Thermo-Electrical Modeling of an Aluminum Reduction Cell

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Abstract: In this research a 3-D thermo-electrical model for an aluminium reduction cell is developed and the effect of operational parameters on the thermo-electrical characteristics of the cell is studied.

The aim, in this paper, has been to evaluate influence of increasing the amperage on side wall ledge (frozen electrolyte) by using thermo- electric model of reduction cells of Almahdi Aluminium Company located in Bandar Abbas.

By comparing of the Results obtained from the solution of model with those obtained from real operation of reduction cells the possibility to increase to production by applying higher amperage was evaluated.

Results from numerical solution including operational temperature, frozen ledge thickness are to a large extent according to expectations and measurements.

It was found that increasing the amperage in Almahdi Pots from plant nominal value of 175 K Amp to 185 K Amp would melt down the protective side freeze resulting in pot failure.

Keywords: Modelling-reduction cell(pot)-Heat Balance-ledge(Frozen Electrolyte)-Finite Element “;”

Introduction

Modelling of Aluminium reduction cells is very complicated which due to existence of different processes, it includes several multi physics such as thermo-electric, thermo-mechanic & thermo- electro mechanic, MHD and ect. Today finite element modelling consider as a mature and advanced technology. Ansys is one of the software that in finite element method solves the fields including multi physics which by means of that, various modelling of Aluminium reduction cells have been affected. All Aluminium smelters in the world by using mathematical modelling attempt to update the equipments and new designs of reduction cells.

In primary Aluminium industry, one of the methods of increasing Aluminium production in factories was raising the amperage in old production lines. In fixed amperage efficiency the production rate improves against flow raising. In Almahdi Aluminium Company in Bandar Abbas increasing the production through raising the amperage was placed on the agenda by management.

Considering that increase of the amperage will lead to the cells heat raising, high temperature results to the ledge corrosion. So before taking any practical action for increasing the amperage of the line, the cell must be modelled and the heat balance reviewed and takes the temperature’s critical points into consideration.

Studying the similar works among technical articles and reports as well as initial researches shows that a large number of studies have been performed so far in order to recognize and analysis of Hall-Herault Aluminium reduction process.

However regarding to complication of process, a mathematical model or software to be able to model all dimensions of this problem perfectly and simultaneously, has not been created yet. At the same moment, it has been attempted to make models to avoid try and error process in designing the cells.

In this project, the numerical, thermo-electrical analysis of Aluminium cells of Almahdi smelter has been made via finite element method. At first, three-dimensional geometry design of cell slice model has been done and then was meshed. In second stage, the specifications of materials (cells components) and boundary conditions was specified. Then after solving the problem, the input amperage was increased and noticed its effect on ledge thickness.

Aluminum Production Process

In this section the aluminium reduction pot and its components as needed are introduced for recognition of parts in thermal analysis. In 1886, however. and independently of each other, Paul Herault of France and Charles Hall of the USA discovered and patented a process by which alumina was dissolved in molten cryolite and decomposed electrolytically to give liquid aluminium. This process has successfully withstood the many attempts to replace it, and no other processes seem like threatening it in the foreseeable future.

The Hall-Herault process is the only method by which aluminium is produced industrially today.

Thus, in the Hall-Herault process, named after its inventors, liquid aluminium is produced by the electrolytic reduction of alumina (A120s) dissolved in an electrolyte (bath) mainly containing cryolite (Na3AlF6)

A very simplified schematic drawing of the main features of an alumina reduction cell is shown in **Fig. 1.**

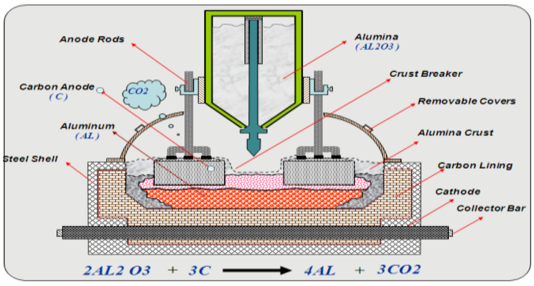


Fig. 1: Schematic drawing of the main features of an alumina reduction cell

In the cell one or several carbon anodes are dipped into the bath, and produced oxygen from process, collected onto anode. However, in effect of this process the oxygen immediately reacts with the carbon anode and thus gradually consumes it by the formation of gaseous carbon dioxide (C02l. Under the bath there is a pool of liquid aluminium, which contained in a preformed carbon, lining With Insulation materials inside a steel shell. The aluminium is formed at the electrolyte/metal interface which acts as the cathode thus. The overall chemical reaction can be written:

