

Development and Application of Aluminium Electrolysis Energy Saving Series Technology Based on Steady Metal Flow and Heat Preservation

Yanan Zhang¹, Kaibin Chen², Huaijiang Wang³, Xugui Zhang⁴, Yongfeng Cao⁵, Bin Fang⁶, Qingguo Jiao⁷, Yanhui Liu⁸, Guisheng Liang⁹ and Changlin Li¹⁰

1, 5. Deputy Director

2. General Manager

3. Assistant General Manager

4. Chief Engineer

6, 7. Senior Engineer

8, 9, 10. Engineer

Zhengzhou Non-ferrous Metals Research Institute of CHALCO,
Zhengzhou, China

Corresponding author: zhangyanan828@163.com

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Abstract

In response to the major common technical difficulties in high-efficiency production of aluminum electrolysis cells under low voltage and low energy consumption, Zhengzhou Non-ferrous Metals Research Institute Co. Ltd of CHALCO has successfully developed Aluminum Electrolysis Energy Saving Series Technology based on Steady Metal Flow and Heat Preservation through systematic research on “optimization of conductive materials and structures-cathode current stabilization-isotherm control-physical field balance optimization”, effectively solving the technical problems of high energy consumption, low efficiency, and short service life of aluminum electrolysis cells. The goal of significant energy conservation and emission reduction has been achieved. This technology was developed in 2013 to form the prototype FHEST 1.0, achieving DC power consumption < 12 500 kWh/t Al. By 2020, on the basis of FHEST 1.0, the FHEST 2.0 was iteratively upgraded to achieve DC power consumption < 12 300 kWh/t Al. At present, this technology has been promoted and applied in approximately 3 000 cells of different types, ranging from 180 kA to 500 kA, achieving a total of 3.55 billion kWh of electricity savings and 2.114 million tonnes of carbon dioxide emissions reduction. Starting from 2023, FHEST 3.0 is being developed, and the test cell has achieved DC power consumption of less than 11 800 kWh/t Al. This article provides a detailed introduction to the development, industrial testing, and industrial implementation, and application of FHEST energy-saving cell technology. This technology provides technical support for the smelters to achieve large energy conservation and carbon dioxide emission reduction.

Keywords: Aluminum electrolysis, Low cell voltage, High efficiency, Steady current insulation.

1. Introduction

China has set the goal of peaking carbon dioxide emissions before 2030 and achieving carbon neutrality before 2060. This has increased the pressure on the aluminum reduction industry to “dual control of both energy consumption and intensity”, and promoted the green transformation and high-quality development of the electrolysis aluminum industry. China's aluminum reduction industry will continue to develop environment-friendly and highly energy-efficient technologies. Since 2013, Zhengzhou Non-ferrous Metals Research Institute Co. Ltd of CHALCO (ZRI) has been focusing on the technical challenges of low voltage, low energy consumption, and high efficiency production technology for aluminum electrolytic cells. A series of technical research and industrial experiments have been carried out [1-5], and a deep knowledge in energy-saving

technology system for aluminum electrolysis has been formed. Aluminum Electrolysis Energy Saving Series Technology based on Steady Flow and Heat Preservation (FHEST) has been successfully developed.

The technical route of the FHEST technology is shown in Figure 1:

- 1) Reduce the voltage drop of conductors in various parts of the electrolytic cell, including anode voltage drop, bubble voltage drop, cathode voltage drop, anode clamp voltage drop, and busbar voltage drop, etc;
- 2) Improve the magnetohydrodynamic stability of electrolytic cells, including optimizing the material and structure of cathode carbon blocks and steel collector bars to reduce horizontal current and open ACD;
- 3) Improve the raw material quality, including the conductivity and oxidation resistance of prebaked anodes, as well as the particle size and solubility of metallurgical grade alumina, etc.;
- 4) Assist with reasonable thermal balance design, process technical parameters, and intelligent control system optimization and upgrading.

