International Journal of Manufacturing Economics and Management
ISSN 2784-1278 ISSN-L 2784-1278, Vol. I, No. 1 / 2021

THE CIRCULAR ECONOMY ASPECTS AND RECYCLING OF MATERIALS IN THE AEROSOL INDUSTRY

Katarzyna Niemiec[1,2], Anna Fitrzyk[2], Cezary Grabowik[1]

[1]University of Technology, Faculty of Mechanical Engineering,
Konarskiego 18A, 44-100 Gliwice, Poland
[2]JagoPro Sp. z o.o., ul. Szczakowska 35, 43-600 Jaworzno, Poland

Corresponding author: Katarzyna Niemiec, katarzynaniemiec@jagopro-aerosol.pl

Abstract: New decade brings new challenges for all participants in the goods' life cycle in the industry. The circular economy gives the leads how to face the problem of the product development, production, usage and utilization and their impact on the environment. This paper will review not only the existing law requirements in the waste management but also the possible the examples of the circular economy solutions in the aerosol industry. The analysed solutions consist of aerosol containers manufacturers' innovations, sustainable approach of the aerosol products manufacturers as well as possibilities of aerosol products and elements segregation and recycling. As a result of this article it will be found out that although aerosol products have always been seen as damaging to the environment, modern aerosols can combine the convenience and safety of their use with environmental safety.

Key words: aerosol products, circular economy, recycling, aluminium, steel

1. INTRODUCTION

Circular economy seems to be a new approach for achieving sustainability in micro (enterprises), meso (regions) and macro (national) levels. It is transforming today's linear supply chain (take, make, dispose) to circular (take, make, distribute, use and recover) [30]. Geissdoerfer et al. defined "circular economy as a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling" [21]. Although the concept of the circular economy itself was found in the literature in the late 1970s, we can observe significant growth of studies in this topic in the second decade of the 21th century [21].
The perfect example of the circular economy attitude in macro level is the actions taken by the European Union. In 2015 European Commission created and adopted the Circular Economy Action Plan, in which whole product lifecycle was covered: from design of the product to the waste management including also legislative proposal on the last element [7]. In the annex to this action plan also the timeline for the actions was presented.
Additionally to the Circular Economy Action Plan, in July 2018 European Union also implemented combined directives on the waste management: Directive (EU) 2018/850 of the European Parliament and of the Council of 30 May 2018 amending Directive 1999/31/EC on the landfill of waste [11]; Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste [12] and Directive (EU) 2018/852 of the European Parliament and of the Council of 30 May 2018 amending Directive 94/62/EC on packaging and packaging waste [13].
The main targets presented in those directives are:

- recycling 65% of municipal waste by 2035,
- recycling 70% of packaging waste by 2030,
- recycling of specific packaging materials should be: paper and cardboard: 85%; ferrous metals: 80%; aluminium: 60%; glass: 75%; plastic: 55%; wood: 30%,
- reducing landfill to maximum of 10% of municipal waste by 2035.

Actions described above were planned to bring benefits for both environment and the economy. In March 2019 Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the implementation of the Circular Economy Action Plan [41]

shows that 54 actions have been completed or are being implemented and continued towards next years. Positive results encouraged to further efforts on another on-going initiatives.
For aerosol industry circular economy approach is a big challenge due to the multi-material composition of the aerosol products. Due to the fact that different types of the materials are used for production of aerosols (aluminium, stainless steel, glass and plastic, chemical raw materials (including propellants) of natural and synthetic origin), the proper segregation seems to be the key for further processing. According the current definition aerosol is a non-refillable product, so the reusage of the aerosol packaging is at the moment not possible. Although those two difficulties close some solutions for the ecological approach, the others are willingly used by the whole environment related to aerosols.

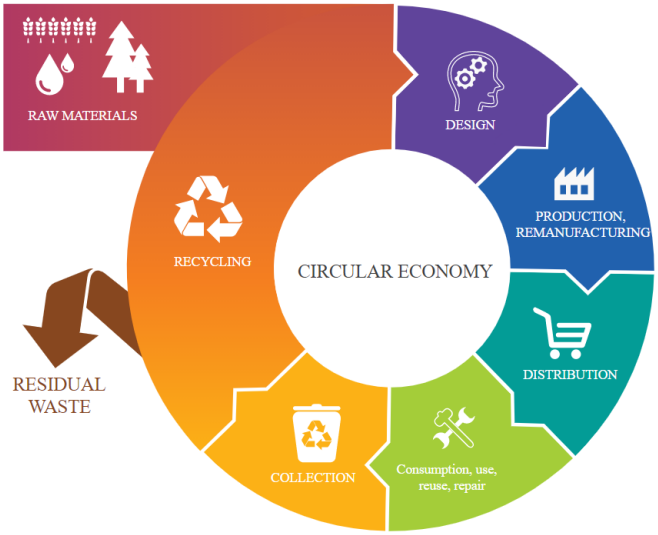

Fig. 1. Circular economy [6]

