STUDIA UBB AMBIENTUM, LXIV, 2, 2019, pp. 67-77
(RECOMMENDED CITATION)
DOI:10.24193/subbambientum.2019.2.06

ALUMINIUM CANS WASTE MELTING IN MICROWAVE FIELD

Alexandra Gabriela PASCARIU[1]*, Ioana ANASIEI[1], Daniela Violeta DUMITRESCU[1], Marian BURADA[1], Mihai Tudor OLARU[1], Beatrice Adriana ŞERBAN[1], Paul COVIC[2], Felicia COSMULESCU[3], Ciprian ŞCHIOPU[4], Tiberiu CÎMPAN[4]

[1]National R&D Institute for Nonferrous and Rare Metals, 102 Biruintei Blvd., Pantelimon, Romania, 077145
[2]S.C. Claudiu Toprom S.R.L., 111 Pantelimon Str., Bucharest, Romania, 021597
[3]S.C. Cosfel Actual S.R.L. 95-97 Calea Grivitei, Bucharest, 010705
[4]Environmental Health Center, 58 Busuiocului Str. Cluj Napoca, 400240
**Corresponding author: danieladumitrescu@yahoo.com*

ABSTRACT. Recycling of aluminium, particularly aluminium beverage cans is important due to several economic and environmental reasons. Aluminium beverage cans are by far the most recycled consumer beverage packages globally, by units, weight and percentage recycled. It amounts to more than twice the recycling rate and recycled content percentages for beverage packages of other materials. Recycling of aluminium requires only 5-10% of the energy for primary aluminium production. In this paper, the melting of cans wastes in microwave furnace as well as the treatment of noxious emissions in a microwave thermal filter has been preliminary investigated. Melting temperature, composition of the melting - protection fluxes as well as waste/flux ratio on the metal recovery efficiency have been investigated. During the cans waste melting, due to the burning of paint and lacquer coatings, environmental toxic compounds such as: volatile organic compounds (VOCs) (acetone, benzene, ethylbenzene, styrene, toluene, etc.) have been detected in the effluent gases. The treatment was carried out by passing the gases through a microwave susceptor granular material filter (SiC balls), placed in a microwave transparent tube. It was observed that the temperature of the filter has a major influence on the neutralization of the toxic compounds, the content in the gases being reduced below the legal limits.

Key words: *aluminium cans waste, microwave melting, toxic compounds, thermal filter.*

INTRODUCTION

The recycling of aluminium is an important activity in the context of sustainable development and environmental protection, due to its economic and environmental potential. A high percent of drink cans are made of aluminium; while almost all food cans are made of steels, aluminium unique properties make it adequate for holding carbonated beverages.

Aluminium beverage cans are the most recycled packaging materials because of the high value of the wastes globally produced, but also because this process is useful in saving energy and reducing emissions (Appleton et al, 2005).

In this paper is investigated the melting process of the aluminium beverage cans in the microwave furnace. Microwave melting is a novel technology which presents a series of major advantages compared to the classical pyrometallurgical processes, such as simultaneous evolution of the heating gradient in the entire volume of material, a much higher heating rates (Capuzzi and Timelli, 2018) that shorten the melting time by 70-85%, allowing energy savings (Verran and Kurzawa, 2008) and higher processing capacities and a superior quality of the obtained materials by reducing the melt impurification through oxidation. Microwave heating also offers the possibility to neutralize the gaseous emissions by passing the gas through a granular microwave susceptor material thermal filter (Das and Hughes, 2006; Gupta and Wong, 2007; Chandrasekaran et al., 2011).