$2Al_2O_{3\,(dissolved)} + 3C_{(s)} \rightarrow 4Al_{(l)} + 3CO_{2\,(g)}$

The bath

A bath which mainly contains Cryolite is used because of its unique and unmatched capacity as a solvent for alumina. The bath is not consumed as such during the electrolyze process, but some losses occur, mainly by vaporization. Addition to cryolite as the main component of bath, usually below matters developed in the bath. The bath in modern alumina reduction cells may typically contain.

6 to 13 mass% of aluminium fluoride (ALF3)
4 to 6 mass% of calcium fluoride (CaF2)
2 to 4 mass% of alumina (Al2O3)

In some cases 2 to 4 mass%, lithium fluoride (LiF) and /or magnesium fluoride (MgF2) may be added. In these cases, the content of aluminum fluoride is usually below 6 to 7 percent. The bath temperature during cell operation is typically in the range 940 to 970°C. [2]

The bath Height in the pots does not vary much and is usually close to 20 cm. The inter-polar distance, in other words, the vertical distance between the bottom side of the anode and the surface of the pool of liquid metal, is typically 4 to 5 cm. Thus in addition of its main function as a solvent for alumina and to enable its electrolytic decomposition to form aluminium in electrolyze process, the bath produced a physical separating layer between manufactured aluminium metal on cathode and the carbon dioxide gas on anode.

Fig. (2) recovery boiler lining of the *ALMAHDI Aluminium Cor* is shown

3-Modeling

3-1-model construction

Using Solid Work software, 3D model was built based on available - 2 dimensional drawings of ALMAHDI Aluminum pots.

In this paper final modified geometry of sliced model for half anode, in Design Modeller environment was simulated and used.

For determining the material property, meshing, applying boundary condition and solving thermo electrical problem, the model were executed in thermal-Electric mode.

In the next step thermo physical properties of reduction pot's structure were defined in engineering data module; Two most important parameters were isotropic resistivity and isotropic thermal conductivity , that to achieve accurate results are preferred to be defined as a function of temperature.

"Correct definition of the contact surfaces between adjacent parts is very important in a Thermo electrical analysis".

In the next step all contacted parts were evaluated by using produced model geometry in mechanical mode.

In the next step sliced model was meshed;"meshing is one the most important steps in a 3D analysis".

Correct meshing of a model in the areas where there are high temp. Gradient like bath, melted aluminium metal and side walls (where side freeze forms) requires choosing mesh size small enough so as to produce accurate results. Sliced model illustrated in fig. 3 is composed of 60536 Elements.

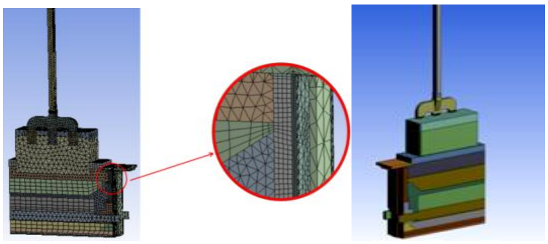


FIG.3: Half Anode(slice) Model Mesh

Using mostly Sweep method for Meshing, increased accuracy and made solution convergence.

3-2-Boundari Condition

As in the sliced model only half an anode is included therefore current entering the anode Rod cross section, A, is assumed to be 4860 Amp.

Regarding pot nominal amperage of 175 KAmp, Current value was calculated as below:

18 (No of anodes in a pot) *2(half anode)*4860=174960 Amp

Another boundary condition in the B zone is Zero Voltage for cathode collector bar ends.