This technology was developed in 2013 to form the prototype FHEST 1.0, achieving DC power consumption < 12 500 kWh/t Al. By 2020, on the basis of FHEST 1.0, the FHEST 2.0 was iteratively upgraded to achieve DC power consumption < 12 300 kWh/t Al. Starting from 2023, FHEST 3.0 is being developed, and the test cell has achieved DC power consumption of less than 11 800 kWh/t Al.

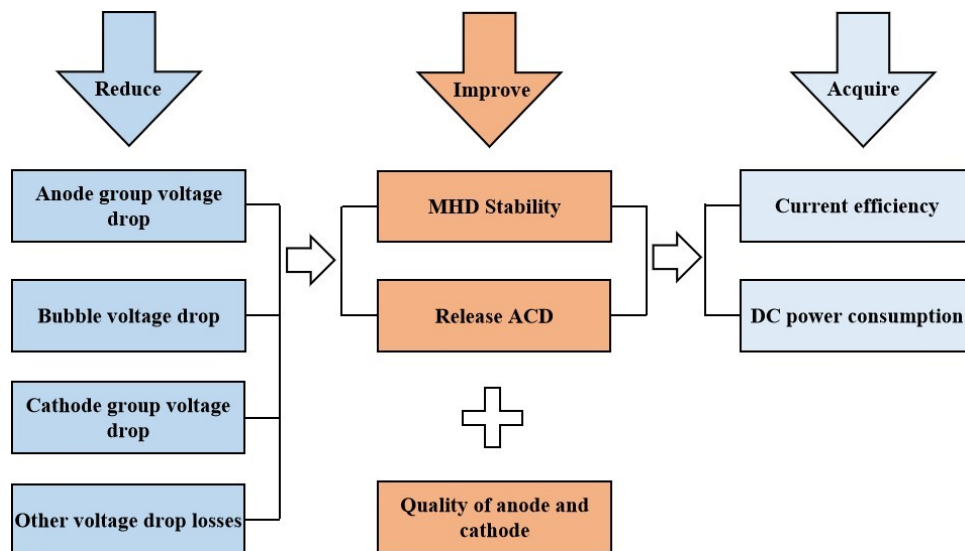


Figure 1. Technical route of FHEST technology.

2. FHEST 1.0

2.1 Technical Approach

Starting the research in 2013, this technology aims at low DC power consumption for aluminum reduction. Based on numerical simulation modeling, integrated design with steady metal flow, low cathode voltage drop technology, redesigning the side wall ledge distribution and taking into account cell operation, the new design criterion is established for FHEST 1.0. The main techniques include: steady metal flow optimization techniques, voltage balance optimization techniques, thermal field design optimization technology, cell operation parameters optimization. Schematically, this is presented in Figure 2.

