Al-Khwarizmi Engineering Journal, Vol. 14, No. 3, September, (2018)
P.P. 81- 91

Al-Khwarizmi Engineering Journal

Recovery of Aluminum from Industrial Waste (Slag) by Melting and Electrorefining Processes

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(Received 23 August 201 7; accepted 18 March 2018)
https://doi.org/10.22153/kej.2018.03.002

Abstract

Slag of aluminum is a residue which results during the melting process of primary and secondary aluminum production. Salt slag of aluminum is hazardous solid waste according to the European Catalogue for Hazardous Wastes. Hence, recovery of aluminum not only saves the environment, but also has advantages of financial and economic returns. In this research, aluminum was recovered and purified from the industrial wastes generated as waste from both of State Company for Electrical and Electronic Industries (Baghdad/AlWaziriya) and General Company for Mechanical Industries (Babylon/-Al-Escandria). It was found that these wastes contain tiny proportions of other elements such as iron, copper, nickel, titanium, lead, and potassium. Wastes were recovered for green sustainability, saving energy and cost effectiveness. The method applied for recovering aluminum was pyro-metallurgical method by smelting and refining. X-Ray fluorescence spectroscopy and X- Ray diffraction techniques of the slag sample were used to determine the chemical analysis and phases, respectively. Melting experiments were conducted by using different types of fluxes ($KAlF_4$, NaCl, KCl and $AlCl_3$) at different percentages (0, 5, 10 %) and different melting temperatures (700, 750, 800ºC). Design of Experiment (DOE) by Taguchi method, orthogonal array L9, was used in melting experiments. Melting efficiency of aluminum was equal to 84.7%. Electro-refining of aluminum was done by using anhydrous aluminum chloride and NaCl as ionic liquids at low temperature 100 ◦C in electro-refining method producing aluminum of 99% purity.

***Keywords**: Design of Experiment (DOE), Electro-refining, Melting process, %Recovery, Salt slag of aluminum.*

1. Introduction

Aluminum is the most abundant element after the oxygen and silicon in the earth's crust (by weight). It is never been as a free metal in nature and constitutes approximately 8% of the solid earth surface. Aluminum (Al) is one of the most important metals, since its industrial production, demand for aluminum has been continuously increasing to around 53 million tons in 2014 and its application has expanded to variety of economic sectors. Aluminum contains a combination of important properties that makes it a metal used in many fields, in the medical, military, aerospace, marine, and several household uses [1]. There are three ways for extracting Aluminum, primary source from aluminum ores (bauxite ore), secondary source from aluminum scrap and white dross, tertiary source from black dross and salt slag. Extraction of aluminum starts with bauxite mining, bauxite is processed into alumina, and then alumina is processed into aluminum metal. Extraction of aluminum involves mining of bauxite (open pit), and alumina is produced by Bayer process. Secondary aluminum production is by electrolytic smelting by Hall Heroult technique [2]. Recycling aluminium is also known as Secondary aluminum. All aluminum products can be recycled after use. Recovering of aluminum is very important because of several environmental and economic reasons. Comparison with extraction of aluminum, recycling of aluminum products needs as little as 5% of the energy, and emits only 5% of the greenhouse gas. Recycling of aluminum has environmental amelioration and economical advantage. In the production of aluminum as shown in (Table 1) there is a significant difference in energy between aluminum extraction and recycling compared with other metals; 186 MJ/kg for primary compared to 10-20 MJ/kg for secondary [3]. About 50% of scrap is old scrap (scrap from end of life products EOL). Recycling is fully dependent on scrap as an important source in the aluminum industry, such as used cans, foils, extrusions, commercial scraps, turnings, and old rolled or cast metal. Aluminum can also be recovered from skimming, dross and slag [4].

Table1,
Comparison of Primary and Secondary Aluminum Smelting Processes (data from Gil 2005).