Based on the above presented scheme (Figure 1), the circular economy approach can be seen at each step of aerosol designing, production and development. Beginning with the packaging manufacturers who are improving the usage of recycled materials and seeking for the reduction of raw materials usage, while constantly ensuring high user safety. Then it is continued through reduction of pollution and carbon emissions during manufacturing process, reduction of waste, as well as the replacement of environmentally hazardous propellants with ecofriendly gases. Closing the loop with an increasing awareness of the consumers on the proper usage, segregation and recycling possibilities of the aerosol products.

2. ENVIRONMETAL APPROACH IN THE AEROSOL CONTAINERS PRODUCTION

According to fundamental document relating to aerosol products the Council Directive of the European Union of 20 May 1975 on the approximation of the laws of the Member States relating to aerosol dispensers (75/324/EEC) as amended by directives 94/1/EC, 2008/47/EC and 2013/10/EU (ADD), "aerosol dispenser shall mean any non-reusable container made of metal, glass or plastic and containing a gas compressed, liquefied or dissolved under pressure, with or without a liquid, paste or powder, and fitted with a release device allowing the contents to be ejected as solid or liquid particles in suspension in a gas, as a foam, paste or powder or in a liquid state" [8].
Since 1974, when the first Molina / Rowland report on the negative impact on the ozone layer of chlorofluorocarbons (CFCs, CFCs), commonly used in aerosol products at that time was presented, the aerosol products become perceived as not ecological friendly. And although since 1989 freons are not used in aerosol products beside some pharmaceuticals, the customers still are afraid that they are a threat to the environment. [14]. Second important effect on the environment is the construction complexity. The aerosol containers must be resistant enough to withstand the internal pressure of up to 18 bars and bursting pressure of 22 bars [8]. Due to those requirements the materials such as steel, aluminium, glass and plastic must have the suitable properties and thickness so their production processes must be adjusted to obtain those properties and the usage of material might be higher than in other, not pressurised products.
In 2018 in Europe more than 5.5 billion aerosol units were produced, and globally it is 16 billion units. Among those numbers, it is estimated that about 55% are made of aluminium, 44% of steel and glass and plastic containers with less than 1% of share [15, 26]. Glass and plastic aerosol containers still remain marginal due to the European Union legal restrictions on the permitted volumes of this type of containers. However very

advanced work is carried out in case of PET packaging for example leading by European Aerosol Federation (FEA) or The Plastic Aerosol Research Group (PARG). Although it was planned for this year that in updated ADD higher volumes than 220 ml would be allowed, this adjustment will not be a part of EU Commission's work in 2020 due to the numerous questions on the recycling of plastic aerosols cans [16].
Based on those numbers as well as the definition of the aerosol product, which exclude reusage of the aerosol container itself, it seems very profitable to focus on the material usage reduction and real post-consumer recycled scrap used as a raw material for container production.

2.1 Metal containers
As metal containers constitute the vast majority of cans used for aerosol production, also their influence on the environment is the biggest. Their manufacturers are aware of this impact, so the significant innovations in the field of metal containers are introduced since years. It is also observed that sustainable solutions are proposed even by the slugs or steel producers.