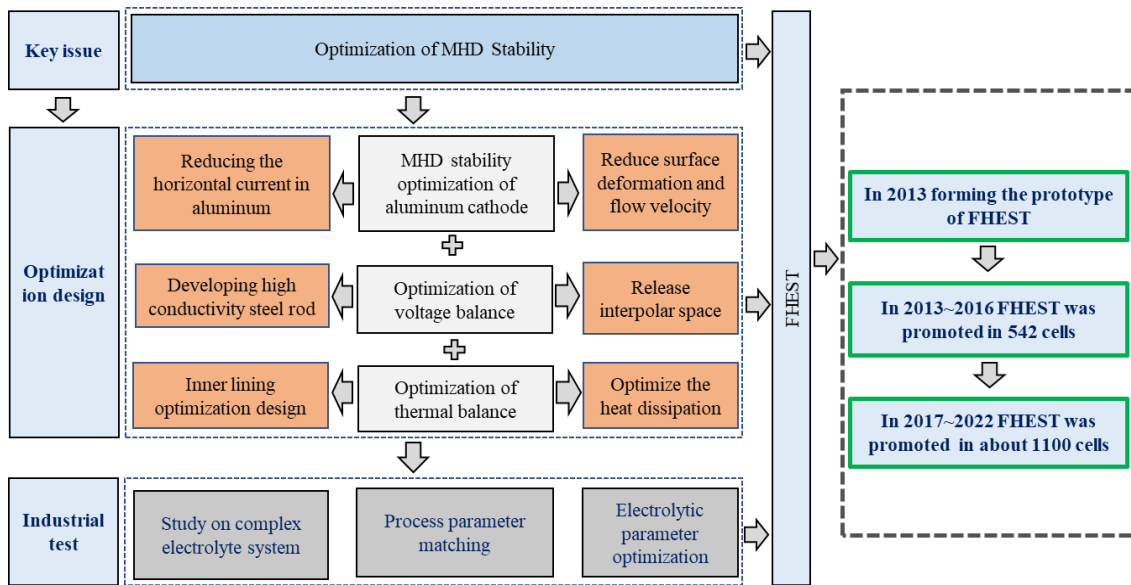


Figure 2. Technology elements of FHEST 1.0.

Optimizing of the current distribution and the magnetic field distribution in the cells could reduce the variations and liquid metal flow velocity and improve the stability of the aluminum pad. In optimizing voltage balance in the cells, the main target is to reduce the cathode voltage drop. Geometric design and material selection of the cathode blocks and cathode assembly are combined to reduce the voltage drop. The FHEST 1.0 cell lining is designed according to the features of local energy dissipation and bath liquidus temperature. The isotherms are optimized to form the ideal side ledge and improve the cathode life. This also reduces the heat loss of the lower side wall. Reasonable operational parameters are determined by the theoretical derivation and scientific computing combined with the actual situation in the cells. All of these optimizations could guarantee the FHEST 1.0 cells operating with cell voltage of 3.85 V, ACD of more than 4 cm and the side ledge of more than 15 cm. The FHEST 1.0 cells produce aluminium at steadily DC power consumption below 12 500 kWh/t Al.

2.2 Industrial Experiment of FHEST 1.0

Three FHEST 1.0 test cells were built to demonstrate the results of the FHEST 1.0 in one of the smelters in China. The cells were started up in December 2013 and January 2014 and were all in stable operation by May 2014. Figure 3 presents the construction of the FHEST 1.0 test cell. Table 1 shows the average in performance of the three FHEST test cells, together with traditional cells prior to the performance test, both at nominal amperage of 350 kA.

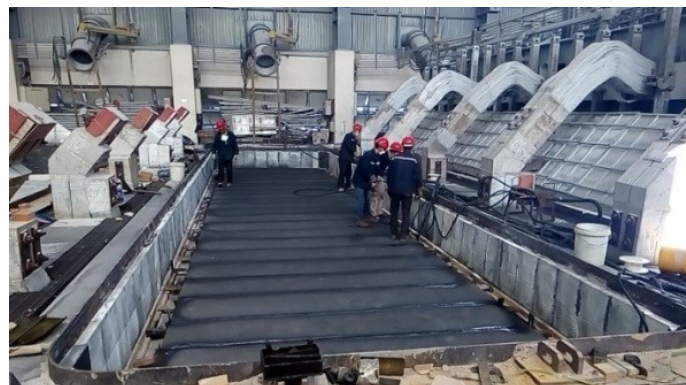


Figure 3. Construction of the FHEST 1.0 test cell.**Table 1. FHEST 1.0 test cells and traditional cells key performance indicators at 350 kA.**

KPI	Units	FHEST 1.0 test cells	Traditional cells
Cell voltage	V	3.887	4.091
Thickness of side ledge	cm	18.7	10.7
Operation temperature	°C	951	956
ACD	cm	4.2	5.0
Cathode voltage drop	mV	265	341
Current efficiency	%	91.5	90.6
DC power consumption	kWh/t Al	12 659	13 450

As shown in Table 1, the FHEST 1.0 test cells were operated at 951°C. It produced steadily with cell voltage of 3.887 V, current efficiency of 91.5 %, and DC power consumption of 12 659 kWh/t Al. Compared with that of traditional cells, the cell voltage is lower in 204 mV, the current efficiency increased by 0.9 % and the DC power consumption is lowered by 791 kWh/t Al. The energy saving is obvious for the FHEST 1.0 test cells at 350 kA. From 2014 to 2016, after optimizing and implementing test cells in two other electrolytic aluminum enterprises, the DC power consumption was achieved to be less than 12 500 kWh/t Al.