Parameters	Primary Smelting	Secondary Smelting
Consumption of energy(GJ/t		
Al produced) Atmospheric	174	10
emissions (kg/t Al	204	12
produced) Solid waste (kg/t	2,100 to	400
Al produced) Consumption	3,650 57	1.6
of water (kg/t Al produced)		

The main general categories of operations included in the secondary aluminum production are scrap pretreatment, smelting and refining. Pretreatment operations of scrap involve sorting, processing, and cleaning scrap. Smelting and refining operations involve "cleaning, melting, refining, alloying, and pouring of aluminum recovered from scrap". Some steps may be combined or reordered, depending on the quality of scrap, scrap sources, design of the furnace, availability of auxiliary equipment and product specifications. Factory configuration, the type of scrap usage, and the output product vary over the secondary aluminum industry. During melting process for aluminum scrap, a layer of oxide is formed on the surface of the molten in large quantities, and the oxide layer must be removed from the molten product for a high quality finished product. In order to avoid the formation of more oxidation phases and enhance an easier separation during smelting, the flux must be used to protect the molten. The flux works on docking with the impurities to be removed from the molten and separating the metal from the impurities as oxide. The molten surface layer is made of oxides, gases, fluxes and some metals with a quantity of metal additive. Its common name is aluminum slag [5]. A large number of experiments and studies indicate that the bulk of undesirable metals is a real and increasing problem, at every metal recycling processes, P. E. Tsakiridis, et al.(2012) studied a process for the recovery of aluminum by treating black dross of aluminum , a waste formed during aluminum scrap smelting [6]. Li Jinping et al. (2007) investigated the recovery of aluminum and iron from boiler slag taken from factories using coal. Recovery of aluminum based on the applications of hydro-metallurgical processes, like leaching, precipitation, solvent extraction, crystallization and re-crystallization and using sulfuric acid (H_2SO_4) as a leachant for recovery of aluminum [7]. Mikito UEDA et al. (2005) studied a process for recovering of aluminum from aluminum dross by a floating separation of Al from oxides and then electrolysis of oxides implemented in molten salt bath of 51 mol % NaF, 33 mol% AlF_3, and 16 mol% $BaCl_2$ at 1073K, by the flotation separation [8]. In status of aluminum, the schedule of problematic impurities is very large, involving but not limited to Fe, Si, Cu, Mg, Ni, Zn, Pb, Cr, Mn and V [9]. The production of secondary Al annually generates worldwide a considerable amount of slag (more than 3.5 million tons dross and salt slag), which presents the variability of chemical and mineralogical composition. Generally, the Al slag is a mixture of Al oxide, metals, chloride, fluoride, alloying elements and salts from the fluxing agent, nitride, carbide, sulfides, and other substances, which are the result of molten Al reactions with other elements present in the melting system. In contact with rain water, they can react emanating inflammable or toxic gases, such as methane and ammonia, or may become soluble, infiltrating the soil and finally reaching the groundwater; therefore, they are considered dangerous for the environment [10]. The main purpose of this project is to understand the fundamental knowledge of recovery of aluminum from industrial waste in Iraq and the limitation of recovery. The aims and scope of the study are summarized by the following: (1) this research was designed to explain the different parameters affecting on recovery of aluminum from industrial waste (slag) using melting technique. (2) Recovery of aluminum from the industrial waste (slag) by collecting the slag and then crushing, smelting and refining to obtain aluminum with high purity. (3) Investigating the effect of major factors that may affect the efficiency of melting, such as temperature, types of fluxes, stirring and using inert gas (Argon).

2. Experimental Work

To prepare data-base of characterization of waste produced in Iraqi general companies, samples of slag have been taken from different regions in Iraq and then tested. The slag sample used in this work is from General Company for Electrical and Electronic Industries (Baghdad-Al Waziriya) and General Company for Mechanical Industries (Babel-Alescandria). The chemical composition of slag's sample is shown in Table 2. The chemical analysis was conducted in The Ministry of Science and Technology. The used tests involved chemical composition, microstructure, XRF and scanning electron microscope. Effect of additives of the flux has been studied with different fluxes and different percentages of fluxes through melting process. In order to study the effect of re-melting recovering parameters on the salt slag of aluminum, the designs of experiment and optimization should be performed. This study is designed to determine the important parameters and the method of characterizations. The different techniques used to evaluate the object of study are also explained. The process planning is summarized in Figure 1.