EXPERIMENTAL

The experimental microwave equipment for melting the aluminium beverage cans is presented in figure 1. It consists of a cylindrical enclosure made of steel (1), in which are five rectangular windows for mounting the microwave magnetrons (6). The axes of the windows are positioned in different horizontal planes, the angle between the axes is 72°, thus radiating different areas of the susceptor material (3). In order to reduce the heat loss, the interior of the enclosure is covered with a thermal insulation layer (2) made of super-alumina ceramic fibres with resistance to temperatures up to 1600°C. Coaxial, there is placed the melting crucible (4), made of graphite-clay mixture, approx. 1 litter capacity, clothed in a microwave susceptible material (3) made of silicon carbide. The batch heating is performed by five 2.45 GHz microwave generators (6) of 850 W maximum power. The temperature is measured using a ceramic sheath K-type thermocouple (8).

Generated harmful gases and dust are captured through the exhaust pipe (9), fixed in the furnace cover (7), and which is connected with the gas treatment thermal filter (11). The filter consists of a steel cylinder in which windows are cut out for the installation of three 2.45 GHz magnetrons (13) of 850 W power. A microwave transparent quartz cylinder is placed inside the steel cylinder and contains a microwave susceptible material SiC (12) in the form of 5-10 mm diameter granules. The temperature inside the thermal filter is measured with a K-type thermocouple. Gas and dust sampling are carried out through nozzles (10, 14) attached to the exhaust tube (9) just before and after the filter.

The laboratory MW experimental non-ferrous waste melting installation is presented in figure 2.

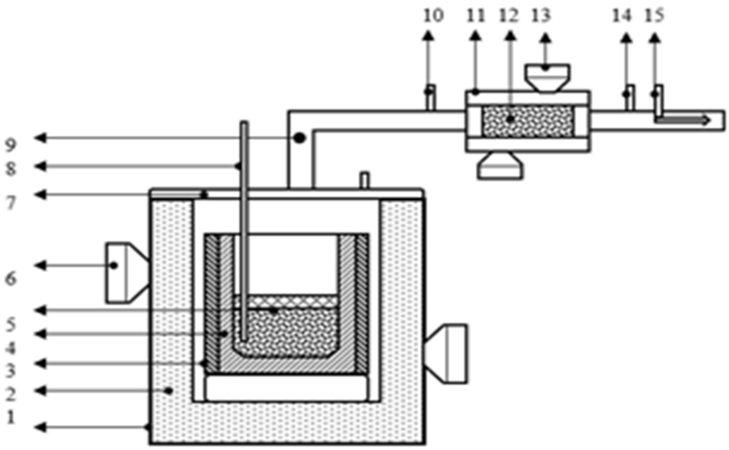

Fig. 1. *Microwave melting furnace and gases thermal filter*

1. Furnace body (steel); 2. Thermal insulating material; 3. MW susceptor material (SiC); 4. Melting graphite crucible; 5. Charge (Al cable waste + cover flux); 6. Furnace MW magnetrons; 7. Furnace cover (steel); 8. Thermocouple (K-type); 9. Flexible exhaust tube (steel); 10, 14. Gas sampling socket pipe; 11. Burning gases thermal filter treating; 12. MW susceptor material (SiC balls); 13. Filter MW magnetrons; 15. Compressed air tube

Fig. 2. *Laboratory microwave furnace and gases thermal filter installation*

In order to protect the metal bath and reduce the metal losses through oxidation, during the melting process of the aluminium beverage cans are used fluxes or fusing agents (in liquid or solid state). The fluxes have an important role in decreasing the melting interaction with gases from the microwave furnace atmosphere and the fusing agents can refine and purify the melting, or modify the casting structure. In the experimental work, the used fluxes were NaCl, KCl, NaF, CaF_2 and cryolite. In table 1 are presented the compositions of the fluxes used for aluminium alloys.

Table 1. *Compositions of the fluxes used for aluminium beverage cans melting*

Code	**NaCl**	**KCl**	**CaF_2**	**NaF**	**Cryolite Na_3AlF_6**
FL 1	35	35	15		15
FL 2	50	50			
FL 3	45	45		10	
FL 4	40	40			20

In establishing the chemical composition of the fluxes, there must be taken into consideration the price of the components and the ratio between the efficiency and the price of the expensive elements on the productivity of the industrial metals/alloys waste recovery process (Liu and Muller, 2012).

