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Recycling and Processing of Aluminium Potlining Wastes

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Abstract: The study reviews the problems of solid waste generation from aluminum production. Researchers conducted scientific work in order to create the technological scheme of processing the reduction pot waste which is part of the design-budget documentation for the waste management workshop under the framework of technogenic aluminum plant project. The data of the chemical composition of the cathode lining materials from dismantled aluminum reduction pot devices was acquired. The state of lining materials from three aluminum factories was studied. Researchers developed methods and compiled sampling cards for lining sections of reduction pots with different capacities.

Key words: Aluminum reduction pot, cathode lining, waste lining products, chemical analysis, fluoride recovery, cyanide destruction

INTRODUCTION

For today in areas with major energy sources there are a lot of factories for the production of aluminum by reduction pots which form and store hundreds of thousands of solid waste tons (Sorlie and Oye, 2010). In these regions, the acute problem of utilization and processing of technogenic products arise to ensure safe living. Today leading international aluminum producers are investing in the construction of modern technological facilities and landfills (Li and Chen, 2010).

Information on emissions are controlled by the International Aluminium Institute (IAI). According to reports, Russian aluminum enterprises at 1 ton of aluminum using reduction pots with self-baking anodes produce up to 130-155 kg of emissions and with the application of advanced technology with prebaked anodes-up to 67 kg. In 2015 according to enterprise data in Russia was produced 3.74 million tons of aluminum. As a result, aluminum smelters produce and annually dump or store in landfills >400 thous. tons of coal and brick lining from dismantled reduction pots and anode butts. During the electrolysis of dissolved alumina in fluoride salts melt at a temperature of 960°C, stable cumulative formation of highly toxic alumina fluoride carbon containing waste-afteruse liner reduction pots, anode butts and fine slurry with a carbon content of 25-70%, fluorine 6-16%, aluminum 4-10% and sodium 6-19%, 0.1-1.3% sulfur, cyanide and 1% other components (Li and Chen, 2008).

MATERIALS AND METHODS

Chemical analysis: researchers conducted scientific reseach in order to create the technological scheme of processing the reduction pot waste which is part of the design-budget documentation for the waste management workshop under the framework of "Technogenic aluminum plant". The state of lining materials on the three companies was studied. Authors developed methods and compiled sampling cards for lining sections of reduction pots with different capacities. Chemical analysis of designated areas of the cathode unit shown in Table 1.

Reduced levels of fluoride in higher power reduction pots is connected with the use of silicon carbide in the side lining plates and use of the new barrier materials. The increase of aluminum fluoride content is associated with the technology of reduction pots with lower bath ratio (with AlF_3 excess). With increase in service life increases the level of fluoride salts treatment of carbon-graphite refractory materials. Figure 1 shows the dependence of the lining treatment from the period of the pot service based on processed statistical data for the cathode reduction pots with burnt anodes 175 kA. The treatment ratio was determined from the difference between the weights of the cathode device before starting and after turning off into the overhaul. After dismantling and removal of coal hearth expected treatment of refractory materials was calculated by the suggested scheme.

On average, in aluminum production during a year for purpose of major repairs from 30-100 reduction pots are being disabled and materials from baths are kept under

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Table 1: Composition of used lining material from reduction pots of different capacity after their switch off to capital overhaul

Variables	Values		
Reduction pot power (kA)	160	175	300
Reduction pot life time (days)	1266	1157	1031
Waste material composition			
Loose carbon C (%)	51.6	52.3	58.90
Metallic aluminum (%)	4.9	5.6	3.800
Alumina Al_2O_3 (%)	9.9	10.1	5.400
Silica SiO_2 (%)	19.1	22.8	14.10
Sodium fluoride NaF (%)	9.5	5.9	4.800
Aluminium fluoride AlF_3 (%)	3.2	2.6	3.900
Magnesium fluoride MgF_2 (%)	2.2	1.9	0.500
Calcium fluoride CaF_2 (%)	5.5	4.9	4.300
Titanium dioxide TiO_2 (%)	0.05	0.03	0.003