2.1.1 Aluminium cans
Aluminium containers are most often made as one-element structures (monoblock) and in this version they are made on one production line – starting from the slug (low and wide cylinder made of 99-99,7% pure aluminium) and finishing on the palletisation process. The quality control of the production process is made online, as there is no possibility to stop the process during production. They are most often made using the cold-pressed method where during impact extrusion the slug is pressed with a stamp and extruded to the shape of "cup". Then it is brushed, cleaned, varnished and decorated. The last production step is a multi-stage process where the neck and collar are formed. The upper part of the cylinder is formed into a smaller opening (most common is one-inch opening) which will be later closed with the valve in the aerosol filling company [37].
The specific manufacturing process of the aluminium aerosol cans requires appropriate planning and maintenace of the production line in order to ensure circular approach and reduction of energy and materilas used during this proces.
Another very important impact is the can weight and thickness of its walls. One of the first aluminium cans weight reduction process was introduced in 2001, when Exal (now Trivium Packaging) company started to work on aluminium cans called Coil-to-Can (C2C). The new hybrid technology allows them to combine the shape and decoration possibilities. During continuous improvement they were also able to develop this technology and now they are able to produce lightweight aluminium cans which are 30% to 40% lighter than cans made via standard impact extrusion (IE). But it is not the only circular economy aspect used by slug's producer. They also decided to utilize from 57% to 65% post-consumer recycled aluminium alloy to manufacture these cans, as opposed to the 99.7% pure virgin aluminium required for IE [32, 33].
The other global aluminium cans' producer Ball Corporation together with Henkel Beauty Care developed a lighter version of the aluminium aerosol container – ReAl. Also in this type of container 25% of recycled material is used. It additionally allows to reduce the weight of a standard aluminium container by 15% [4, 17, 20].
Also the smaller companies present their innovative ecological solutions. Moravia cans is offering DWI (draw and wall ironing cans) aluminium shaped can which is 20% lighter than standard ones and is using 40% pre-consumer scrap (waste materials which were created during the manufacturing or delivering processes prior to delivery to a consumer) and 25% post-consumer scrap (waste produced by the end consumer). According to their measurements this solution allows to place in the palletisation process 20% more cans per pallet and hence use 20% less pallets and reduce truck movements in 20% [36].
Similar sustainable innovation was made by German company Tubex. They used a new, patented by Tubex and slug supplier Neuman Aluminium, alloy for slugs which is using 25% of real post-consumer recycled scrap. But it was not the only improvement made by Tubex. Their "Yes green can "is not only 20% lighter due to the reduced wall thickness and slightly modified shape of the shoulder, but also has water-based base-coating and over-varnish. Additionally, a solvent-free interior powder coating rounds off this sustainable packaging. As the reduced thickness of walls made the cans more susceptible to dents during packing and transport, Tubex introduced a new packing technique where cans are placed on pallet by robots. This solution paid off with 15% more cans on the pallet and hence 15% less warehouse space [26, 44, 47].

2.1.2 Steel cans
Steel aerosol cans production process is very different from aluminium. First of all, most of the steel cans are made of three pieces – top, bottom and body. What is more, their production is divided into several steps and it is made on separate production lines. Steel sheet are delivered to containers manufacturers, most often in the form of coils, which are then straightened and cut into sheets of appropriate dimensions using a guillotine. Then,

the sheets are covered with varnish, thermally hardened in an oven and covered with paint. The decorated sheets are cut with the planned size of the container and rolled into the form of a cylinder in which the longitudinal edges overlap. The edges of the container are welded. This is very important step for container tightness. A protective coating may be applied to the surface of the weld during the welding operation. Then the collar is turned at both ends of the cylinder and the neck nad flange are formed. The bottoms and the tops are made in separate processes and the general sequence is very similar. This process consists of cutting, varnishing / paint and shaping the form of these elements. In the next stage of the steel container production process, the container body is connected to the bottom and the top of the container. The basic system for closing aerosol cans is a double seam. The quality of the weld and seams is tested inline – the container is filled with air under the pressure corresponding to the set test pressure value and the leaks are observed [34].
Although the production process is different, the tinplate cans producers are also implementing weight reducing solutions. Arcelor Mittal, world known steel manufacturer, is cooperating with their customers in order to achieve continuous improvement of 3-piece aerosols for all formats and industrial applications. Their goal is to introduce new market benchmark with body gauge at 0.13 mm – it means approximately 25% thickness reduction. Arcelor Mittal together with Ardagh Group (now Trivium Packaging) propose the lightest 3-piece steel aerosol for a range of Henkel's hairspray products. They achieved wall thickness of 0.13 mm for 250 ml aerosol can. It allows for a 15% saving in materials and water. But Arcelor Mittal do not focus only on the material for the body of the can. Also top and bottoms are planned to be thinner. Tops from 0.27 – 0.32 mm today to a probable 0.25 – 0.29 mm and bottoms from 0.23 – 0.31 mm today to a probable 0.21 – 0.26 mm [38].
One of the largest packaging steel manufacturers in Europe - thyssenkrupp Steel Europe, also can be seen as the pro-ecological innovator. Their new premium material rasselstein® Solidflex is lighter, more stable and safer. According to their researches it is an extremely strong material which has also very good forming properties. Thanks to these properties, thinner material can be used, while stability of the cans remains consistent. This innovation results in a weight reduction of up to 14 % compared to standard aerosol cans [40, 45].
Another positive example might be recent collaboration between Colep – European producer of tinplate aerosols and Henkel who introduced Syoss hairsprays line with decreased thickness of the steel what ensured 18 % weight reduction in comparison to the classing 3-piece tinplate can which comply with law requirements and FEA standards [25].