According to the information provided by CanPack manufacturer, the aluminium beverage cans are produced using AlMn1Mg1 alloy. In table 2 is presented the chemical composition and in table 3 are presented the technical data of the aluminium beverage cans.

Table 2. *The chemical composition of the aluminium beverage cans*

El.	Mn	Mg	Fe	Si	Cu	Zn	Others	Al
% gr.	1-1.5	0.8-1.3	Max. 0.7	Max. 0.3	Max. 0.25	Max. 0.25	Each 0.05 Total 0.15	rest

Table 3. *Technical data for aluminium beverage cans*

Beverage can weight (500ml)	Exterior paint/Interior protection polish	Al alloy
16.8 – 17.2	3-4.5% (for efficiency can be considered 4%)	rest (96%)

The aluminium beverage cans (figure 3) were dryed for 30 minutes in stove, on a temperature of 60^0C, to eliminate the residual humidity. After drying, the beverage cans were manual and mechanical pressed. In experiments, the number of aluminium beverage cans were almost 12/charge, the total mass was of 200 – 203g and the quality of used flux was of 40g/charge (20% from the waste charge).

Fig. 3. *Aluminium beverage cans*

The obtained experimental data, regarding the mass of the aluminium beverage cans introduced in the microwave furnace, flux and the obtained ingot are presented in table 4.

Table 4. *Experimental data regarding the melting of the aluminium beverage cans in the microwave field*

Exp. code	Charge		Temp. [°C]	Crucible	Obtained materials, [g]			η_{rec}
	Al beverage cans mass, g	Flux, 40 g			Metallic ingot	Metal granule	Slag	
DA1	203.1	F1	700	SiC	141.2	40.1	40.4	72
DA2	201.7	F1	700	Graphite	136.8	49.5	30.4	70
DA3	202.4	F1	750	SiC	163.2	28.8	73.9	80
DA4	202.8	F1	750	Graphite	170.9	16.3	46.9	87
DA5	200.3	F1	800	SiC	147.5	31.4	76.8	76
DA6	201.5	F1	800	Graphite	150.8	27.2	68.1	78
DA7	201.2	F2	750	SiC	147.8	19.3	42.5	76
DA8	200.8	F2	750	Graphite	149.3	21.4	38.8	77
DA9	202.3	F3	750	SiC	152.4	16.8	47.2	78
DA10	201.6	F3	750	Graphite	158.2	20.5	31.5	82
DA11	200.5	F4	750	SiC	165.7	21.2	43.8	86
DA12	203.4	F4	750	Graphite	173.5	19.4	50.7	88

In figure 4 are presented the aluminium recovery output, depending on the working temperature and the crucible material, using a F1 flux and in figure 5 is represented the aluminium recovery output for 750^{0}C working temperature.