Table 2: Dependence of average waste composition from their storage time in polygons

	Storage time (years)		
Waste composition	3	10	20
Loose carbon C (%)	49.60	45.30	44.900
Metallic aluminum (%)	2.90	2.60	1.800
Alumina Al_2O_3 (%)	9.90	8.10	5.400
Silica SiO_2 (%)	19.10	18.80	17.100
Sodium fluoride NaF (%)	10.50	3.90	1.800
Aluminium fluoride AlF_3 (%)	4.20	3.60	1.100
Magnesium fluoride MgF_2 (%)	2.20	1.90	0.050
Calcium fluoride CaF_2 (%)	5.50	3.90	0.300
Titanium dioxide TiO_2 (%)	0.01	0.02	0.007

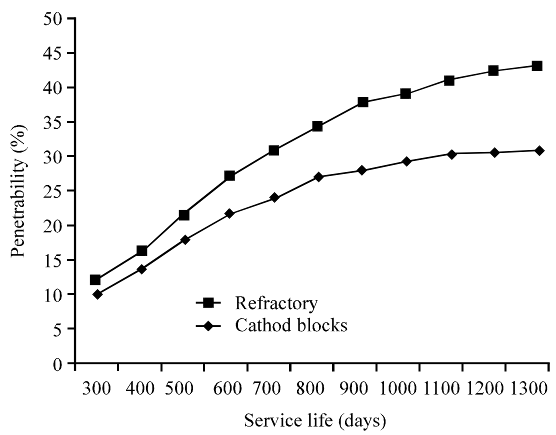

Fig. 1: Dependence between cathode material treatment and reduction pot service life

the influence of an atmospheric precipitation. Development of recycling technology and renovation of waste storages (polygons) began only in the last decade. Currently there is no comprehensive data on the situational conditions at the sites and the degree of waste decomposition. Selected samples from different parts of the three aluminum factory landfills showed that 65% of nonorganic materials have not decayed over 20 year of storage (Table 2). The content of silicon and aluminum oxides in the brick lining is on average >40% but it is not processed at the plants being sent to the landfills. Decrease is mainly connected with fluoride content. The greatest environmental danger comes from the solid waste such as soluble fluorides such as sodium fluoride and cyanide. These compounds are washed away by precipitation and have an adverse effect on the health of not only workers but also to the people living in the zone of production influence.

RESULTS AND DISCUSSION

Processing scheme: Methods of disposal are based on the physical-chemical studies of the properties and structure of waste from reduction pot production which allow to define the fundamental possibility of its use in production (Rustad *et al*., 2000). Organization of processing the waste liner on a small scale is impractical. Therefore, small reduction pot workshops provide only a preliminary crushing and sorting of dismantled lining. Despite the fact that there is a need for recycling of old dumps and landfills of reduction pot production, only on some aluminum factories attempts are made to recycle lining and cinders on specialized lines. During removal from the cathode, reduction pot and aluminum casing are recovered and smelted at the reduction pot workshop, while coal lining is sent for recycling.

There are a couple of technically well-developed alternatives for production waste recycling (Lisbona *et al*., 2013). They can be divided into storage technologies (material is decomposed or utilized in other industries) and recovery-recycling technology (fluoride is recovered for use in the production of primary aluminum). Waste treatment methods in which aluminum fluoride is obtained, represent the greatest interest from an economic point of view.

Storage technology:

- Incineration for energy production
- Flux additives in the steel industry
- Energy and mineral additives in cement production
- Transformation into an inert material for dumps combustion in a fluidized bed furnace; gypsum process; leaching process; heat detoxification process
- Production of red brick

Recovery-recycling technology:

- Removing fluoride with the help of leaching: cryolite regeneration processes; AlF_3 regeneration processes
- Pyro-hydrolysis
- Pyro sulfur process
- Silica pyro-hydrolysis
- Extraction of graphite