2.2 Plastic containers

Plastic packaging seems to be the biggest problem in the European counties. 70% of the European citizens are worried about plastic content in the packaging, while metal packaging is under consideration of only 5% of people [46]. With this kind of approach, wider implementation of plastic aerosol seems to be too challenging.
Plastic containers are manufactured in two stages. In the first step - injection molding - the dry polyethylene terephthalate pellets are heated until they are plasticized. The plasticized material is injected under pressure into the mold and immediately cooled. In this preform, the containers can be transported to locations closer to the filling companies, which reduces the costs of transporting these types of containers. The next step is to heat the preforms using different temperatures for different zones, which ensures the proper course of the blowing process. The preform is then placed in a blow mold, where throught the neck the air is blown and the container takes the shape corresponding to the shape of the mold [42]
Despite the anti-plastic politics, Plastipack Packaging not only is waiting for the European Union higher volumes of plastic aerosol container approval, but also is looking for possibilities to make polyethylene terephthalate (PET) eco-friendlier. Together with European national aerosol associations they are conducting PET aerosol recycling trials. Firstly, in cooperation with British Aerosol Manufacturers' Association (BAMA) and French Aerosol Association (CFA) they checked whether PET aerosol products are identified as PET by the automatic sorting technology in material recovery facility (MRF). The test showed that this kind of waste was positively identified by the high-speed automatic sorting machines. Although not every MRF is equipped with this kind of technology, it proved that it is possible.
The next step for Plastipack was to incorporate recycled material into plastic aerosol container. In comparison, it is achieved in beverage industry and possible to incorporate 25-100% of recycled PET in the bottles. However, this trials are still running, some results were already presented. It is highly possible to use 25% of recycled content and the plastic aerosol containers are still passing all the safety tests which are required for aerosol containers [10].

2.3 Glass containers

Glass industry is the oldest in the packaging sector. 1500 years BC Egyptians were using it for balm and creams storage [39]. Since that time, glass is widely used, but for aerosol product it was firstly used in 1953 when

Wheaton Glass developed a coating method for glass made of PVC [28]. The plastic coating helped the bottle withstand minor falls on hard surfaces, and if it breaks, prevents the glass from splashing.
Glass containers are produced by the blowing method and, depending on the intended use of the container, various variants of the blowing method are used. In the case of aerosol packaging, the method used for the production of narrow neck bottles is blow-blow or the more modern press-blow method for narrow necks, where the walls of the containers are much thinner [24].
Due to the restrictions on the maximum capacity of aerosol dispensers made of glass and the properties of the glass itself, they are rarely used in aerosol products. In accordance with current European legislation, glass dispensers with a durable protective coating can have a maximum volume of 220 ml, and 150 ml for unprotected glass dispensers.
Glass is 100% recyclable in the closed recycling circulation process and is the perfect example of the circular economy. Since its negligible share in aerosol containers market, there are no significant pro-ecological projects in glass aerosol containers.

3. CIRCULAR ECONOMY APPROACH IN AEROSOL PRODUCTS' MANUFACTURING

Manufacturers involved in all steps of the aerosol production are following law requirements regarding circular economy. They are applying their pro-ecological approach in order to fulfil the consumer expectations. Usage of eco-friendly propellants, minimising the volatile organic compounds (VOC's) or compression of the aerosol products are some of the sustainable examples.
The standard aerosol production manufacturing process consists of below steps:

1. Delivery of the raw materials and packaging components to the filling company.
2. Quliaty control of the delivered raw materials and packaging components.
3. Mixing of the formula from raw materials.
4. Placing the packaging components on the production line (on the feeding table, valve lifter, capper or manually).
5. Filling the can with the formula.
6. Placing and crimping the valve on the can.
7. Gasing with the propellant.
8. Coding of the product.
9. Weight control of the product.
10. Leakage control in the bath test.
11. Actuator placing.
12. Cap placing.
13. Labelling.
14. Visual quality control of the product.
15. Packing into the boxes and on the pallets.

Above described production process might vary depending on the product specification and packing options, but on each step there are the possibilities to introduce circular economy aspects.