2.3 Industrial Implementation of FHEST 1.0

Since 2017, it has been widely promoted and applied in smelters by China Aluminum Corporation Limited (CHALCO). In 2017, the application was fully accepted and implemented in CHALCO smelters. FHEST 1.0 has been successfully implemented in approximately 2 800 cells at 180–500 kA in China. Table 2 shows the implementation in representative application smelters. FHEST 1.0 cells achieved DC power consumption below 12 500 kWh/t Al.

Table 2. FHEST 1.0 implementation results in 5 smelters.

Smelter	Amperage (kA)	Number of cells (cell)	D.C. before implementation (kWh/t Al)	DC of FHEST 1.0 cell (kWh/t Al)	Energy saving effect (kWh/t Al)
Smelter 1	180	110	12 846	12 488	-358
Smelter 2	200	87	12 750	12 484	-266
Smelter 3	240	53	13 000	12 502	-498
Smelter 4	300	168	12 926	12 458	-468
Smelter 5	400	137	13 004	12 499	-505

3. FHEST 2.0

3.1 Technical Approach

In 2020, based on FHEST 1.0, FHEST 2.0 was developed by optimizing the voltage drop of various conductors, the magnetic fluid stability, and the energy balance, integrating energy-saving technologies such as graphitized cathodes, phosphorus iron casting in assembling cathode blocks, and low resistance steel stubs, achieving DC power consumption below 12 300 kWh/t Al. Schematically this is presented in Figure 4.

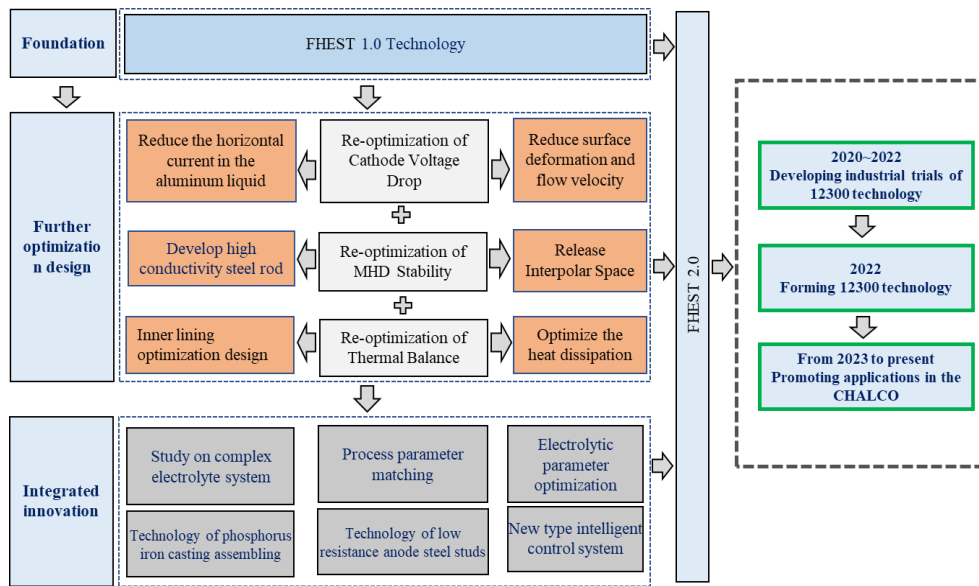


Figure 4. Technology elements of FHEST 2.0.