Overall heat transfer was estimated by convection to the air at 3 main zones (surfaces), at bottom surface (D zone), at Upper surface (E zone) and side surface(C zone). Convectional heat transfer coefficient and ambient temperature was defined separately for each zone. Boundary conditions were applied to the model as illustrated in **Fig.4.**

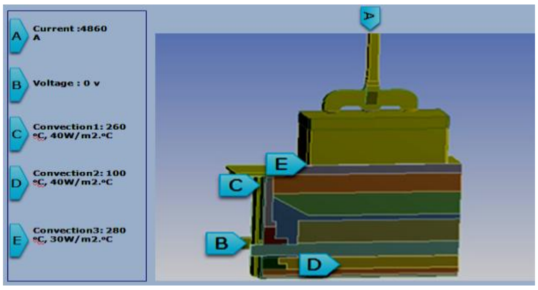
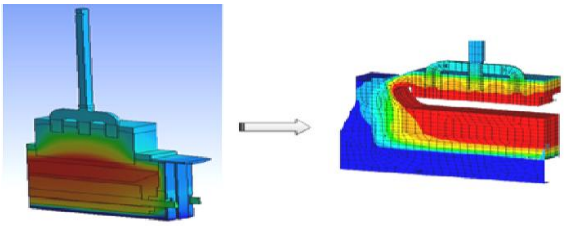


Fig.4: boundary condition in slice model(Almahdi pot)

4- Result and Discussion

Using ANSYS a Model was built and solved with finite element method. After induction of boundary conduction, solving progress continue till meeting flow and heat convergence conditions. Temperature profile for a current of 4860 Amp is compared with that obtained by Marc Dupuis using the same method in Fig.5.

It can be seen that maximum temperature lies in the center of the pot and its vicinity where there is electrolyte; temperature gradient and profile are very much like those presented in the same works done by others.[6]

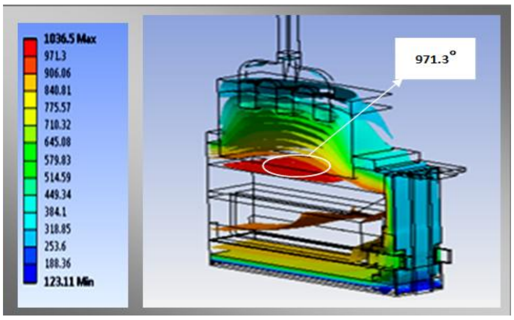


a) Almahdi aluminum pot Temp. Profile b) Temp.profile evaluate by Marc Dupuis

Fig.5: Comparison Almahdi pot Temp. Profile with research by Marc Dupuis

The temperature profile as an isotherm plates in Almahdi aluminium reduction pot also is shown in figure 6.

Fig.6. shows isotherms from model solution in Almahdi Pots.



Bath temperature values obtained from numerical solution and routine bath measurements by process control for two pots are compared in Fig.7.

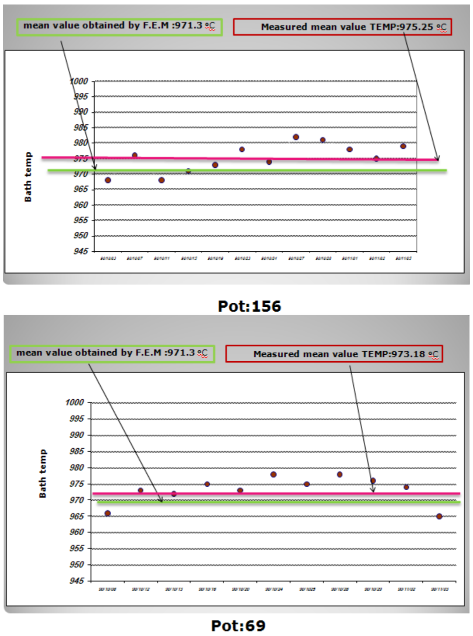


Fig.7: Comparison of pot mean bath temp. Measured and obtained from numerical solution.

Temperature profile in side wall area is illustrated in fig.8

Electrolyte freeze to form side ledge in pot- side wall due to high heat transfer to ambient air and other contacted surfaces; temperature in bath/ledge interface is 920 °C. As it seen the temperature and its attained profile on pot's side wall and ledge vinicity is about 920 degree.

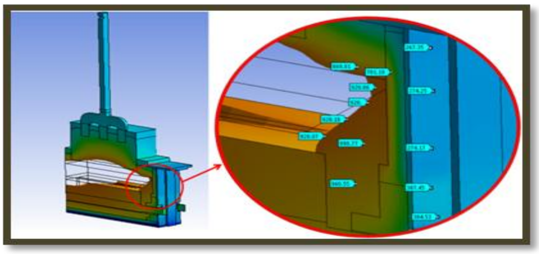
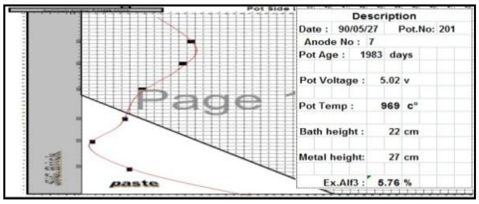


Fig.8: Informed ledge at 920 °C and Temp. Distribution on side wall of Almahdi pot

Side ledge formation has a significant role in protecting side wall refractory against highly corrosive molten bath; prolonged bath high temperature will eventually result in local refractory failure letting bath to flow out of pot steel shell .i.e., tap out.