3.1 Propellants

Since the 1950s, when aerosol products were introduced to the market for civilians, their continuous sales increase up to year 1974, in which the first Molina / Rowland report appeared on the negative impact on the ozone layer of chlorofluorocarbons (CFCs, freons) commonly used in aerosol products at that time. Negative opinions about aerosol products meant that their dynamic development in production slowed down. The solution to this problem was to replace freons with other propellants, and from 1989 aerosol industry voluntary removed CFCs from their products [14]. Despite this change, many of the propellants which are in use today are still dangerous to the environment, that's why liquefied flammable gases are more commonly replaced by compressed gases like nitrogen, carbon dioxide or even compressed air. Not only they are making less damage to the environment, but also are more stable [5].
An example of the greenest aerosol technology is Airopack – innovative dispenser where plastic container is fitted with compressed air. It is even called "air-powered pressurised containers" not an aerosol, as it contains no harmful propellants but only pure air [26].

3.2 Bag-on Valve Technology

Another sustainable example in aerosol products is bag-on-valve technology (BOV). This production system consists of multi-layered and flexible pouch welded to an aerosol valve, the aerosol container and nitrogen or

compressed air which is injected between the can and pouch as propellent. In this kind of product there is no contact between propellant and the product itself, what is commonly used ex. In pharmaceutical industry. But BOV products have also environmental benefits. First of all, there is no need to use flammable propellants and instead of this eco-friendly air or nitrogen are used. And what is more, up to 100% product emptying is possible. It helps to minimise the residues of the product in aerosol waste and due to this fact also it is also helpful in the recycling processes [9, 27].

3.3 Valve innovation

The Anyway Spray is using different than usual type of dip tube. Instead of one hole at the end, it has sealed end and millions of microscopic holes thorough its entire length. This solution enables usage of aerosol in 360^0 orientations, it is possible to use it to the last drop and what is very important – it is designed to work with compressed gases like nitrogen and compressed air without any loss of propellant. Thanks to this innovation, there is a possibility to reduce VOCs emission to the atmosphere [18].

3.4 Compressed product in the can

Unilever company proposed a solution in which the overall dimensions of the packaging, and thus its volume, have been reduced by half, and by compressing the product inside, the product has not lost its effectiveness. This solution significantly reduced the amount of material consumed in the container production process. This action not only resulted in environmental benefits, but also a reduction in transport costs [29].

4. SEGREGATION AND RECYCLING POSSIBILITIES OF THE AEROSOL PRODUCTS

According to the Council Directive of the European Union of 20 May 1975 on the approximation of the laws of the Member States relating to aerosol dispensers (75/324/EEC) as amended by directives 94/1/EC, 2008/47/EC and 2013/10/EU [8], the aerosol packaging cannot be used or refilled again as it is possible to be done for example with glass bottles.

Although on the requirements for aerosol products industry countries and continents seem to speak in the same voice, when it comes to the segregation and recycling, there are still many different regulations. According to Nicholas Georges the technology to recycle aerosols should be the same, but at the moment there are different approaches in different countries [22].

Below the general scheme of recycling possibilities of the aerosol products is presented (Figure 2).

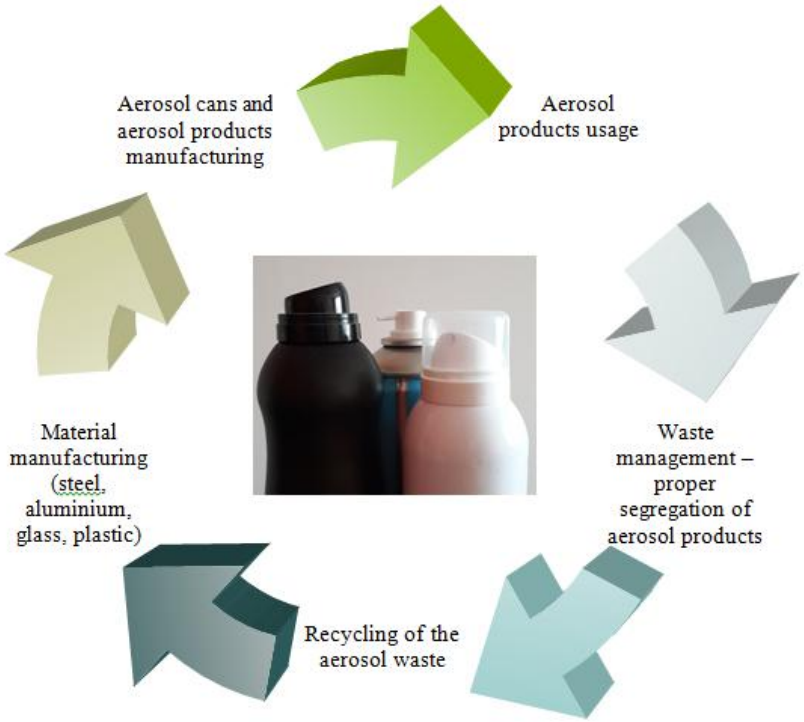

Fig. 2. General scheme of aerosol recycling possibilities [own study]