Table 3: Main ways to industrial waste recycling

Process names	Recovered material	Scale	Main goal
Caustic leaching	Cryolite	Industrial	Cryolite production
Sedimentation	Sodium fluoride	Industrial	Market realization
Vacuum distillation	Cryolite, sodium	Experimental	Cryolite production
Hydration	Carbon	Industrial	Cathode carbon recovery
Acid treatment	HF($A1F_3$), aluminate	Lab	$A1F_3$ production
Distillation, pyro-hydrolysis	HF($A1F_3$), aluminate	Lab	$A1F_3$ production
Lime leaching	HF(AlF_3), carbon aluminate	Lab	$A1F_3$ production
Hydrolytic treatment	-	Pilot	Landfills

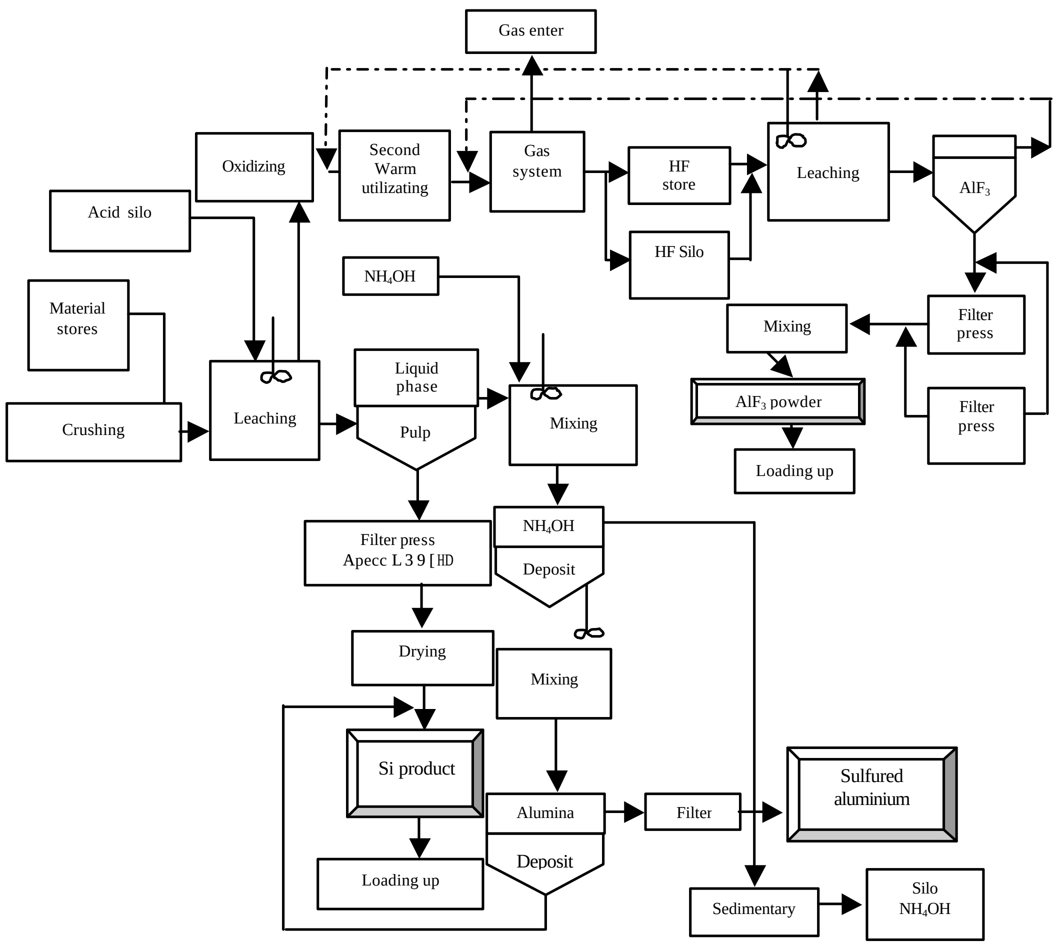

Fig. 2: Scheme of waste recycling from primary aluminum production

- Additives to the carbon cathode
- Additives in the carbon anode

Some foreign aluminum companies are very active in the development of different versions of the processing of aluminium wastes in (Table 3) researchers provide an overview of approaches to industrial waste recycling. Only some of the ways are developed up to the stage of industrial implementation due to the fact that they do not fully utilize spent anodes and cinders lining because of the low efficiency of processes or for economic reasons (Diez and Marsh, 2001). Considered wastes contain in its composition valuable components which can be obtained during processing to gain substantial economic and environmental benefits.