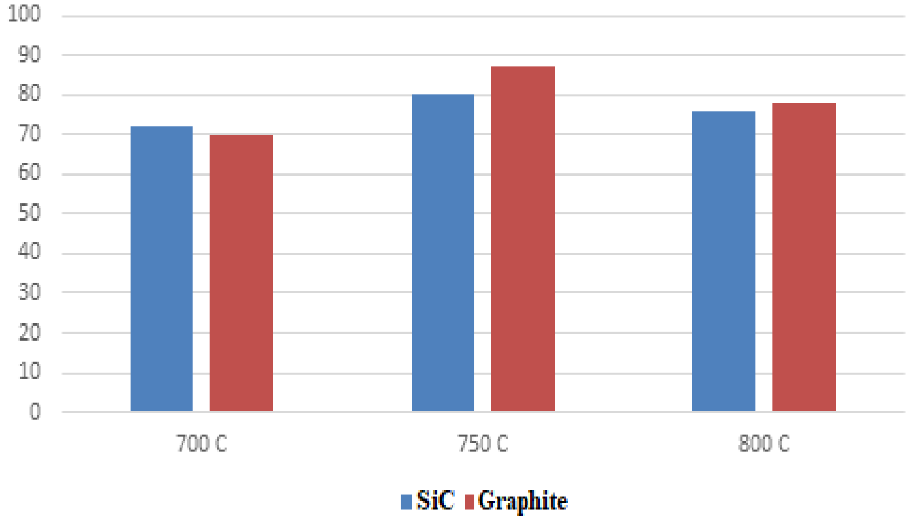

Fig. 4. *Aluminium recovery output, using F1 flux*

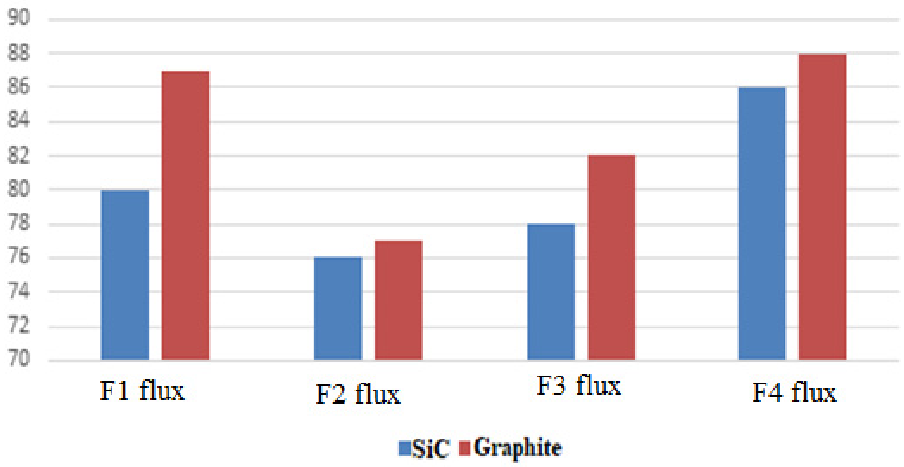

Fig. 5. *Aluminium recovery output on 750^{0}C, depending on the melting flux composition and the crucible material*

After the melting process of the aluminium beverage cans in microwave field were obtained aluminium ingots (table 5) and slag (table 6), which were analysed in laboratory.

Table 5. *Chemical composition of the ingots obtained on the melting process of the aluminium beverage cans*

Exp. code	Cu	Fe	Mg	Mn	Pb	Si	Ti	Zn	Al
DA4	0.146	0.376	0.86	0.77	0.038	0.084	0.014	0.047	base

Table 6. *Chemical composition of the slags obtained on the melting process of the aluminium beverage cans*

Exp. code	Al	Si	Cu	Mg	Pb	Zn	Sb	Sn	Other
DA4	27.70	18.50	0.35	0.10	0.018	0.13	0.005	0.016	rest

In figure 6 can be observed the aluminium metallic ingot and slags obtained on the melting process of the aluminium beverage cans.

Fig. 6. *Aluminium metallic ingot and slags obtained on the melting process of the aluminium beverage cans*

The harmful gases generated in the melting process of the metallic wastes in the microwave field (Sun et al., 2005) were treated using a thermal filter (figure 2) containing three magnetrons. For example, the volatile organic compounds (Van der Harst et al., 2016) were determined before and after passing through the thermal filter using aluminium beverage cans and 40g or 60g of flux or on different temperatures: 660^{0}C and 700^{0}C (table 7). There can be observed different values of the total amount of the volatile organic compounds, due to the thickness and composition of the paint layer applied by aluminium beverage cans manufacturers.