By optimizing the design and using a combination of graphite cathode, cast iron rodding, and high conductivity steel cathode collector bar, the horizontal current density in the aluminum liquid and cathode is reduced by 52 % and 42 %, respectively, as shown in Figure 5. Through voltage balance optimization design, integrating aluminum-steel direct welding technology, low resistance steel stubs technology, high-quality anode carbon dust-free technology, slotted anode technology, etc., it was possible to achieve voltage of 3.82 V, to reduce the anode group voltage drop to below 320 mV, and to reduce the cathode voltage drop to below 200 mV. These improved components are shown in Figure 6. By optimizing energy balance design, the total heat dissipation of the electrolytic cell is less than 1.62 V (equivalent voltage) and the initial solidification isotherm is located in impermeable layer in the lining.

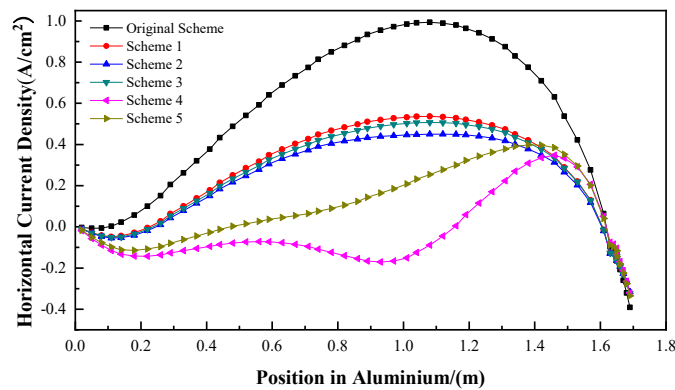


Figure 5. FHEST 2.0 aluminium liquid horizontal current optimization.



Figure 6. Low resistance anode steel stubs (left). Carbon dust-free slotted anodes (right).

3.2 Industrial Experiment of FHEST 2.0

In 2022, industrial integration tests were conducted in three potlines (200 kA, 400 kA and 500 kA). Table 2 shows the main KPI of FHEST 2.0 test cells. The 200 kA potline test cells have an average age of 558 days, with an average current efficiency of 92.8 %, average DC power consumption of 12 248 kWh/t Al, and an average cathode voltage drop of 207 mV. The 400 kA series test cells have an average age of 462 days, with an average current efficiency of 94.4 %, average DC power consumption of 12 153 kWh/t Al, and an average cathode voltage drop of 237 mV. The 500 kA series test cells have an average age of 525 days, with an average current efficiency of 92.3 %, average DC power consumption of 12 265 kWh/t Al, and an average cathode voltage drop of 207 mV. The average DC power consumption for the 6 test cells is 12 238 kWh/t Al.

Table 2. Main KPIs of FHEST 2.0 test cells.

KPI	Units	Cell 1#	Cell 2#	Cell 3#	Cell 4#	Cell 5#	Cell 6#
Amperage	kA	217	217	402	402	500	500
Cell age	day	570	546	463	462	528	522
Cell voltage	V	3.843	3.818	3.845	3.855	3.804	3.794
Thickness of side ledge	cm	22.2	23.2	14.5	13.7	15.7	13.2
Operation temperature	°C	931	932	953	951	945	946
ACD	cm	4.3	4.5	4.3	4.2	4.2	4.4
Cathode voltage drop	mV	205	210	235	240	203	211
Current efficiency	%	93.5	92.2	94.4	94.4	92.4	92.2
DC power consumption	kWh/t Al	12 248	12 340	12 138	12 169	12 268	12 263

3.3 Industrial Implementation of FHEST 2.0

In 2023, FHEST 2.0 technology has begun to be promoted and applied in CHALCO smelters. Currently, 186 cells in the 300 kA to 500 kA potlines have been promoted and applied in 4 smelters. The average voltage of the FHEST 2.0 technology cell is 3.828 V, the average current efficiency is 92.6 %, the average DC power consumption is 12 326 kWh/t Al, and the average cathode voltage drop is 203 mV, as shown in Table 3.

