Separation of Beverage Cartons Layers

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Abstract

The aim of this work was to find a way for easy separation of layers of beverage cartons. The characterizations of separated products were performed by infrared spectroscopy. Three types of solvents were utilized for separation of polyethylene (pentane-1-ol, hexane-1-ol and octane-1-ol). It was found that separated polyethylene from beverage cartons is not pure substance, but contains some amounts of dyes independently of the used solvent. The best solvent for polyethylene dissolution is octane-1-ol, which removed 99.5% of polyethylene contained in carton. The infrared spectra proved that the trace amounts of polyethylene left on the paper as well as on the aluminium surface. Other possible way of separation all layers was suggested.

Keywords: beverage cartons, recyclation, polyethylene, aluminium, cellulose

Introduction

The beverage cartons are the most widely used packing in food industry. The benefits are lightness and shape of packing, re-sealable packing which are popular for producer and consumers of many beverage cartons. These cartons protect freshness, flavour and nutritional quantities, enabling distribution, either at ambient temperatures or under refrigerated conditions, and thereby enabling extended shelf-lives for consumer beverages (Kowalska, et. al, 2006; Krawczyk, 2016; Agamuthu and Visvanathan, 2014; O kartonie, 2016).

The most commonly used beverage packages are composed from cellulose, polyethylene and aluminium foil or only from cellulose and polyethylene. The cartons contain 75–80% of cellulose. The long high quality fibres are used to provide the strength of the material. 20% of material consists of low-density polyethylene (LDPE) which has function of barrier for moisture and microorganisms. Eventually, aluminium foil is added (5% of the mass) as layer about 6.5 μm thin. The function of aluminium is to act as barrier against oxygen and direct light (Agamuthu and Visvanathan, 2014, O kartonie, 2016; Nadir et al.,2008).

The popularity of beverage cartons causes pressure on the treatment of industrial wastes, because all three layers of beverage cartons are recyclable themselves, but recycling of the composite materials is more difficult. According to the Directive (DIRECTIVE 2004/12/EC) the Member States undertake to achieve the required levels of recycling and recovery of packaging waste. This directive creates more expectations in relation to the effectiveness of the used recovery method.

The waste processing industry has only few ways for treatment of these materials. Beverage cartons can be recycled by the utilization of thermal compression process to manufacture high strength bio-composite panels which can be used as traditional wood based panels (Kowalska et al., 2006; Nadir et al., 2008; Bekhta et al., 2016; Żakowska, 2008).

Currently, companies most often process cellulose. The described method uses the hydropulping and swelling of cellulose. The small pieces of beverage cartons are intensively mixed with water. Sometimes, sodium hydroxide or other alkali-agent is added as catalyst to the mixture. This mixture are stirred about 15–60 minutes when thin layers of polyethylene and aluminium are obtained as waste and on fibres of the cellulose are obtained as product. The cellulose is then used for manufacturing of notebooks, toilet paper, packaging for eggs etc. (Kowalska et al., 2006; Nadir et al., 2008; Innowacyjne technologie zagospodarowania odpadów,2008).

The hydropulping method is long time used, but separation of aluminium and polyethylene is difficult. The waste beverage cartons can be sort by induction and gravitation or the waste polyethylene and aluminium foils can be processed by plasma technology. Plasma technology uses electrical energy to produce plasma (~15 000°C) and it changes mixture to paraffin and pure aluminium (Agamuthu and Visvanathan, 2014; Korniejenko et al., 2010; Mroziński, 2016). Both methods are energetically arduous and expensive. The other ways for obtaining aluminium from waste (such as formic acid separation) are studied (Yan et al., 2015; Rodríguez-Goméz et al.,2015).

The aim of this work is to propose the procedure for low cost separation of all layers of beverage cartons.

Materials and methods

The beverage cartons were cut to small pieces (10x10 mm) and they were used for experiments. Sep-

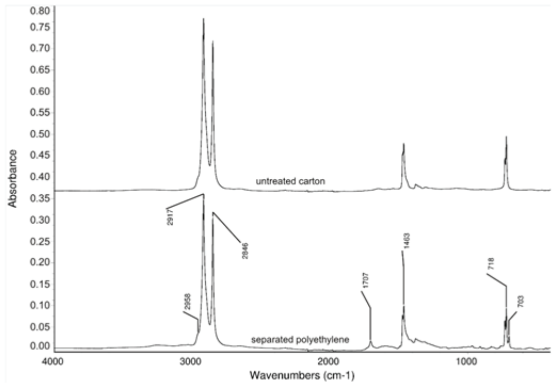

Fig. 1 Infrared spectra of untreated beverage carton and separated polyethylene

Rys. 1 Spektrografia w podczerwieni nie przetworzonego kartonu po napojach oraz oddzielonego polietylenu