Random measuring of ledge thickness of pot 201 in 18 August of 2011 showed that carbon paste had been damaged severely due to no side ledge existence; this pot was cut out service 4 days later in 22 August 2011. Ledge profile for pot 201 is shown below.



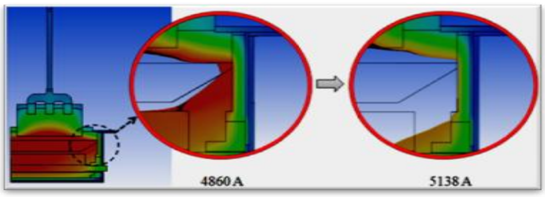
Description
Date : 90/05/27 Pot.No: 201
Anode No : 7
Pot Age : 1983 days
Pot Voltage : 5.02 v
Pot Temp : 969 c°
Bath height : 22 cm
Metal height: 27 cm
Ex.Alf3 : 5.76 %

Fig.9: Measured ledge thickness on pot 201

Side ledge thickness in Almahdi pots is measured by process control technicians. In figure 9 has obtained a comparison between formed ledge in numerical analysis and real measurement. Practically ledge measuring first done by anode extraction and then measured which this operation resulted to failure of top shape

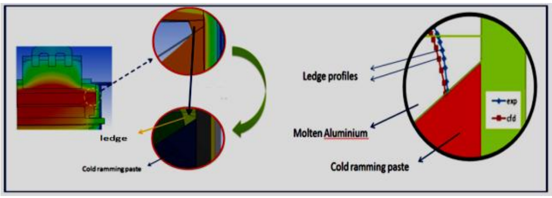
The thickness resulted from numerical solution and that measured by process control could be compared in Fig.10. To Measure Side ledge thickness requires pulling out anodes from a pot which in turn increases the ledge thickness closer to the bath surface; therefore it is better to compare the thickness from numerical solution at lower levels of the profile.

Side ledge profile at the lower level is compared in Fig.10; it can be seen that the profile from both methods are very close together. After amperage raising from 175 to 185 ka and induction of 5138 A flow as a new boundary condition and solving the sliced model it is seen that ledge in pot side walls removed completely. In figure 11 this significant result has been shown.



a)Line Amper:175 KA b)Line Amper:185 KA

Fig.10: Compare between Exp. ledge thickness and numerical method



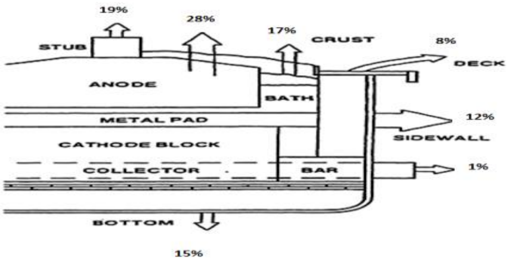
Heat dissipating from Almahdi pot in form of flux, energy and percentage are given in table 1.

Position	Heat Flux (w/m2)	Heat (w)	%
Sidewall	1440	931	12
Bottom	1351	1110	15
Collector Bar	7933	83	1
Deck Plate	3048	609	8
Crust	6872	1236	17
Anode	1272	2069	28
Stub	2568	1419	19

Table 1: Cell Heat Loss Distribution

Heat losses from different areas in pot are illustrated in Fig.12.

Figure.12: heat loss in Almahdi reduction pot acc. to table 1



Conclusion

The results of pot thermal and electrical analyzes are according expectation. Electrolyte temperature, pot shell temperature, and frozen electrolyte layer (ledge) approve above mention.

Besides, temperature and voltage distribution which have been achieved are the same as other major factory research in this regards.

Research shows increasing amperage from 175KA to 185KA in Almahdi pots decreases thickness of frozen electrolyte layer (ledge) and finally destroying side wall and pot.

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