Table 7. *Volatile organic compounds (VOC) measurements before and after treating in the thermal filter (B f – before filter treatment; A f – after filter treatment)*

	DA 2		**DA 4**		**DA 6**	
	B f	A f	B f	A f	B f	A f
VOC	94.6	4.28	85.9	1.08	137.58	0.46
Ethanol	8.09	0.21	10.45	-	15.04	-
Acetone	14.78	1.43	17.76	0.58	20.68	0.46
2-Butanone	0.69	-	0.97	-	1.70	-
Benzene	15.30	1.17	15.24	0.5	20.65	-
Butanol	4.51	0.21	2.94	-	5.95	-
1,4-Dioxane	1.39	-	1.0	-	1.65	-
Toluen	15.22	0.52	9.9	-	17.57	-
Ethylbenzene	7.69	-	5.34	-	11.96	-
Xylene	3.75	0.59	2.55	-	4.07	-
Styrene	19.01	0.15	15.94	-	29.28	-
1-Methylethyl-benzene	1.72	-	1.33	-	3.01	-
Propylbenzene	0.63	-	0.67	-	1.31	-
Trimethylbenzene	0.30	-	-	-	0.31	-
Izopropyltoluene	1.53	-	1.83	-	4.39	-

CONCLUSIONS

The recycling of aluminium, particularly aluminium beverage cans is an important environment and economic activity, in the context of sustainable development of industry. In the article was presented the melting process of the aluminium beverage cans in the microwave furnace, due to technological advantages, compared to the classical pyrometallurgical processes. The preliminary experiments demonstrated that the microwave melting of the compressed aluminium beverage cans, as well as the microwave thermal filter treating of gaseous emissions are reliable methods. There were obtained aluminium ingots, which can be reintroduced in the economic circuit.

Due to the thermal decomposition of the paint layer, which is applied on the surface of the aluminium beverage cans, harmful compounds such as benzene, toluene, ethylbenzene, xylene, HCl, etc. have been determined in the effluent gases.

The gaseous emissions were treated in a microwave thermal filter, in order to reduce their concentration below the legal limits. It was observed that the temperature of the filter has a major influence on the neutralization of the toxic compounds (benzene, HCl).

ACKNOWLEDGEMENTS

This paper has been achieved with the financial support of the National Authority for Scientific Research and Innovation and of the Ministry for European Funds, through the project POC-A.1-A1.2.3-G-2015 / ID: P_40_397, Contract 17/01.09.2016, SMIS 2014 +: 105532.

REFERENCES

Appleton T.J., Colder R.I., Kingman S.W., Lowndes I.S., Read A.G., 2005, Microwave technology for energy-efficient processing of waste. *Applied Energy*, **81**, pp. 85–113.

Capuzzi S., Timelli G., 2018, Preparation and Melting of Scrap in Aluminium Recycling: A Review. *Metals*, **8** (249), p. 1-24

Chandrasekaran S., Basak T., Ramanathan S., 2011, Experimental and theoretical investigation on microwave melting of metals. *J. of Materials Processing Technology*, **211**, p. 482–487.

Das S., Hughes M., 2006, Improving aluminium can recycling rates: A six sigma study in Kentucky. *JOM: the journal of the Minerals, Metals & Materials Society*, **58** (8), pp. 27-31, DOI: 10.1007/s11837-006-0049-1.

Gupta M., Wong W.L.E., 2007, *Microwaves and Metals,* Singapore, 228 p., doi:10.1002/9780470822746

Liu G., Muller D.B., 2012, Addressing Sustainability in The Aluminium Industry: A Critical Review of Life Cycle Assessment. *J. Clean. Prod*., **35**, p. 108-117.

Sun X., Hwang J.-Y., Huang X., Li B., Shi S., 2005, Effects of microwave on molten metals with low melting temperatures. *Journal of Minerals & Materials Characterization & Engineering*, **4** (2), pp. 107-112.

Van der Harst E., Potting J., Kroeze C., 2016, Comparison of different methods to include recycling in LCAs of aluminium cans and disposable polystyrene cups. *Waste Manag*, **48**, pp. 565-583, doi: 10.1016/j.wasman.2015.09.027.

Verran G., Kurzawa U., 2008, An experimental study of aluminium can be recycling using fusion in induction furnace. *Resources, Conservation and Recycling,* **52** (5), pp. 731-736, doi: https://doi.org/10.1016/j.resconrec.2007.10.001.