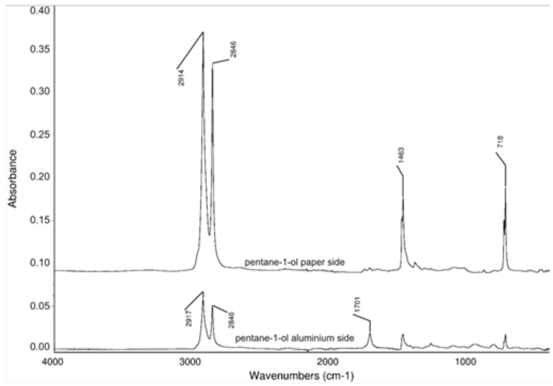

Fig. 2 Infrared spectra of beverage cartons sides after pentane-1-ol separation

Rys. 2 Spektrografia w podczerwieni stron kartonów po napojach po rozdziale za pomocą pentan-1-olu

aration of beverage cartons was realized with 3 solvents (pentane-1-ol (Lach-Ner Ltd.CZ), hexane-1-ol (ACROS OrganicsTM, USA) and octane-1-ol (Fluka, Germany)) with the ratio 1g of material/15 ml of solvent. The mixture was boiled under reflux on burner for 30 min. Mixture was filtered (through the Büchner funnel) to the cold water after 30 min. LDPE was precipitated on water surface and the suspension was filtered again through membrane filter Pragopor (< 0.40 µm, Pragochema Ltd., CZ). Polyethylene was dried for 24 hours on air at ambient conditions. The pieces with cellulose and aluminium foil were dried in the dryer at 105°C and characterized by IR spectroscopy.

The characterization of layers was performed by IR spectroscopy on the FTIR spectrometer Nicolet 6700 (Thermo Scientific, USA). Infrared spectra were recorded by attenuated total reflectance (ATR) method with diamond single bounce crystal. The spectra were measured in the spectral range 4000–400 cm^{-1} (256 scans, resolution 4 cm^{-1}, appodization Happ-Genzel DTGS/KBr detector in the middle IR range). Baseline correction was performed.

Molecular modelling was performed for estimation of solvents polarity. Dipole moment was selected for polarity quantification. OpenSource software Avogadro (Avogadro, 2016) with molecular mechanics (force field MMFF94) was utilized. Structures of solvents were modelled, geometries were optimized and dipole moments were calculated.

Results and discussion

The separation of polyethylene layers of beverage cartons was performed with three different solvents. The infrared spectra were measured for each side of small pieces of cartons – aluminium side and cellulose side, for untreated cartons and separated dried polyethylene.

The infrared spectrum of untreated carton (Figure 1) shows only polyethylene bands, which confirms the composition of beverage cartons (Agamuthu and Visvanathan, 2014; Nadir et al., 2008). The bands at 2917 and 2846 cm^{-1} belong to the stretch vibrations of $–CH_2$ groups. Bands at 1463 and 718 cm^{-1} belong to the deformation vibrations of $–CH_2$ groups. The small shoulder at 2958 cm^{-1} indicates stretch vibration of $–CH_3$ group. The separated polyethylene contains some

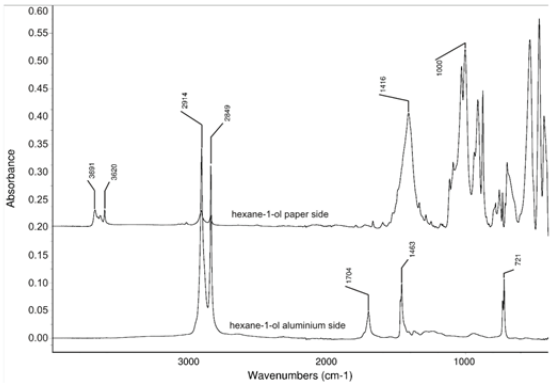

Fig. 3 Infrared spectra of beverage cartons sides after hexane-1-ol separation

Rys. 3 Spektrografia w podczerwieni stron kartonów po napojach po rozdziale za pomocą heksan-1-olu

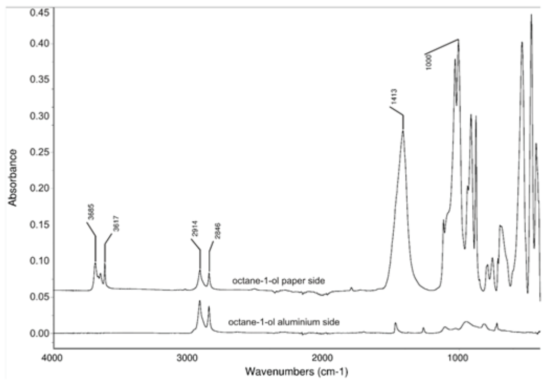

Fig. 4 Infrared spectra of beverage cartons sides after octane-1-ol separation

Rys. 4 Spektrografia w podczerwieni stron kartonów po napojach po rozdziale za pomocą oktan-1-olu

impurities such as pigment used for print on the carton. Infrared spectrum (Figure 1) shows this pollution as bands between 1000–750 cm^{-1} and band 1707 cm^{-1}. The separated polyethylene is not pure substance, but can be used as source for recycled materials.