Table 2,
Chemical composition of slag's sample, wt%

Si	Fe	Cu	Mn	Cr	Ni	Zn	Ti	Pb	V	Al
4.494	24.85	24.09	4.50	1.192	0.848	17.82	0.0005	1.213	0.0010	Bal

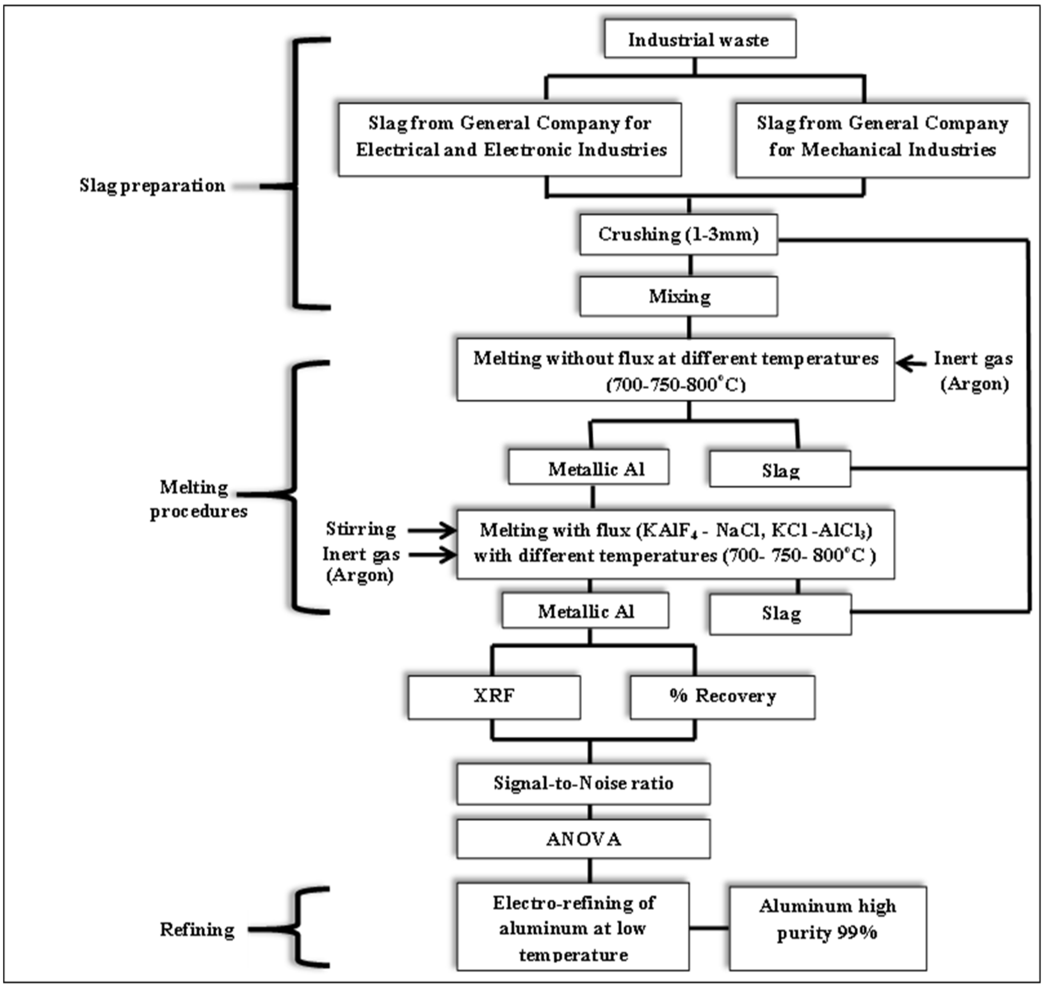

Fig. 1. Flow diagram of beneficiation technique.

2.1. Fluxing and Degassing of Aluminum

In aluminum (Al) smelting and especially in the re-melting of industrial waste, such as slag, a large amount of oxide and nonmetallic impurities formation is common. In order to prevent the oxidation and removal of impurities, multi types of fluxes such as $KAlF_4$ (Foseco, Staffordshire England B783TL), which was obtained from the General Company Electrical and Electronic Industries, were used. Also, other types of fluxes, such as (NaCl, KCl and $AlCl_3$) were utilized with the use of inert gas (Argon).

