ECONOMIC BENEFITS OF METALLURGICAL WASTE PROCESSING

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Abstract

At present, the Tetra Pak waste cartons are brought to be disposed of in well technologically equipped paper mills, where they are pulverized. The fibre is then used in the production of recycled paper and the sandwich press of polyethylene and aluminium foil is then transported to a landfill or to an incinerator. As a progressive technology for reusing the aluminium foil as well as the energy use of polyethylene seems to be the pyrolysis. The process itself and the subsequent handling of its products require advanced risk management, both technological and economic. The article deals with the pyrolysis treatment of Tetra Pak, the properties of pyrolysis products and the possibilities of separation, which would lead to metallurgical aluminium production. The aim of the article is to draw attention to the economic potential of today's totally insignificant waste that is costly to store or burn. The reuse of material and metallurgical processing in the Czech Republic could cover 1,500-2,100 tonnes of aluminium, which represents a financial volume of at least CZK 25-30 million. The goal of the author's team is to prove the economic potential hidden in waste beverage carton and its comparison with market value. It also aims to identify the risks and propose their management. In order to prepare the project implementation, it is necessary to compile a model including the identification of risks and the way to eliminate them.

Keywords: Risk management, economic benefits, Tetra Pak, pyrolysis, metallurgy

1. INTRODUCTION

The aluminium price peaked in 2018 at its highest value since 2012. This is due to new US sanctions against Russia affecting the Rusal aluminium company, which is the leading producer of this metal. As the primary aluminium sources in the world are gradually disappearing, it is necessary, like with other raw materials, to look for recycling options. Therefore, the aim of this article is to draw attention to the economic potential of today's absolutely insignificant waste that is costly to store or burn. The target of the author's team is to prove the economic potential hidden in waste beverage carton and compare it to its market value.

At present, there are two global issues regarding the matter: first is the limited amount of scrap metal and second the limited quality of the recycled material that is, among other things, dependent on existing recycling technologies [1]. Aluminium recycling is an important area of research, primarily due to the enormous energy savings achieved through the production of aluminium products from secondary resources [2]. There are articles that deal with the creation of a model for the evaluation of basic raw materials [3]. To use such models in practice, companies need systematic support [4].

Aluminium can be obtained in different ways. Life cycle assessment methodology (LCA) clearly shows that secondary aluminium, i.e. recycled aluminium, is far more beneficial than the primary one, more environmentally friendly and economically less demanding [5]. One option is to recycle PC assemblies, where most aluminium is in power supplies, IDE cables, hard drives, floppy disks, and motherboards [6]. Another possibility of recycling aluminium is to recycle aluminium cans from beverages, which can be reused for their repeated production after their recycling [7].

2. TETRA PAK WASTE CARTONS

Tetra Pak cartons are one of the most common food package, especially for milk, dairy products and other non-preserved drinks. To prevent degradation of the protected content due to UV radiation, aluminium foil is also applied to the multi-layer structure. Among the layers are also paperboard and polymers.

Tatra Pak cartons, which are recycled within the „yellow containers", are consequently part of the EKO-KOM recycling system. Currently, this type of waste is supplied to technologically equipped paper mills, where it gets pulped. Within the Czech Republic, the only place that is able to use waste carton packaging is JIP Větřní Paper Mill, a.s. The fibre is used in production of recycled paper and the residues of polyethylene and aluminium layers are weighed into an in-house dump.

Technological problems with material re-use of cardboard included in Tetra Pak packages are balanced out by its high quality. The obtained fibre comes primarily from Nordic trees, which have a shorter growing season and thus grow more slowly. This positively influences the fibre, which then has a longer length and therefore can be recycled multiple times.

3. ENERGY UTILIZATION OF THE BY-PRODUCTS

The biggest problem of the JIP Větřní, Paper Mill a.s. concerns app. 30,000 tonnes of the by-product - the residues of the layers after pulping that have been piling up on the in-house dump since 2009. Due to the high proportion of polyethylene, the by-products have a significant caloric value that fluctuates around 25 MJ/kg.