Authors offer a modern and technically well developed concept of technical alternatives for recycling the wastes from aluminum production according to the following diagram. In scheme design a variant of fluoride components wet processing was considered. Due to the large amount of energy required, alternatives were considered, taking into account its low value in areas with available hydropower and using waste heat from the combustion products. The following processing steps are included in the project:

- Preparation of materials: crushing, sizing, grinding
- Processing: thermal (high-temperature leaching), chemical treatment to remove dangerous gases
- Production: mixing with chemicals, drying, manufacturing of the final product

With this in mind authors developed a diagram of technogenic raw materials processing from reduction pot production (Fig. 2). Coal and refractory lining comes to storage units and goes further to crushing operation and after it is subjected to leaching in acidic conditions where it is separated into two parts.

Step 1: Leach slurry is reacted with the oxidant, the exhaust gases are captured and fed to the gas cleaning system, wherein happen a partial regeneration of hydrofluoric acid. After reaction with the oxidant is performed, leaching with hydrofluoric acid starts and product is further condensed to AlF_3. Then the pulp is put into circulation. The resulting aluminum fluoride is filtered, dried and sent to the warehouse of finished products. After leaching the pulp is fed to the thickener where a thickened cake mixed with the condensation product is sent to the washing, filtering and drying. As a result of redistribution we obtain silica fume which is shipped to the production of bricks, silicate and glass products.

Step 2: Drained thickener is treated with ammonium hydroxide and fed to the subsequent step of condensation. Draining is regenerated and sent to the initial stage of the process. The sludge from thickener is leached with dilute sulfuric acid with the addition of alumina. Thereafter, condensation occurs and further condensed products are connected with the sludge from thickener and draining occurs during the washing, evaporation and drying.

At all stages of the production monitoring of the content of toxic substances in the air and its purification are carried out in order to remove them from the harmful emissions that are released into the environment.

The fundamental solution is that for the processing of waste (consisting of dismantled brick lining of reduction pot aluminum production) authors offer autoclave neutralization of soluble fluoride, cyanide; release (extraction) of aluminum compounds, alkali metals; the use of carbon and prevention from harmful emissions to the environment. Exploitation of new recycling methods improves the environment by binding water-soluble fluorine compounds in the lining into insoluble form, and also by neutralization of the cyanide in the raw materials and in lining which allows to remove about 90% of the aluminum compounds and alkali metals. It is possible to use carbon in linings as a reductant and energy resource and the solid residue-the sludge after the hydro-chemical treatment-is used for the production of cement, silicate bricks or road construction.

The results of these studies and industry practice allow development of technology to recycle aluminum carbon fluoride consistent wastes from reduction pot production with resulting yield of commercial products (aluminum fluoride, silica fume, aluminum sulfate, etc.). Emissions (dust and gases) and solid waste (spent linings) produced are essentially negative parts of reduction pot mass balance. Suggested scheme makes possible development of energy saving technologies along with life safety in areas with high number of aluminum company.

CONCLUSION

Today, there is the need to develop the concept of technogenic plant construction for complex processing of aluminum industry waste (secondary aluminum, foundry slag, lining cathode, anode stubs) after environmental monitoring of poligons. Some aluminum companies have started to carry out environmental protection measures and try to create a project "Kyoto Protocol" on the UNFCCC requirements for the joint implementation and clean development mechanism projects. How complete are these measures remains to be seen. Currently, researchers suggested the methodological and technical grounds of processing aluminum waste which can solve the problem of recycling waste products of reduction pot.

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