4.1 Post-consumer aerosols

Aerosol products are made of different types of materials. Starting from different packaging elements made of aluminium, steel, plastic, glass and paper (labels); formula made of chemical raw materials and finishing with propellant which very often are flammable. This is why full aerosols are mainly classified as hazardous by safety regulations. When it comes to the post-consumer waste they are often classified as multi-material waste and sometimes still as dangerous waste [19], although the amount of propellant residues is only 1-2.5% by weight and 1-2.5% of product. Products with foam base might have bigger residual content (5-15%), but the flammability is very low in that case. Undamaged cans typically had residual gas pressure of 1.5-3.0 bar. Moreover, according to the definition of the household hazardous waste defined by National Household Hazardous Waste Forum, empty aerosol cans should not be regarded as household hazardous waste [43].

However, based on above facts, in aerosol containers' recycling process the risk of serious incident or accident is low [43], at the same there are the risks of different hazards: an ignition of an explosive atmosphere (ATEX), a Boiling Liquid Expanded Vapour Explosion (BLEVE) and a liquid pool fire [29].

In order to ensure safety of the aerosol cans' recycling, Smith and Linton and later on the basis of their report BAMA has published Best Practice Guidelines for Post-Consumer Aerosol Can Recycling [1, 43]. The most important safety rules for segregation and collection processes are:

- Only aerosols from domestic waste should be handled by material recovery facility (MRF). The aerosols from the commercial waste stream should be handled in specialized recycling facilities.
- Only empty aerosols should be handled by MRF. Half-full or full aerosols should not be put by consumers in the domestic waste bins.
- Aerosol should not be segregated from the steel and aluminium recyclate streams.
- No-smoking policy should be enforced during all waste stream (collection, transport and material handling).

Additionally, there are several rules which are directly connected with MRFs work and safety procedures, ex. good ventilation where aerosols are handled, fire extinguishers should be available and what is also very important, standard operating procedures should be written and operators should be trained in order to ensure safety of work and handling with aerosol waste.

4.2 Other aerosol waste

However empty aerosols from household waste stream are recyclable and more and more willingly classified as non-hazardous waste, full or partially full aerosol products and those which comes from industrial, commercial and institutional premises are mainly classified as hazardous waste. Similar classification we can find in US as well as in UK [2, 3, 23]. What is very important, full or partially full aerosols cannot be handled by MRFs, because there is a hight risk that during storage and crushing them in press, random and not controlled perforation of aerosol can might happen. Notwithstanding, this kind of aerosols still might be recycled, once they are punctured and the content is removed from the can. Detailed instructions are described for example by BAMA in their dedicated guidelines [2].

5. CONCLUSIONS

In 2018 over 5.5 billion aerosols were made in Europe creating a significant level of waste [15]. In US approximately 1% of the yearly produced aerosols are properly and safely recycled. In Europe it is even less, as still recycling is not the most common solutions for aerosol waste [31]. Based on the observed annual growth in Europe and in the world it is estimated that in 2020 the demand for aerosol products reach over 18 billion units [35]. This could be very important impact on the circular economy when those products would become a larger part of the recycling processes. It is worldwide observed that for all involved areas starting from chemical raw materials suppliers, packaging components manufactures, aerosol producers and finally consumers and material recovery facilities, the circular economy is not only the written vision, but it is the everyday path to better future.

6. ACKNOWLEDGMENT

Paid from the funds of the Ministry of Science and Higher Education under contract No. 12 / DW / 2017/01/1 of 07/11/2017 in the amount of PLN 4 433 520.00.