2.2. Preparation of Slag

The slag sample of 15 kg received from General Company Electrical and Electronic Industries and General Company for Mechanical Industries was crushed by laboratory jaw crusher. Slag particles size at the end of operation was (1-3 mm) and then slag was mixed in a mechanical mixer.

2.3 Melting Procedure

After crushing and mixing, the smelting process of slag is carried out. 100 gm of slag samples are weighed on a sensitive balance, then placed in a crucible made of alumina and then placed in the electrical furnace. The slag was melted at different temperatures (700 - 750 - 800ºC) under inert gas (Argon) to prevent the oxidation that occurs during the melting process, then removing the slag that formed at the top of the molten and then pouring the molten in the mold. The mold used in this process was carbon steel and it was heated to 300ºC before pouring the melt into the mold. Smelting process product was conducted at different temperatures (700-750-800ºC) using fluxes ($KAlF_4$ - NaCl , KCl - $AlCl_3$) with different quantities and using inert gas (Argon) and stirring process for the molten. The molten was poured again into the mold and then tested in XRF.

The efficiency of melting process was determined using two terms, namely
% Recovery and % Yield.

% Recovery = M2/M1 … (1)

% Yield = M2/M1+M3 … (2)

Where:

M1: Weight of the slag before melting. **M2**: Weight of the sample after melting. **M3**: Weight of the flux.

2.4 Electro-Refining of Impure Aluminum at Low Temperature

In the electro-refining process, the impure aluminum alloy is used as the anode and it is electro-refined in an ionic liquid prepared from anhydrous $AlCl_3$ and NaCl. Electro-refining methods at low temperature (100 ◦C) produce aluminum with 99% purity. Electrolysis at low temperature can provide significant energy savings. For this purpose, anhydrous $AlCl_3$ and NaCl are the ionic liquid. The non-pure aluminum is placed as an anode and a solution of (anhydrous $AlCl_3$-NaCl). The cathode is either pure aluminum or pure copper. This electrolysis is capable of removing Mn, Fe, Si, Cu, Zn, Ni, and Pb. The solution can be reused more than once, thus making the process more environmentally friendly. This is because the ionic solution is stable at low temperatures. Aluminum deposited on the cathode can be seen by Light optical microscopy and scanning electron microscope (SEM).

2.5 Process Variables and Design of Experiment (DOE)

Operation variables of temperature, weight of $KAlF_4$ flux, weight of NaCl, KCl flux and weight of $AlCl_3$ flux were chosen as main four control factors with their identical three levels to be investigated. Table 3 shows the investigated four controlled factors and their three corresponding levels.

Table 3,
Controlled factors and their corresponding levels

Controlled Factors	**Correspondence Levels**		
	Level 1	**Level 2**	**Level 3**
Weight of $KAlF_4$ flux, wt%	0	5	10
Weight of NaCl, KCl flux, wt%	0	5	10
Weight of $AlCl_3$ flux, wt%	0	5	10
Melting temperature,ºC	700	750	800

Nine experiments were selected according to Taguchi method (Orthogonal array) (Table 4). Using the Taguchi rules with three levels and four processing variables, the nine experiments using L9 array is described in (Table 5). Table 6 represents all nine experiments with their levels.

Two trials were made for each experiment to get the average data.

Table 4
Taguchi orthogonal array [11]

Orthogonal Array Selector

Number of Levels ↓ Number of Factors →

Number of Parameters (P)

Number of Levels	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	L4	L4	L8	L8	L8	L8	L12	L12	L12	L12	L16	L16	L16	L16	L32
3	L9	L9	L9	L18	L18	L18	L18	L27	L27	L27	L27	L27	L36	L36	L36
4	L'16	L'16	L'16	L'16	L'32	L'32	L'32	L'32	L'32						
5	L25	L25	L25	L25	L25	L50	L50	L50	L50	L50	L50				

Number of Levels	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32
3	L36	L36	L36	L36	L36	L36	L36								
4															
5															

Table 5,
Taguchi orthogonal array for melting process L9

Experiments	Controlled factor 1	Controlled factor 2	Controlled factor 3	Controlled factor 4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 6,
The experiments used in the melting process