Therefore, they can be used in the form of a solid alternative fuel for heating plants and power plants. On the basis of the analysis it was found that the by-products contain residue paper material (cardboard), which is the result of imperfect pulping. After burning a sample the ash was subjected to an XRF analysis that determined a high proportion of calcium (Ca). That is cause by the limestone, contained in the carton. Due to the high combustion temperature (850 °C), a chemical reaction known as "lime burning" occurs

$$\mathrm{CaCO_3 + heat = CaO + CO_2} \qquad (1)$$

The nature of the ash generated by burning PolyAl can be visually described as consisting of a "white" powder and a "grey" aluminium material. The white part of the ash has a clear basic character. If, for example, 0.5 g of this ash is poured into 5 ml of water, the pH of the solution is 9-10. This reaction can be described as "lime slaking" where

$$\mathrm{CaO + H_2O = Ca(OH)_2} \qquad (2)$$

The reaction occurs when the ash from the boiler of the heating plant is cooled in a water bath or when it is deposited on the dump where it absorbs the atmospheric humidity. There is another fact pointing at the disadvantages of using the combustion method. Calcium hydroxide (slaked lime) will have a strong reaction with the aluminium, that will not oxidize when burned where

$$\mathrm{3Ca(OH)_2 + 2Al = 6H_2 + Ca_3Al_2O_6} \qquad (3)$$

The result of the reaction is hydrogen (H_2) and calcium aluminate ($Ca_3Al_2O_6$). Due to the reaction in a humid environment, the hydrogen concentration can rise uncontrollably to an explosion endangering the heating plant's technological equipment and the lives of people. As a consequence of the above, the energy utilization of the by-products from pulping of the Tetra Pak waste cartons in a form of a solid alternative fuel and its co-incineration with the primary fuel of the heat plant seems to be extremely unrealistic.

4. THERMAL SEPARATION

Unlike simple combustion, pyrolysis or thermal separation appears as a progressive technology for the material reuse of the aluminium foil and the energy utilization of polyethylene. It is a thermochemical process that takes place in a reducing environment without oxidation [8]. The process temperature ranges from 450 °C to 550 °C [9]. At this temperature, therefore, the reaction (1) does not occur and the substances contained in the solid residue of the pyrolysis will not pose a risk in the humid environment. See reactions (3).

During the pyrolysis process, so-called dry distillation occurs when the hydrocarbon gases, which are the product of thermal degradation of polyethylene, are released from the by-products. After cooling in the condenser cooler, some of the gases condense in the form of so-called liquid hydrocarbons. The non-condensed residue is made up of pyrolysis gas with a calorific value of between 36 and 40 MJ/m3.

The main components of the pyrolysis gas are methane (CH_4), carbon monoxide (CO), hydrogen (H_2), carbon dioxide (CO_2) and hydrocarbon gases (C1 to C5). Pyrolysis gas is an ideal fuel for natural gas mixing and combustion in gaseous fuel burners [10]. The optimal application of the gaseous mixture seems to be using it in the K3 boiler at JIP Větřní, a.s. This boiler produces steam technology for the needs of paper machines.

Liquid hydrocarbons represent a significant energy potential for use in boilers with liquid fuel burners. Yield of liquid hydrocarbons from Tetra Pak dispensers is dependent on the choice of process parameters of pyrolysis. The following table shows the test results of 12 November 2014 carried out by the ENET Center on PYROMATIC 250 located in the premises of TCO Vitkovice [11].