The infrared spectra of both sides of beverage carton after leaching in the pentane-1-ol show polyethylene from paper and aluminium side (Figure 2). The polyethylene from paper side is almost pure and small bands under 2000 cm^{-1} probably belongs paper structure. The infrared spectrum of polyethylene from aluminium side shows lower intensity of all peaks belonging to polyethylene (2917, 2846, 1463 and 718 cm^{-1}) in the comparison with untreated carton. The lower intensity of peaks is caused by dissolution polyethylene in pentane-1-ol.The band at 1710 cm^{-1} is the stretch vibration of –C=O. The carbonyl group forms probably by the oxidation or degradation of pentane-1-ol. The pentane-1-ol primarily dissolves the polyethylene from aluminium side. The efficiency of polyethylene removing is 19% (see table1).

Figure 3 shows infrared spectra of carton after separation of polyethylene with hexane-1-ol. The higher amount of polyethylene is removed from the paper side. The bands between 3691–3620 cm^{-1} can probably belong to the vibrations of structure of kaolinite, which is probably used as filler of paper. The peaks at 2914 and 2849 cm^{-1} belong to the stretch vibrations of $–CH_2$ groups. The vibration bands at 1416 cm^{-1} could probably belong to carbonates ($- CO_3^{-2}$), which are also used as filler. The bands under 1000 cm^{-1} belong to the structural vibrations of functional groups of paper. The aluminium side does not show significant changes compared to the untreated carton. The intensity of polyethylene bands and carbonyl peak at 1704 cm^{-1}show the dissolution of polyethylene and oxidation or degradation of hexane-1-ol. The efficiency of the polyethylene removing is 58.5%.

The infrared spectra at Figure 4 belong to the carton after separation of polyethylene in the octane-1-ol. The aluminium side of treated carton exhibits only trace amounts of polyethylene and absence of other bands suggest that aluminium foil is not subject to oxidation process. The spectrum of paper side shows only bands of paper and its fillers. The bands between 3685–3617 cm^{-1} can indicate presence of small amount of kaolinite.

Tab. 1 Removal efficiency of polyethylene and parameters of solvents

Tab. 1 Skuteczność usuwania polietylenu oraz parametry rozpuszczalników

Solvents	Boiling point [°C]	Carbon chain length	Dipole moment [Debye]	Efficiency [%]
pentane-1-ol	137.80	5	1.56	19.0
hexane-1-ol	157.47	6	1.55	58.5
octane-1-ol	195.20	8	1.55	99.5

The band at 1413 cm^{-1} belongs probably to carbonates and bands of under 1000 cm^{-1} belong to the functional groups of paper. Infrared spectra confirmed the removal efficiency determined gravimetrically. The Removal efficiency of polyethylene was 99.5%.

It was found that the removal efficiency of polyethylene from the beverage carton depends strongly on the boiling point related to the carbon chain length of the solvents. The calculated dipole moments (table 1) show that polarity of the used solvents is comparable to each other and thus it does not influence the removal efficiency. The best solvent is octane-1-ol, which achieves the best removal amount of polyethylene (efficiency 99.5%). Moreover, the octane-1-ol foams at boiling point and few separated aluminium foil flow on the foam.

Further experiments can be focused on the optimization of conditions for separation all layers. The stirring can help to form the foam during the separation. The polyethylene will be dissolved in the solution. The aluminium foil will flow on the surface of foam. The paper soaked by octane-1-ol will be on the bottom of mixture. The paper can be dried after separation and used as fuel.

Conclusion

The separation of layers of beverage cartons was studied. The obtained data shows that separation of polyethylene is successful with octane-1ol. The removal efficiency is 99.5%. The separation process depends on the boiling point associated with carbon chain length of used solvents. The influence of polarity is negligible in the case of selected solvents. The aluminium foil does not exhibit any oxidation changes after the separation in the octane-1-ol. The separation of other layers of beverage cartons will be studied further.

Acknowledgements

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Rozdział warstw kartonów po napojach

Celem artykułu jest znalezienie sposobu na łatwy rozdział warstw kartonów po napojach. Charakterystyka rozdzielonych produktów została opracowana na podstawie badań spektroskopii w podczerwieni. Do rozdziału zastosowano trzy rozpuszczalniki polietylenu (pentan-1-ol, heksan-1-ol oraz oktan-1-ol). Stwierdzono, że rozdzielony polietylen z kartonów po napojach nie jest czystą substancją, ale zawiera pewne ilości barwników, niezależnie od stosowanych rozpuszczalników. Najlepszym rozpuszczalnikiem dla oddzielenia polietylenu jest oktan-1-ol, który usunął 99,5% polietylenu zawartego w kartonie. Spektrografia w podczerwieni wykazała, że śladowe ilości polietylenu pozostały na papierze, jak również na powierzchni aluminiowej. Inny możliwy sposób rozdziału wszystkich warstw został zasugerowany w artykule.

Słowa klucze: kartony po napojach, odzysk, polietylen, aluminium, celuloza