Experiments	Weight $KAlF_4$ flux	Weight NaCl,KCl flux	Weight $AlCl_3$ flux	Melting temperature,(°C)
1	0	0	0	700
2	0	5	5	750
3	0	10	10	800
4	5	0	5	800
5	5	5	10	700
6	5	10	0	750
7	10	0	10	750
8	10	5	0	800
9	10	10	5	700

3. Results and Discussion

The results obtained from the melting processes of slag by melting it in electrical furnace with different temperatures (700,750, 800°C), using different types of fluxes ($KAlF_4$, NaCl, KCl, $AlCl_3$), using inert gas, stirring to recover the aluminum alloys, and design of melting experiments by Taguchi method depending on the controlled factors.

Table 7,
Values and average of melting percentage of Aluminum with and without using flux at different temperature at (TOA) L_9.

Exp.	Weight $KAlF_4$ flux	Weight NaCl,KCl flux	Weight $AlCl_3$ flux	Melting temperature, °C	Melting 1 Al wt%	Melting 2 Al wt%	Average melting Al wt%
1	0	0	0	700	83.611	83.8	83.7055
2	0	5	5	750	84.39	84	84.1950
3	0	10	10	800	84.57	84.1	84.3350
4	5	0	5	800	84.66	84.73	84.6950
5	5	5	10	700	85.1	84.9	85.0000
6	5	10	0	750	84.1	83.8	83.9500
7	10	0	10	750	84.34	84.7	84.5200
8	10	5	0	800	84.2	83.6	83.900
9	**10**	**10**	**5**	700	88.7	88.97	88.8350
Mean weight for all experiments is 84.7							

Table 8,
Best optimal levels values of controlled factors for the Aluminum melting with using fluxes , inert gas (Argon) and stirring.

Factors	Value	Level
Weight $KAlF_4$ flux	10	3
Weight NaCl,KCl flux	10	3
Weight $AlCl_3$ flux	5	2
Temperature (°C)	700	1

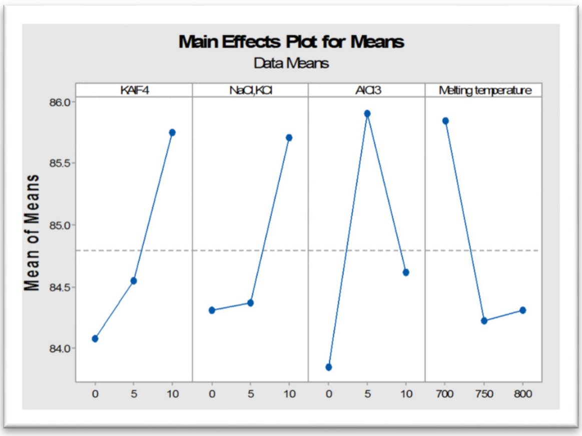

Fig. 2. Melting efficiency of Aluminum by using defferent types of fluxes and different temperatures for each level of the controlled factors.

3.1. Signal-To-Noise (S/N) Ratio

At parameters design, the factors were divided into two kinds: control factors which can be easily controlled by the experimenters and noise factors which can be difficult or expensive to control during operation. To determine (S/N) ratio, there are three types of formulations. In this study, the second formula is used which represents the larger signal to noise ratio, giving the best melting efficiency [12-13].

1- Lower is the better

$$\frac{S}{N} = -10 \log\left(\sum_{i=1}^{n} \frac{Yi^2}{n}\right) \quad \ldots(3)$$

2- Higher is the better

$$\frac{S}{N} = -10 \log\left(\sum_{i=1}^{n} \frac{1}{nYi^2}\right) \quad \ldots(4)$$

3- Nominal is the better

$$\frac{S}{N} = 10 \log\left(\sum_{i=1}^{n} \frac{Yi^2}{S^2}\right) \quad \ldots(5)$$

Table 9,
Values of S/N ratio for melting aluminum by using different fluxes and different temperatures.