As of now, FHEST technology, including FHEST 1.0 and FHEST 2.0, has been applied in approximately 3 000 cells in the 180 kA to 500 kA potlines, achieving a total of 3.55 billion kWh overtime of electricity savings and reducing carbon dioxide emissions by 2.114 million tonnes.

Table 3. FHEST 2.0 implementation results of the application smelters.

Enterprise	Amperage (kA)	Number of cells	Cell voltage (V)	Cathode voltage (mV)	Current efficiency (%)	Dc power consumption (kWh/t Al)
Smelter 1	400	33	3.834	200	92.8	12 311
Smelter 2	500	35	3.814	207	92.5	12 287
Smelter 3	400	27	3.833	205	92.9	12 295
Smelter 4	300	105	3.829	202	92.6	12 322

4. FHEST 3.0

In 2023, building on the FHEST 2.0 technology, the FHEST 3.0 technology is being developed with further busbar and cell voltage drop reduction, improved MHD stability of the cell, optimized thermal balance though lining design, and a new generation of intelligent cell control system. This technology is expected to achieve DC power consumption < 11 800 kWh/t Al. As of now, the average age of three FHEST 3.0 test cells in a 500 kA potline is 274 days, with an average cell voltage of 3.797 V, average current efficiency of 94.6 %, average DC power consumption of 11 957 kWh/t Al, and an average cathode voltage drop of 163 mV, as shown in Table 4. Another six FHEST 3.0 technology test cells are currently being designed and implemented.

Table 4. Main KPIs of FHEST 3.0 test cells.

KPI	Units	Cell 1#	Cell 2#	Cell 3#
Amperage	kA	500	500	500
Cell age	day	281	272	270
Cell voltage	V	3.801	3.804	3.786
Thickness of side ledge	cm	16.5	18.8	16.2
Operation temperature	°C	954	953	956
ACD	cm	4.2	4.4	4.1
Cathode voltage drop	mV	162	166	162
Current efficiency	%	94.7	94.8	94.4
DC power consumption	kWh/t Al	11 961	11 958	11 952

Compared to the FHEST 2.0 technology, the FHEST 3.0 technology test cell has graphite cathode blocks, high conductivity collector bar with copper inserts, reducing the cathode voltage drop by about 40 mV. By using energy balance and material balance as the control method, intelligent monitoring and control is carried out, applying multivariable correlation coupling technology. A new generation of intelligent control system for aluminum electrolysis cells adapted to non-uniform and complex electrolyte systems has been developed, achieving an alumina concentration of 1.5–2.5 %, a control rate of over 95 %, an outlet opening rate of over 98 %, and a 100 % accuracy in breaker blockage alarms, as shown in Figure 7 left. The use of insulated hoods and energy balance control on the upper part of the cell greatly reduces the heat loss of the electrolytic cell, as shown in Figure 7 right.



Figure 7. Left: Intelligent control system for FHEST 3.0 technology test cell, Right: Insulated hoods for FHEST 3.0 technology test cell.

5. Conclusions

Zhengzhou Non-ferrous Metals Research Institute Co. Ltd of CHALCO has successfully developed Aluminum Electrolysis Energy Saving Cell Technology based on steady flow and heat loss reduction through systematic research on "optimization of conductive materials and structures, cathode current optimization, cathode freezing-isotherm control, and the physical field balance optimization". This technology was developed in 2013 to form the prototype FHEST 1.0, achieving DC energy consumption < 12 500 kWh/t Al. By 2020, on the basis of FHEST 1.0, the FHEST 2.0 was iteratively upgraded to achieve DC power consumption < 12 300 kWh/t Al. As of now, FHEST technology, including FHEST 1.0 and FHEST 2.0, has been promoted and applied to approximately 3000 cells in 180 kA to 500 kA potlines, achieving a total of 3.55 billion kWh of electricity savings and reducing carbon dioxide emissions by 2.114 million tonnes. Starting from 2023, FHEST 3.0 is being developed, and the tests cell have achieved DC power consumption around 11 950 kWh/t Al, with the aim of achieving 11 800 kWh/t Al in near future.

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