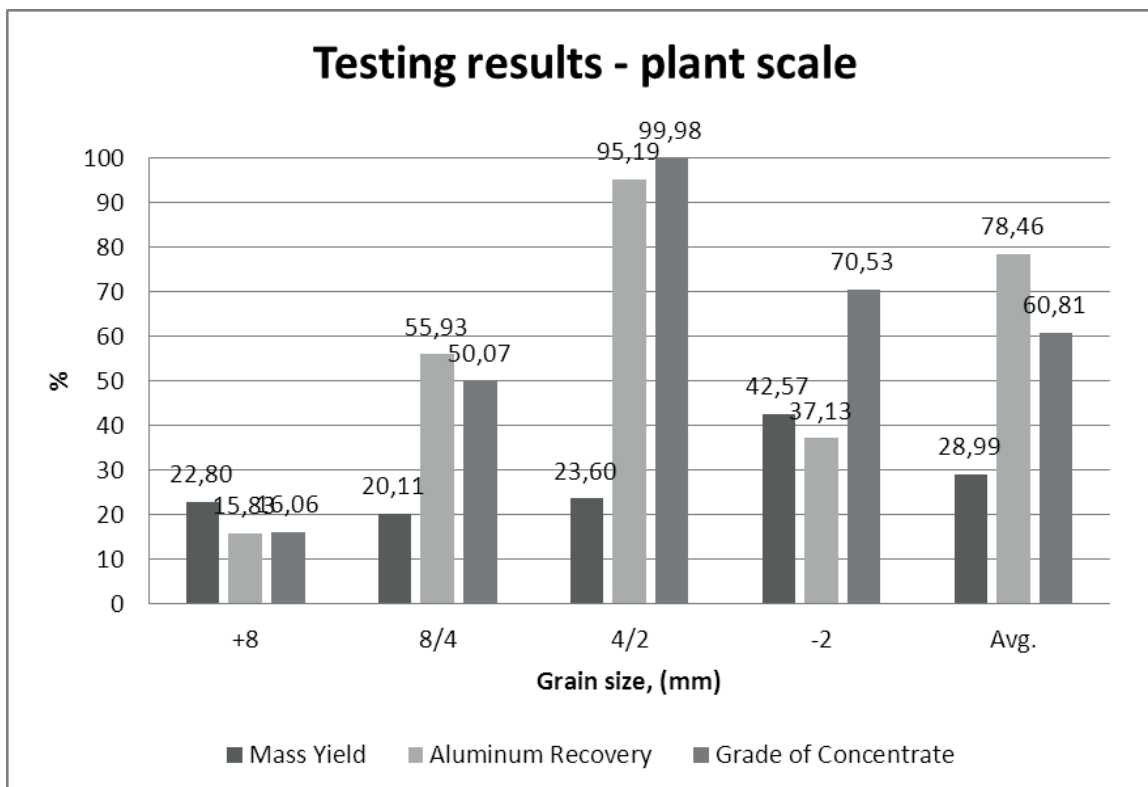


Fig. 4 Testing results of small capacitors in plant scale shaking table  
 Rys. 4 Wyniki badań małych kondensatorów na stołach koncentracyjnych w skali pilotowej

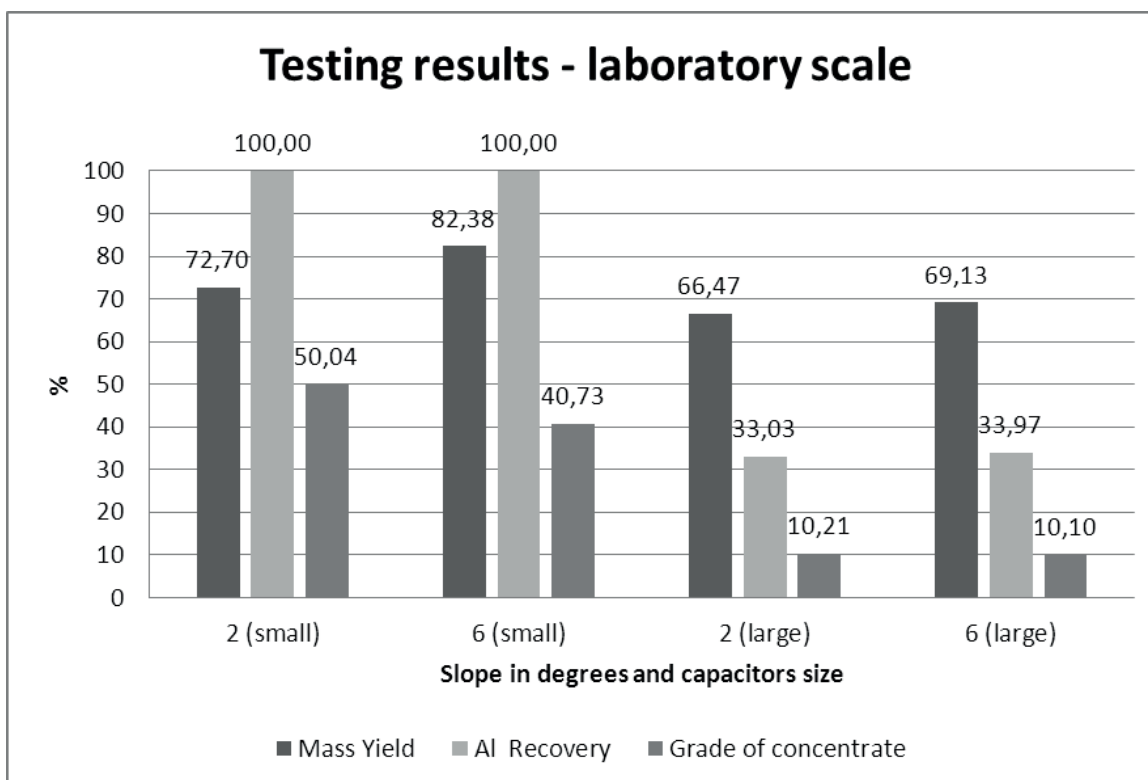


Fig. 5 Testing results in laboratory scale shaking table  
 Rys. 5 Wyniki badań na stole koncentracyjnym w warunkach laboratoryjnych