Exp.	Weight $KAlF_4$ flux	Weight NaCl, KCl flux	Weight $AlCl_3$ flux	Melting temperature, °C	Melting 1 Al wt%	Melting 2 Al wt%	S/N Ratio
1	0	0	0	700	83.611	83.8	38.4551
2	0	5	5	750	84.39	84	38.5057
3	0	10	10	800	84.57	84.1	38.5201
4	5	0	5	800	84.66	84.73	38.5572
5	5	5	10	700	85.1	84.9	38.5884
6	5	10	0	750	84.1	83.8	38.4804
7	10	0	10	750	84.34	84.7	38.5391
8	10	5	0	800	84.2	83.6	38.4751
9	10	10	5	700	88.7	88.97	38.9717
Mean of SN ratio for all experiments is 38.55							

3.2. Analyses of Variances (ANOVA)

This analysis method is used to determine the importance of any processing variable on the overall of the process concern (Table 10). The general terms described are in % importance [14].

$$SS_T = SS_{(KAlF4)} + SS_{(NaCl,\ KCl)} + SS_{(AlCl3)} + SS_{Temp.} + SS_{error} \quad \dots (6)$$

$$SS_T = \sum_{1}^{n} x_i^2 - \frac{G^2}{N} \quad \dots (7)$$

$$SS_C = \frac{\sum_1^n x_i^2}{n} - \frac{G^2}{N} \quad \dots (8)$$

Where:

SS_T is total sums of squares parameters and error. G is sum of the results data for all the experiments.
N is total number for all the experiments. i is level number. C is one of the tested parameters. $\sum x_i$ is sum of results for all experiments; i.e, at parameter c and at level i, and n is number of parameters.

Degree of freedom was calculated by the following equation:

$$DOF_C = C-1 \quad \dots (9)$$

$$DOF_T = T-1 \quad \dots (10)$$

Where; C represents the levels for each parameter (controlled factor), and ***T*** represents the number of experiments.
Also, contribution percentage (%ρ) was calculated for each controlled factor and for the error from the following equation

$$\rho\% = \frac{SS_C}{SS_T} \quad \dots (11)$$

When:
$\rho_{error} \leq 15\%$, so the chosen controlled factors are not active.
$\rho_{error} \geq 50\%$, so the chosen controlled factors are active.
Table10 summarizes ANOVA data obtained from equations. The table shows the contribution of each controlled factor on the melting efficiency of aluminum from slag.

Table 10,
ANOVA for melting aluminum from slag for each controlled factors.

Factors	Degree of freedom (DOF)	Sum of squares (S)	% contribution (%ρ)
Weight $KAlF_4$ flux	2	0.037	18.407
Weight NaCl, KCl flux	2	0.037	18.407
Weight $AlCl_3$ flux	2	0.057	28.358
Temperature °C	2	0.047	23.382
Error	0	0.023	11.442
Total	8	0.201	100%

3.3. Electro-Refining of Aluminum at Low Temperature

Electro-refining methods are shown in Figure 3 for produced aluminum of 99% purity at 1.5 volt and low temperature about 100°C by using anhydrous aluminum chloride $AlCl_3$ and NaCl.