7. REFERENCES

1. British Aerosol Manufactures' Association (2008). *Recycling Post-Consumer Aerosols*. Available from https://www.bama.co.uk/publications.php Accesed: 13/07/2020.
2. British Aerosol Manufactures' Association (2008). *Retail disposal of full or part full aerosols.* Available from https://www.bama.co.uk/publications.php Accesed: 13/07/2020.
3. British Aerosol Manufactures' Association (2012). *Recycling empty aerosols from industrial, commercial and institutional premises*. Available from https://www.bama.co.uk/publications.php Accesed: 13/07/2020.
4. Caridad, A., (2014). *Aerosol Containers. New technology drives sustainable, cost effective innovation,* Spray Technology & Marketing, No. 12, December 2014, pp. 14-15.
5. Caridad, A., (2017). *Global Aerosol Overview,* Spray Technology & Marketing, **9**, pp. 16-20.
6. *Circular economy: the importance of re-using products and materials* (2015). Available from https://www.europarl.europa.eu/news/en/headlines/economy/20150701STO72956/circular-economy-the-importance-of-re-using-products-and-materials, Accesed: 05.04.2021.
7. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions (2015). *Closing the loop - An EU action plan for the Circular Economy 2015 European Commission.* Available from https://eur-lex.europa.eu, Accesed: 15/08/2020.
8. *Council Directive of the European Union of 20 May 1975 on the approximation of the laws of the Member States relating to aerosol dispensers* (1975). Official Journal of the European Communities L147. Available from https://eur-lex.europa.eu, Accesed: 15/08/2020.
9. Chouldrhry, K., (2020). *Where to next with bag-on-valve-technology?* World Aerosols, No. January/February 2020, pp. 20-21.
10. Crawford, M., (2020). *With the right approach, PET aerosols can make o positive contribution*, World Aerosols, No. January/February 2020, p. 17.
11. *Directive (EU) 2018/850 of the European Parliament and of the Council of 30 May 2018 amending Directive 1999/31/EC on the landfill of waste* (2018). Official Journal of the European Union L150. Available from https://eur-lex.europa.eu, Accesed: 15/08/2020.
12. *Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste* (2018). Official Journal of the European Union L150. Available from https://eur-lex.europa.eu, Accesed: 15/08/2020.
13. *Directive (EU) 2018/852 of the European Parliament and of the Council of 30 May 2018 amending Directive 94/62/EC on packaging and packaging waste* (2018). Official Journal of the European Union L150. Available from https://eur-lex.europa.eu, Accesed: 15/08/2020.
14. European Aerosol Federation, (2016). *Highligts on Aerosol History*. Available from www.aerosol.org, Accesed: 15/08/2020.
15. European Aerosol Federation, (2019). *Annual Report 2018*. Available from www.aerosol.org, Accesed: 15/08/2020.
16. *Fall Forum of the Industrie-gemeinschaft Aerosole E.V.* (2020). Aerosol Europe, **28** 1-2020, p. 14.
17. Farrel, D., *Ball and Henkel unveil further aerosol can lightweighting* (2015). Spray Technology & Marketing, No 6, June 2015. Available from https://www.spraytm.com/ball-and-henkel-unveil-further-aerosol-can-lightweighting.html, Acceses: 15/08/2020.
18. *Finally! An Aerosol with true 360^0 orientations* (2019). World Aerosol, July/August 2019, pp. 36-37.
19. Fitrzyk, A., (2013). *Zutylizować Europę. Europejskie przykłady recyklingu odpadów aerozolowych.* Packaging Polska, **09**/2013. Available from http://packaging-polska.pl/pg/pl/content/ekologia/zutylizowac_europe_europejskie_przyklady.html, Accesed: 07/06/2020.
20. Fitrzyk, A., (2017). *Rozwój rynku oraz kierunki innowacji opakowań aerozolowych.* Opakowanie **11**, p. 51.
21. Geissdoerfer, M., Savaget, P., Bocken, N., Hultink, E. J., (2017). *The Circular Economy – A new sustainability paradigm?* Journal of Cleaner Production, **143**, pp. 757–768.
22. Georges, N., (2020). *Growing the Global Aerosol Industry Together* Spray Technology & Marketing, **01**, January 2020, pp.10, 43.
23. Georges, N., (2020). *The United States changes its classification of aerosol waste.* Aerosol Europe, **1**, pp. 26-27.
24. Grayhurst, P., (2014). *Opakowania szklane* Technika opakowań. Podstawy, materiały, procesy wytwarzania, A. Emblen, and H. Emblen, pp. 147-164, PWN, Warszawa.
25. Hattersley, V., (2019). *Downgauging: When less is more,* Packaging Europe, July 2019. Available from https://packagingeurope.com/downgauging-when-less-is-more/, Accesed: 01/03/2020.

