Energy and Exergy Analysis of Flue Gas Waste Heat from Electrolytic Cells and Measures for Improving Its Grade

Jianjun Zhang[1], Ziqi Yu[2] and Wendong Qin[3]
1. Associate Researcher
Chinese Academy of Sciences - Guangzhou Institute of Energy Conversion, Guangzhou, China
2. Postgraduate Student
Shenyang University of Chemical Technology - School of Mechanical and Power Engineering, Shenyang, China
3. Assistant Engineer
Guangxi Baikuang Metallurgical Technology, Baise, China
Corresponding author: zhangjj@ms.giec.ac.cn
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Abstract

During the aluminium electrolysis process, high-temperature gases such as carbon dioxide are produced. Under the negative pressure of the flue gas exhaust system, a large amount of air from the potroom enters through gaps in the hood, resulting in an increase in flue gas flow and a decrease of its temperature. The cell flue gas waste heat comes from the heat generated by the electrical current through the cell and from the oxidation of the carbon anodes. This paper estimates the gas and heat sources, flow rates, and waste heat amounts in the flue gas. Then, the useful work potential (exergy) of the waste heat is assessed. The higher the flue gas temperature, the greater the waste heat exergy and the higher the convertible energy. The current status of flue gas waste heat utilization is then presented.

Keywords: Aluminium electrolysis, Flue gas waste heat exergy analysis, Exergy improvement measures.

1. Introduction

Aluminium electrolysis production is an high temperature electrochemical process and belongs to the energy-intensive industry due to the high energy consumption per tonne of aluminium during the electrolysis process. Over 50 % of energy is lost in the form of waste heat [1]. The cell heat loss includes in particular the heat loss through flue gas, shell sidewall, cell hoods, and anode stems. Among these, shell sidewall and flue gas heat loss account for a large proportion. Sidewall heat loss is high in temperature but limited by spatial constraints, making the heat recovery difficult. Flue gas heat loss, however, accounts for approximately 36 % of the total heat loss, which is comparable to sidewall heat loss [2]. Since each cell is equipped with a complete gas collection system, recovery of flue gas heat is easier to achieve.

Currently, flue gas heat recovery faces challenges due to large flue gas flow, leading to low temperatures, poor quality of heat, high dust content, and a certain degree of corrosiveness in the gas. The return on investment for flue gas heat recovery is long, and companies are hesitant to invest [2]. Analysing the factors influencing flue gas flow and heat, taking into account the current status of flue gas heat utilization, and analysing the heat exergy, measures to improve waste heat exergy are proposed. Integrating AI analysis, factors affecting waste heat exergy can be combined to explore their internal relationships, find ways to improve the quality of flue gas heat, and stimulate smelters' interest in investing in flue gas heat recovery, thereby improving the overall energy utilization efficiency of the aluminium electrolysis process [1].

2. Determination of Cell Flue Gas Flow

In the aluminium electrolysis production process, the sources of flue gas captured by the cell exhaust system include gases produced during the aluminium electrolysis and the outside air drawn into the exhaust system through the cell gaps, such as those between the cell hoods, between the anode stem and the superstructure roof, etc. The flue cell gas flow rate can be measured using a Pitot tube flow meter installed on the cell main exhaust pipe through fixed measurement holes [3], or it can be estimated using mathematical models and empirical data from potrooms. The flue gas flow rate is related to the gaps in the hood. Different electrolytic cells have varying gap sizes in their hoods. For example, some older hoods have gaps over 2 cm between the hoods; this requires a large amount of gas to be drawn into the hoods to create negative pressure and prevent potroom emissions.

2.1 Process Gases Generated in Aluminium Electrolysis

In the electrolysis, the main gasses produced are CO_2 and CO, and in much smaller quantities CF_4 and C_2F_6 during anode effects. The amount of gas from the electrolytic process can be calculated from the mass balance in the reaction equations of the process, including auxiliary reactions of anode air oxidation and Boudouard reaction, also called carboxy reaction or CO_2 burn of anodes. The amount of process gas is small in the cell exhaust even with well-sealed hoods, typically less than 2 % as shown below.

The aluminium reduction reaction is given in Equation (1) and the reoxidation reactions in Equation (2):

$$2\mathrm{Al_2O_3} + 3\mathrm{C} = 4\mathrm{Al} + 3\mathrm{CO_2} \tag{1}$$

$$2\mathrm{Al} + 3\mathrm{CO_2} = \mathrm{Al_2O_3} + 3\mathrm{CO} \tag{2}$$

Considering that the amount of reoxidation is current efficiency loss, the combination of the two equations gives the overall reaction, Equation (3):

$$2\eta\mathrm{Al_2O_3} + 3\mathrm{C} = 4\eta\mathrm{Al} + 3(2\eta - 1)\mathrm{CO_2} + 6(1 - \eta)\mathrm{CO} \tag{3}$$

where η is the current efficiency (fraction).

From this base reaction Equation (3), the following specific species production in mass can be deduced:

CO_2 production:

$$\frac{m_{CO_2}}{m_{Al}} = 1.2232877 \times (2 - \frac{1}{\eta}) \tag{4}$$

CO production from the re-oxidation reaction:

$$\frac{m_{CO}}{m_{Al}} = 1.5571492 \times (\frac{1}{\eta} - 1) \tag{5}$$

Electrolytic carbon consumption:

$$\frac{m_C}{m_{Al}} = \frac{0.3338615}{\eta} \tag{6}$$

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8. References

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