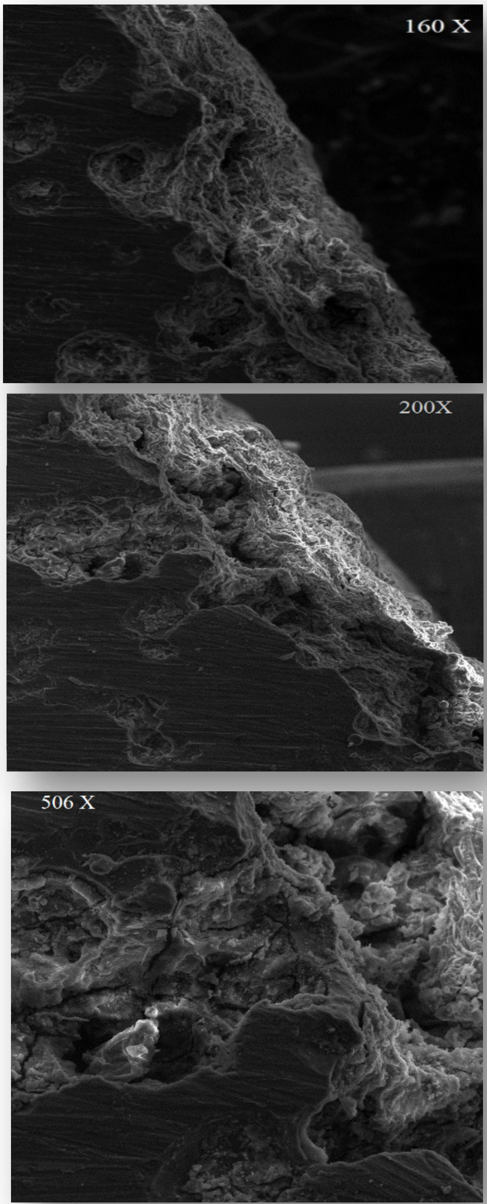

Fig. 3. Scanning Electron Microscope (SEM) images of deposited aluminum produced by Electro-refining process.

3.4. Discussion of Melting Process

Melting process was effective for recovering aluminum from the industrial waste, so using different fluxes, different temperatures, and using inert gas (Argon) and stirring the melt were the alternative for aluminum recovery.

3.4.1. Effect of Adding $KAlF_4$ flux

The effect of adding $KAlF_4$ flux on the melting of aluminum slag was studied, and the ratio of adding $KAlF_4$ flux is in the range of (0 - 10). The results represented in Fig.2 show that the increase in amount of $KAlF_4$ at the melting process leads to increase the melting efficiency of aluminum. The role of $KAlF_4$ flux is to separate metals from slag and oxide and to prevent agitating burning of the aluminum during melting process, and therefore maximizing yields. When $KAlF_4$ is added to a mixture of NaCl and KCl, the fluidity of the flux increased. This increasing fluidity better covers the exposed molten metal and facilitates the release of metals entrapped in the slag. The active fluoride will also remove magnesium (Mg) in the melt and improve the metal purity. It is possible to conclude that the fluoride additions decrease the viscosity of the molten salt and cause an increase in aluminum recovery as the amount of fluoride increases in the molten salt [15]. The best result in adding $KAlF_4$ flux was done at 10 wt% with using inert gas during melting process and stirring the molten metal. At fluoride concentrations 10 wt%, the drop in flux-aluminum interfacial tension was roughly. But generally, the salts especially those containing fluorides can destroy and remove the strong and dense oxide skins from the molten aluminum alloys, which can then freely coalesce. Though, that can be provided up to 10% oxide concentrations, at higher concentrations some forms of mechanical agitation are also required because the coalescence is extremely impaired due to the viscosity changes [16]. Table 10 shows the % contribution (%ρ) of $KAlF_4$. flux is (18.407) on the melting process of aluminum from salt slag.

3.4.2. Effect of Adding NaCl, KCl Flux

It can be seen clearly from Fig.2 the effect of adding NaCl, KCl fluxes on the melting process, the ratio of adding NaCl, KCl fluxes is in the range of (0 - 10). The results represented in Figure 2 show the increasing in amount of NaCl, KCl fluxes at melting process leads to increase the melting efficiency of aluminum. (NaCl, KCl) fluxes added to separate the surface attached to impurities, to enhance coagulation of drops of melt, and to protect the bath surface against oxidation. All the chloride salts formed are less dense than liquid aluminum, and will float and accumulate at the dross layer on top of the melt [17]. Figure 2 also shows that the best result is at 10 wt% of NaCl, KCl flux, and the addition was done with using inert gas (Argon) and stirring the molten metal. Table 10 shows the % contribution (%ρ) of NaCl, KCl flux is (18.407) on the melting process of aluminum from salt slag.

3.4.3 Effect of Adding $AlCl_3$ Flux

The effect of adding $AlCl_3$ during melting process was investigated, and the ratio of addition is in the range of (0 - 10). The results represented in Figure 2 and (Table 7) for experiment no.9. shows the good result was at 5 wt% $AlCl_3$ with 10 wt% $KAlF_4$ flux and10 wt% NaCl, KCl fluxes in melting process and Table 10 shows $AlCl_3$ have the best %contribution (%ρ) is (28.3%) of each controlled factor on the melting of aluminum from slag.