26. Hattersley, V., (2019). *Aerosols: Innovation, design and recycling,* Packaging Europe, November 2019. Available from https://packagingeurope.com/aerosols-innovation-design-and-recycling/, Accesed: 01/03/2020.
27. Hedman, M., (2014). *Integrity in a Can… Bag-on-Valve Technology,* Spray Technology & Marketing, **4**, pp. 18-21.
28. Johnsen, M. A., (2010). *Aerosol containers* The Wiley Encyclopedia of Packaging Technology, K. L. Yam, pp. 24-31, John Wiley & Sons, Inc., Hoboken.
29. Janes, A., Malet, F., (2016). *Evaluation and Mitigation of Fire and Explosion Risks due to the pressure of Aerosol Cans in Metal Waste Recycling,* Symposium Series, No. 161/2016.
30. Langergrabera, G., Puchera, B., Simperlera, L., Kisserb, J., Katsouc, E., Buehlerd, D., Garcia Mateoe, M. C. and Atanasovaf, N., (2020). *Implementing nature-based solutions for creating a resourceful circular city*. Available from https://doi.org/10.2166/bgs.2020.933, Accesed: 15/03/2020.
31. MacKay, M., (2020). *Boost for US aerosol recycling,* World Aerosols, No. January/February 2020, p. 33.
32. Mohan, A. M., (2009). *Aluminium bottle bound for mainstream beverage use,* Packaging World, Available from: https://www.packworld.com/machinery/primary-packaging/article/13345642/aluminum-bottle-bound-for-mainstream-beverage-use, Accesed: 23/05/2020
33. *Moving the industry forward* (2020). Available from http://www.exal.com/why-exal/innovate/, Accesed: 15/08/2020.
34. Niemiec, K., Fitrzyk, A., Grabowik, C., (2018). *Innowacyjność w produkcji pojemników aerozolowych,* Innowacje w zarządzaniu i inżynierii produkcji, R. Knosala, pp. 33-43, Oficyna Wydawnicza PTZP, Opole.
35. Niemiec, K., Fitrzyk, A., Grabowik, C., (2018). *Technological solutions and innovations within aerosol packaging*, Proceedings of ModTech International Conference Romania IOP Conf. Series: Materials Science and Engineering **400**(2018) 022040 doi:10.1088/1757-899X/400/2/022040.
36. *Nothing changes yet everything changes* (2020). Available from https://www.moraviacans.cz/materials-a-technologies, Accesed: 15/08/2020.
37. Page, B., (2014). *Sztywne opakowania metalowe* Technika opakowań. Podstawy, materiały, procesy wytwarzania, A. Emblen, and H. Emblen, pp. 165-223, PWN, Warszawa.
38. Piqemal, C., (2018) *The Ultimate DWI Steel can. How beverage may inspire the aerosol market* Aerosol and Dispensing Forum 2018. Available from: https://www.adfpcdparis.com/en/about-adf/, Accesed: 23/05/2020.
39. *Powrót do korzeni* (2017). Packaging Polska, **04**/2017, p. 58.
40. *Rasselstein Solidflex makes aerosol cans 14 percent lighter* (2020). Available from: *https://www.canmakingnews.com/issues/news-in-brief/rasselstein-solidflex-makes-aerosol-cans-14-percent-lighter/* Accesed: 21/02/2020.
41. *Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the implementation of the Circular Economy Action Plan* (2019). Available from https://ec.europa.eu/environment/circular-economy/implementation_report.pdf, Accesed: 15/08/2020.
42. Riley, A., (2014). *Procesy produkcji materiałów opakowaniowych z tworzyw sztucznych* Technika opakowań. Podstawy, materiały, procesy wytwarzania, A. Emblen, and H. Emblen, pp. 405-460, PWN, Warszawa.
43. Smith, D. N., Linton, D., (2001) *Health and Safety issued in post-consumer aerosol container recycling*, Recources, Conservation and Recycling, **31**/2001, pp. 253-263.
44. *Sustainability. Sophisticated environmental concept with cool look* (2020) Aluminium Aerosol Cans – online magazine, pp. 20-21. Available from: https://cansonlinemagazine.aerobal.org/index.html, Accesed: 17/06//2020.
45. *Tinplate packaging: the spray can is getting lighter* (2020). Available form: https://www.thyssenkrupp-steel.com/en/newsroom/highlights/tinplate-packaging-solidflex.html, Accesed: 15/08/2020.
46. *Wybieramy opakowania z mniejszą ilością plastiku* (2019). Opakowanie, **11**/2019, pp. 46-47.
47. *"Yes green can "- umweltfreundliche Dosen-Produkte und Produktion Ressourcensparender Umgang durch gewichtsreduzierte Dose, Einsatz von recyceltem Aluminium* (2020). Available from https://wj-reutlingen.de/news.html, Accesed: 15/08/2020.

Received: January 21, 2021 / Accepted: June 15, 2021 / Paper available online: June 20, 2021 © International Journal of Manufacturing Economics and Management