est grain size (+8mm) had the worst results because the insufficient degree of material liberation for efficient separation. Further liberation enabled better separation results in grain size 8/4mm. Although the mass yield was lower a few percent, both, grade of concentrate and the aluminium recovery significantly increased. The grain size of 4/2mm had the best results (concentrate grade of 99.98% and aluminium recovery of 95.19%), indicating that the full material liberation was achieved at this grain size. Further reduction in grain size resulted in decreasing separation efficiency. Further comminution results by slightly greater mass yield, but the best concentrate quality (almost 100%) and the best recovery (95%) in testing. The smallest grain size (-2mm) had worse separation results than grain size 4/2mm, but better than both coarse grain sizes. The reason of worse separation results may be the fact that grain size of -2mm contain certain share of fine particles whose mass too small for sedimentation under the action of hydrodynamic force of water and because that they went directly into "slimes" product (Figure 3).

Figure 5 shows results obtained by laboratory scale shaking table for small capacitors up to 25 mm and large capacitors, larger than 25 mm. Also, the separation efficiency is evaluated on the basis of three parameters: mass yield, aluminium recovery and grade of concentrate. Mass yield varied from 66 to 82 percent and it was greater than yield obtained by plant scale shaking table. Mass yield of smaller capacitors was slightly greater than the larger one. Also it could be noticed that the mass yield increased slightly with increasing of tables slope. It was expected, because over a higher table slope particles easier leave the table.

Aluminium recovery from smaller capacitors was significantly better (100%) compared with large capacitors (from 33 to 34%). The reason could be incomplete liberation of aluminium during comminution of larger capacitors. Also it could be noticed that a slope of table had no effect on aluminium recovery, both, for small and large capacitors. Considering the grade of concentrate it can be seen that small capacitors had significantly higher grade of concentrate (up to 50%) compared with larger capacitors (about 10%). Slope changing had effect on mass yield and grade of concentrate in small capacitors separation, while in large capacitor separation has no influence.

### Conclusion

Research has shown that it is possible to use gravity separation on shaking table for aluminium recycling from electrolytic capacitors. The best result were obtained in test of grain size of 4/2mm of small capacitors in plant scale shaking table. Achieved grade of the concentrate was 99.98% and the recovery of aluminium was 95.19%. Coarser grain sizes (+8 and 8/4 mm) showed worse results than the smaller one (4/2 and -2mm). Full material liberation were achieved in grain size -4mm. Tests in laboratory scale showed that small capacitors are more suitable for separation than the larger one. There is an influence of tables slope in separation of small capacitors. The future research in laboratory should be carried out with different slopes of the table and different grain sizes, both large and small capacitors. Special attention should be paid to the degree of comminution.



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### Badania recyklingu kondensatorów

W dzisiejszych czasach urządzenia elektryczne i elektroniczne (EEE) są integralną częścią gospodarstw domowych czy biur, można powiedzieć, że znajdują się w każdej komórce nowoczesnego społeczeństwa. Rozwój technologiczny przynosi ze sobą zarówno zalety, jak i minusy – większa ilość odpadów, w tym odpady elektryczne i elektroniczne (WEEE). Kondensatory i skraplacze są elementem każdego urządzenia elektronicznego. Jest wiele typów kondensatorów, aluminiowe są najpopularniejsze z racji swojego niekosztownego wykonania. Kondensatory elektrolityczne składają się w ok. 50% z aluminium, mogą więc być jego źródłem. Artykuł prezentuje badania nad możliwościami recyklingowymi aluminium pochodzącego z kondensatorów elektrolitycznych użytych jako wzbogacanie grawitacyjne. Rozdział aluminium odbywa się w cylindrycznych kondensatorach o rozmiarze 7 x 80mm przy użyciu stołów koncentracyjnych na mokro. Testowano cztery różnej wielkości ziarna w skali pilotowej (+8mm, 8/4mm, 4/2mm i -2mm) oraz jedno, 4/2mm, w laboratorium. Skuteczność rozdziału oceniona została na podstawie trzech parametrów: wydajności masowej, odzysku aluminium i stopnia wzbogacenia. Wyniki otrzymane w skali pilotowej pokazują, że odzysk aluminium i stopień jego wzbogacenia wzrasta wraz z wielkością ziaren. Najlepszy wynik: uzysk - 95,19% - oraz zawartość - 99,98% - zostały uzyskane dla uziarnienia 4/2mm, podczas gdy wydajność masowa pozostawała stała na poziomie 23%. Badania nad ziarnami o wielkości 4/2mm, prowadzone w środowisku laboratoryjnym, pokazały, że małe kondensatory są lepiej przystosowane do rozdziału aluminium niż duże. Wyniki potwierdzają możliwość odzysku aluminium z kondensatorów o wysokiej jakości.

Słowa kluczowe: e-odpady, kondensatory, recykling, aluminium, wzbogacanie grawitacyjne