3.4.4. Effect of Temperature

The temperature effect on the melting of aluminum by using electric furnace was studied. The results showed that the temperature had a negative effect at 800°C on the melting of aluminum, as shown in Fig.2 No satisfactory explanation is offered for the decrease in the length of the spirals resulting from superheating to 800°C. Gas absorption by the molten aluminum during melting was suggested as a possible explanation of this phenomenon. At the present time, it is generally accepted that hydrogen is the gas most readily absorbed by molten aluminum. Methods of removing hydrogen from molten aluminum or aluminum alloys with chlorine, chlorine mixed with nitrogen, or chlorine compounds have been studied by a number of investigators [18]. Table 10 shows the % contribution (%ρ) of temperature is (23.382) on the melting process of aluminum from salt slag.

4. Conclusions

In this work, the main following conclusions can be obtained:

1. Melting technique of salt slag that obtained from General Company for Electrical and Electronic Industries (Baghdad-Al Waziriya) and General Company for Mechanical Industries (Babel-Alescandria) can be successfully applied.
2. The effect of fluxes (KAlF4, NaCl , KCl) on the melting process was positive, and increasing the level of these three factors led to increase the melting efficiency of aluminum.
3. 3-The effect of AlCl3 flux on the melting process was negative at 10 wt% but was good at 5 wt%, and increasing the level of this factor to 10wt% led to reduce the melting efficiency of aluminum.
4. The effect of high temperature above 800 oC on the melting process was negative, and increasing the temperature led to reduce the melting efficiency of aluminum.
5. Aluminum with high purity was obtained; purity was 99% by electro-refining of impure aluminum by using anhydrous aluminum chloride and NaCl as ionic liquids at low temperature (100oC).
6. The melting efficiency of aluminum was found 84.7 %.

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استرجاع الألمنيوم من المخلفات الصناعية (الخبث) بواسطة عملية الصهر وعملية التنقية

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الخلاصة

خبث الألومنيوم هو البقايا التي تنتج أثناء عملية الصهر لإنتاج الألمنيوم الأولي والثانوي. يعتبر خبث الألومنيوم من المخلفات الصلبة الخطرة حسب البيان الأوروبي للنفايات الخطرة. وبالتالي، استرجاع الألومنيوم من الخبث ليس فقط لحماية البيئة، ولكن أيضا له فوائد اخرى من الناحية المالية والاقتصادية. في هذا البحث تمت عملية استرجاع وتنقية الألمنيوم من المخلفات الصناعية الناتجة عن مخلفات صناعية للشركة العامة للصناعات الكهربائية والالكترونية/ الوزيرية ومخلفات الشركة العامة للصناعات الميكانيكية / الإسكندرية. حيث تحتوي المخلفات بالاضافة الى الالمنيوم على نسب من عناصر أخرى مثل الحديد، النحاس، النيكل، التيتانيوم، الرصاص، والبوتاسيوم. حيث يتم استرجاع الالمنيوم للمحافظة على البيئة، وتوفير الطاقة والكلفة الاقتصادية. وكانت الطريقة المطبقة لاسترجاع الألمنيوم بالطريقة الحرارية عن طريق الصهر والتنقية. واستخدمت تقنيات التحليل الطيفي وتقنيات انعراج الأشعة السينية لعينة الخبث في أيجاد التحليل الكيميائي ومعرفة الاطوار. أجريت تجارب الصهر باستخدام أنواع مختلفة من مزيلات الخبث ($AlCl_3$, NaCl , KCl , $KAlF_4$) و بنسب مختلفة (٠، ٥، ١٠) ودرجات حرارة انصهار مختلفة (٧٠٠، ٧٥٠، ٨٠٠ سيليزية). تم استخدام تصميم التجارب بطريقة تاغوتشي L9، في تجارب الصهر. وكانت كفاءة عملية صهر الألمنيوم 84.7 ٪. وقد تمت عملية التحليل الكهربائي للألمنيوم بأستخدام كلوريد الألومنيوم اللامائي و كلوريد الصوديوم كسوائل أيونية عند درجة حرارة منخفضة ١٠٠ سيليزية ، في طريقة التحليل الكهربائي تم الحصول على الألومنيوم بنقاوة ٩٩٪.