A TECHNO-ECONOMIC OPTIMIZATION MODEL FOR ALUMINIUM ELECTROLYSIS PRODUCTION

Yanfang Zhang, Wangxing Li, Jianhong Yang, Dengpeng Chai, Shilin Qiu, Jingyi Li
1Zhengzhou Research Institute of Chalco, Zhengzhou, 450041, China
2School of metallurgical science and engineering, Central South University, Changsha, 410083, China
3Graduate School of Business and Law, RMIT, Melbourne, 3000, Australia

Keywords: Aluminum production, Techno-economic Analysis, Optimization, Model, Optimal current

Abstract

The total cost and gross income of an aluminium smelter increase nonlinearly with its volume, so their typical model of cost-volume-profit (CVP) analysis is shown in figure 1. The profits rise up firstly and then drop down with the increase of production. The area enclosed by the Income line and the cost line is the profitable zone, while a raw material costs decrease results in the cost line to shift down or the sale price increases lead to the income line to move up, the profit zone will be expanded, and vice versa. Enterprises are usually running in the profit zone, further, if the output achieves the optimal volume -- QOPT, the firm will get the maximum profits -- Emax. If the aluminium smelter enterprises were in different countries and regions or in different time, they would have different profit zones and optimal yield volumes. So we need to study the relationship between the market factors and aluminium production volume and parameters of the technology and process to acquire the optimal volume QOPT for the maximum profits. When the income line is all located below the cost line, this is, the profit zone does not exist, and the company has a loss at any production volume, we also need to study and adjust the aluminum technology and process parameters to get the optimal volume to minimize the loss, and even consider whether to stop cells or not, according to the losses and the forecast duration of the bad market and the restart costs of cell.

Figure 1. Cost-volume-profit analysis model

Now, we will analyse the cost, the volume and the profit of aluminium smelter enterprises.

Production volume and sales income

\[ S = Q \times P_{Al} = P_{ul} \times 24 \times 0.3356 \times 1 \times \eta \times 10^{-3} \times 365 \times N \]

S: Sales income, \( P_{Al} \): Aluminium price, I: Current intensity, \( \eta \): Current efficiency, N: number of pots

Fixed costs -- CF

Fixed costs are those that remain unchanged, irrespectively of the level of output and they include:

Introduction

Under changing external market environment the product cost and sales income of a company are changing during different times, and with different price of raw materials in different regions, the cost and benefit of companies in different regions will vary. Also for an aluminium smelting enterprise the prices of primary aluminium and raw materials are going up and down, and the disparities of the electrical energy prices in different regions, for example in China, where the power price varies from 0.2 Yuan/kWh to 0.6 Yuan/kWh, and alumina prices can vary greatly in different regions and countries because of rich or poor mineral resources. In the areas with various electrical energy prices, or when the electrical energy price changes, or with the great fluctuation in prices of aluminium, alumina or carbon anodes, how can the aluminium smelter enterprises optimize their technology and process data, combined with self practical condition, to adjust the output for maximum benefits? High current density or low current density, is there a more economical technical solution? Based on the current conditions, is it better for benefits to intensify the current or decrease the current? The current density and ACD (anode-cathode distance), voltage, and current efficiency are related closely, and how to get the best economical balance between them?

In this paper, based on a cost-volume-profit (CVP) analysis method, a series of techno-economic analysis and optimization models on aluminium electrolysis production are built. Each smelter, under different market environment, can optimize its parameters of process and technology using the models according the market factors in order to obtain maximum benefit.
Adjusting the production to the optimum volume, it does not need to increase or decrease the number of workers. Furthermore, in China the state-owned enterprises still need to pay wages even if they have stopped production for a period, so we count the salary into the fixed cost.

**Variable costs---CV**

Variable costs are those that change related to the level of output. Usually, variable costs are counted by per ton of aluminium. In fact only the alumina and carbon anode and electrical energy consumption are related closely with the aluminium production, which depends on the current intensity and current efficiency. Auxiliary materials expense and energy cost are mostly related to the running time, so they should be counted by day or per year.

- **Auxiliary materials expense includes:**
  - Electrolyte consumption---$CV_{\text{BATH}}$
  - Consumption of fluoride salts and additives---- $CV_{\text{ALF3}}$
  - Other energy cost---$CV_{\text{POWER-ELSE}}$, includes:
    - Pot fume scrubbing system
    - Compressed air system
  - Sales cost---$CV_{\text{SALE}}$

Sales cost is considered together with the sales price of the aluminium in the model, so it is no longer listed separately.

The part of variable costs counted by time is $CV_1$.

$$CV_1 = 365 \times (CV_{\text{BATH}} + CV_{\text{ALF3}} + CV_{\text{POWER-ELSE}}) \times N$$

$$CV_2 = 365 \times (Q_{\text{AL}} \times P_{\text{C}} + Q_{\text{AL}} \times P_{\text{ALF3}} + Q_{\text{AL}} \times P_{\text{POWER}}) \times N$$

$P_\text{C}$: anode price

$Q_\text{C}$: Carbon anode consumption per ton of aluminium.

$P_\text{C}$: anode price

$-Energy consumption$:

$$CV_{\text{POWER}} = U_1 \times I_1 \times 24 \times P_{\text{POWER}} \times 365 \times N$$

$U_1$: Pot voltage  
$I_1$: Current intensity  
$N$: Pot Number

$P_\text{POWER}$: Electrical energy price

**3 Techno-economic optimization models**

Using the *techno-economic analysis model on aluminium electrolysis production*, we analyse if a smelter should run at high or low current intensity, and if a smelter should rise the production or drop the cost to improve the efficiency when the market is changed, and which balance state of voltage and current efficiency gives the optimal production program for maximum revenue.

Economic evaluation of potline current

According to the Techno-economic analysis model we want to make economic evaluation on production and technical parameters to judge whether the potline current is running at the economic optimal value, and then how to adjust it. According to Eq-1, we can calculate the first-order partial derivative of profits $E$ to potline current $I_1$ to get the partial derivatives. Then if:

$$\frac{\partial E}{\partial I_1} = 0$$

Potline current is running at the economic optimal value

$$\frac{\partial E}{\partial I_1} > 0$$

The smelter needs to increase current to raise the production to improve benefits

$$\frac{\partial E}{\partial I_1} < 0$$

The smelter needs to decrease current to reduce the production to improve benefits

Now, let us put the production of aluminium $Q_{\text{AL}}$ and pot voltage $U$ and the function $f$, which is mainly on the current and current efficiency and the pot voltage, into Eq-1 to solve and obtain $\frac{\partial E}{\partial I_1}$.

$$U = \frac{(U_0 - 1.7)}{1 + 1.7}$$

1.7: Back electromotive force constant

To a design smelter:

$U_0$: Design pot voltage,  
$I_0$: Design potline current

To a running smelter:

$U_0$: Running pot voltage,  
$I_0$: Running potline current