Table 1 Weight of individual fractions [11]

Weight of the dosed material [kg]	Weight of the gaseous phase [kg]	Weight of the liquid phase [kg]	Weight of the solid residue [kg]	Process temperature [°C]
445	132	209.3	102.8	550-600

The solid residue contains 47 % of carbon and 53 % of aluminium and forms the so-called carbon-aluminium mixture for separation. **Table 1** shows that the proportion of aluminium foil in the raw by-products is about 10 %. This figure, however, is not constant for the entire stockpile of the by-products. The solar radiation to which are the upper layers of the dump in JIP Větřní Paper Mill a.s. exposed has already degraded part of the polyethylene foils. In addition, an unknown quantity of very similar waste beverage cartons, which do not contain the aluminium foil, has been brought to the process from the consignments from Germany. Estimation of the employees of the JIP Větřní Paper Mill, a.s. regarding the content of the aluminium foil on the dump ranges from 7 % to 8 % by weight.

5. ECONOMIC BENEFITS

In view of the above, it can be assumed that at present the JIP Větřní Paper Mill, a.s. has approximately 2,100-2,400 tonnes of aluminium foil on its in-house dump. At a price of about CZK 10/kg, it represents the amount of 21 to 24 million CZK. The prices quoted are indicative. There are many factors that affect the resulting price, such as e-auctions [12]. Since the mill produces an additional 5 to 7 thousand tonnes of the by-product from pulping the estimated amount above is not final. The production of Tetra Pak beverage carton shows a growing trend and new organizational measures are put in place by waste companies for better recycling of this raw material from municipal waste.

However, the process of separating the carbon-aluminium mixture precedes the aluminium metallurgical process of the aluminium foil after the pyrolysis process, see **Figure 1**. The problem to be solved does not fall into metallurgy but in the treatment of mineral and secondary raw materials. Using the different physical properties of both elements might solve the problem. Within the Faculty of Mining and Geology of the Báňská University - Technical University of Ostrava, experiments were carried out with flotation methods and separation of the mixture in heavy suspensions, which demonstrated the potential of the chosen methods and at the same time showed the problems that the future investor will have to deal with.

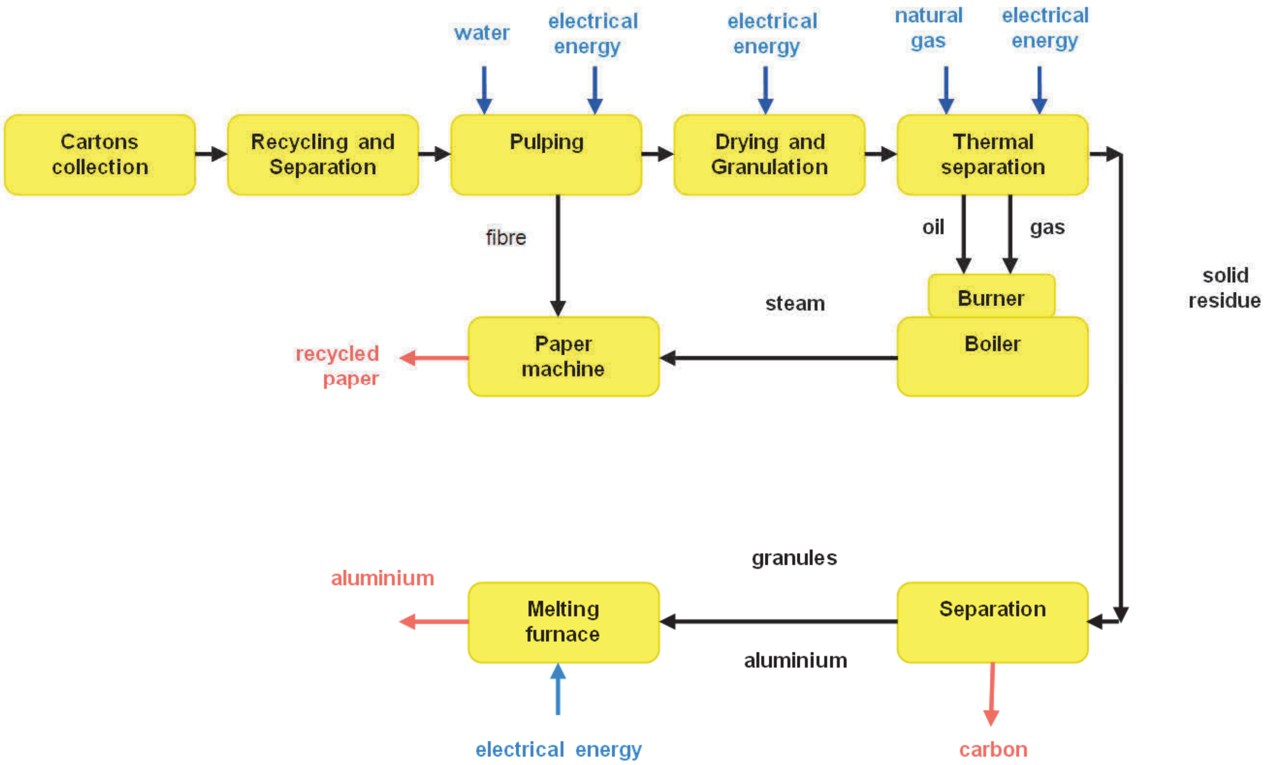

Figure 1 Block diagram of the complex processing of Tetra Pak waste cartons [own study]

Exploiting the energy potential of the polyethylene film can effectively eliminate the cost-effectiveness of the carbon-aluminium separating technology line. Referring to **Table 1** it can be calculated that of the dumped quantity of 30,000 tonnes it is possible to efficiently obtain about 47 % of weight volume in the form of liquid hydrocarbons when applying the pyrolysis process, which is about 14,100 tonnes.

If we assume that pyrolysis gas, which represents 30 % by volume of charge, will be used for the actual heating of the whole process and cogeneration of heat and electricity to cover its own consumption, in addition to the carbon-aluminium mixture, the liquid hydrocarbons are another product of the pyrolysis process.

These are comparable to Liquid Fuel Oil, hereinafter referred to as LTO [13,14], but with reduced calorific value, which is according to 32.65 MJ/kg. The LTO has a calorific value of 42.30 MJ/kg. At the present price of CZK 10,500/tonne of LTO, the price of alternative fuel corresponds to its calorific value of approximately CZK 8,000/tonne. The economic potential of the dump in terms of liquid fuel production can thus be quantified at approximately CZK 112,800,000.

6. RISK MANAGEMENT

The actual process and further handling of the products requires advanced risk management both technological and economical. Technological risks may be identified in pyrolysis (thermal separation), steam generating boilers, carbon-aluminium mixture separation and metallurgical processing of aluminium granules.

The economic risks can be identified at the input of waste beverage cartons into the pulping process, at the steam price for the paper machine, at the electricity price for the aluminium granulator-melting furnace, and in the development of the aluminium price on the global market. EU support can play an important role here [15]. Their management is based on previously developed models and continuous monitoring of market prices. Hardly foreseeable risks include 'political decisions'. In these cases, the market segment does not have to behave according to economic rules but may show turbulence.

Technological risk management can be reliably secured by using a process measurement and control set with an appropriate architecture that needs to be equipped with a redundant processor. If the local control fails, its superior system takes over. The control system monitors the process variables and issues commands to change them. In order to ensure the transport of the carbon-aluminium mixture, it is necessary to take increased safety risks due to the potential explosion of fine carbon dust.

7. CONCLUSION

The article deals with the possibilities of obtaining aluminium in ways other than its regular production. Suggestions for possible new innovative ways are considered not only from the economic aspect but also from the point of view of risk management of this process. It is clear from the text that the recycling of aluminium is the way to economical and environmental savings.

Life cycle assessment methodology (LCA) clearly shows that secondary aluminium, i.e. recycled aluminium, is far more beneficial than the primary one, more environmentally friendly and economically less demanding. An important part of this process is the management of the involved risks, in our particular case it is an advanced process of economic, technological, security and, last but not least, political risk management, based on not always stable political system in the country.

ACKNOWLEDGEMENTS

The article was supported by a specific university research by Ministry of Education, Youth and Sports of the Czech Republic No. SP2018/22 Risk Management Study of Industrial Enterprises in the Czech Republic.

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