In Depth Analysis of Energy-Saving and Current Efficiency Improvement of Aluminum Reduction Cells

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Plan of the Presentation

- Introduction
- Analysis of mechanism and nature of pot work voltage reduction based on energy balance principle
- Irregular cathode technology
- Horizontal current reduction technology
- Current intensification
- Conclusions

Introduction

- The consumption of energy and raw material for aluminum reduction production is very high in recent years, especially power consumption.
- With the energy crisis, the aluminum reduction production cost must be reduced without delay.
- For this, the most efficient method is to reduce the DC consumption by increasing current efficiency (CE) and reducing pot voltage.

Analysis of Mechanism and Nature of Pot Work Voltage Reduction based on Energy Balance Principle

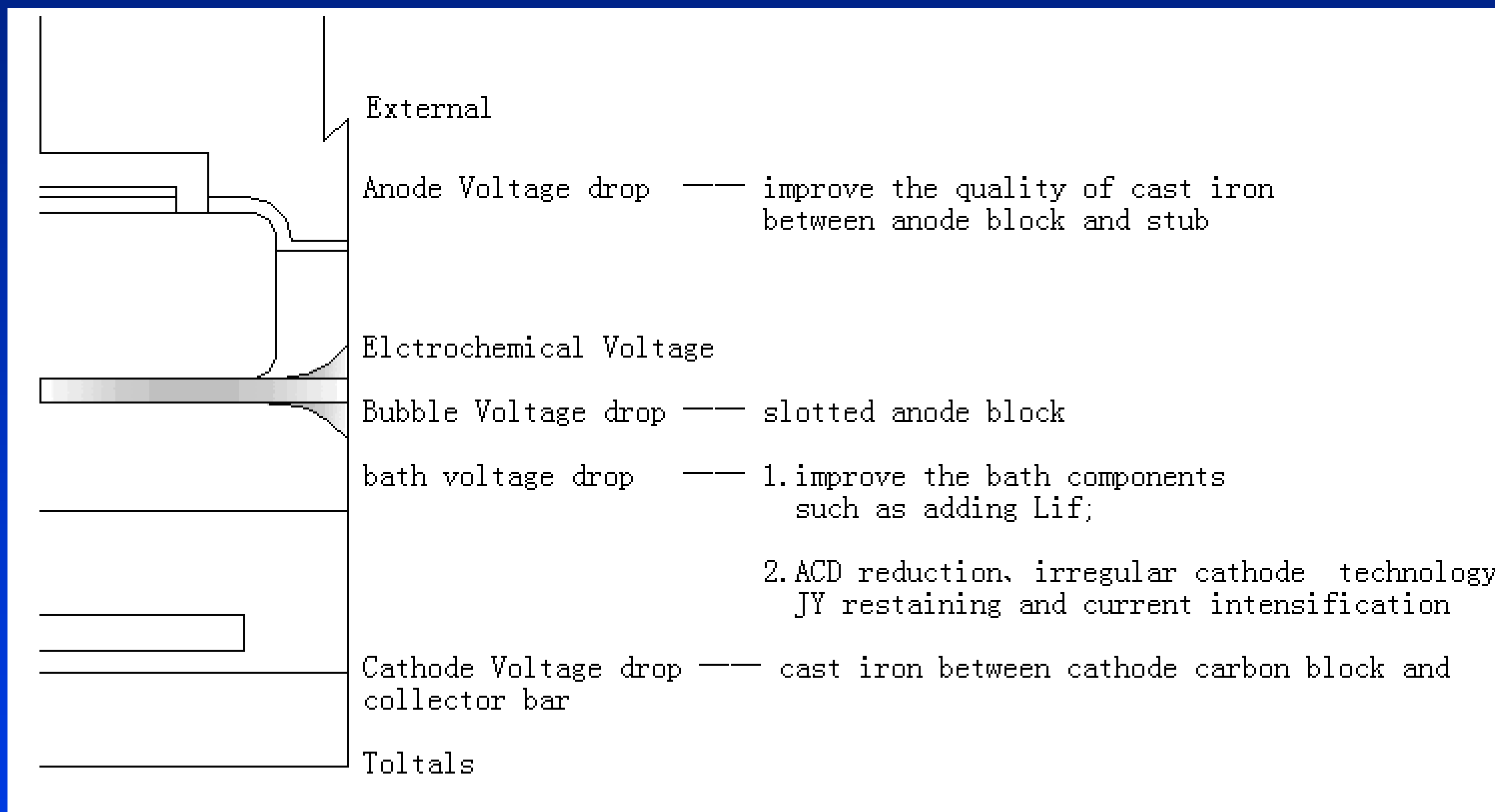
The total pot voltage is just the sum of the parts as follows[2,3]:

$$V_{pot} = V_{anode} + |E_{el}| + \eta_{sa} + \eta_{ca} + V_{bub} + V_{ACD} + \eta_{cc} + V_{cath} + V_{ext} \qquad (1)$$

Where:

V_{pot}	is the Pot Voltage (V);
V_{anode}	is the Anode Voltage (V);
$\|E_{el}\|$	is the Equilibrium Potential (V);
η_{sa}	is the Anode Surface Overvoltage (V);
η_{ca}	is the Anode Concentration Overvoltage (V);
V_{bub}	is the Bubble Voltage (V);
V_{ACD}	is the Voltage Across the ACD (V);
η_{cc}	is the Cathode Concentration Overvoltage (V);
V_{cath}	is the Cathode Voltage (V);
V_{ext}	is the External Voltage (V).

Analysis of Mechanism and Nature of Pot Work Voltage Reduction based on Energy Balance Principle



Heat input structure and approaches of voltage reduction

Perspective of ACD reduction

We can divide the type of applications used to reduce the ACD:

1) Irregular cathode technology

2) Horizontal current reduction technology

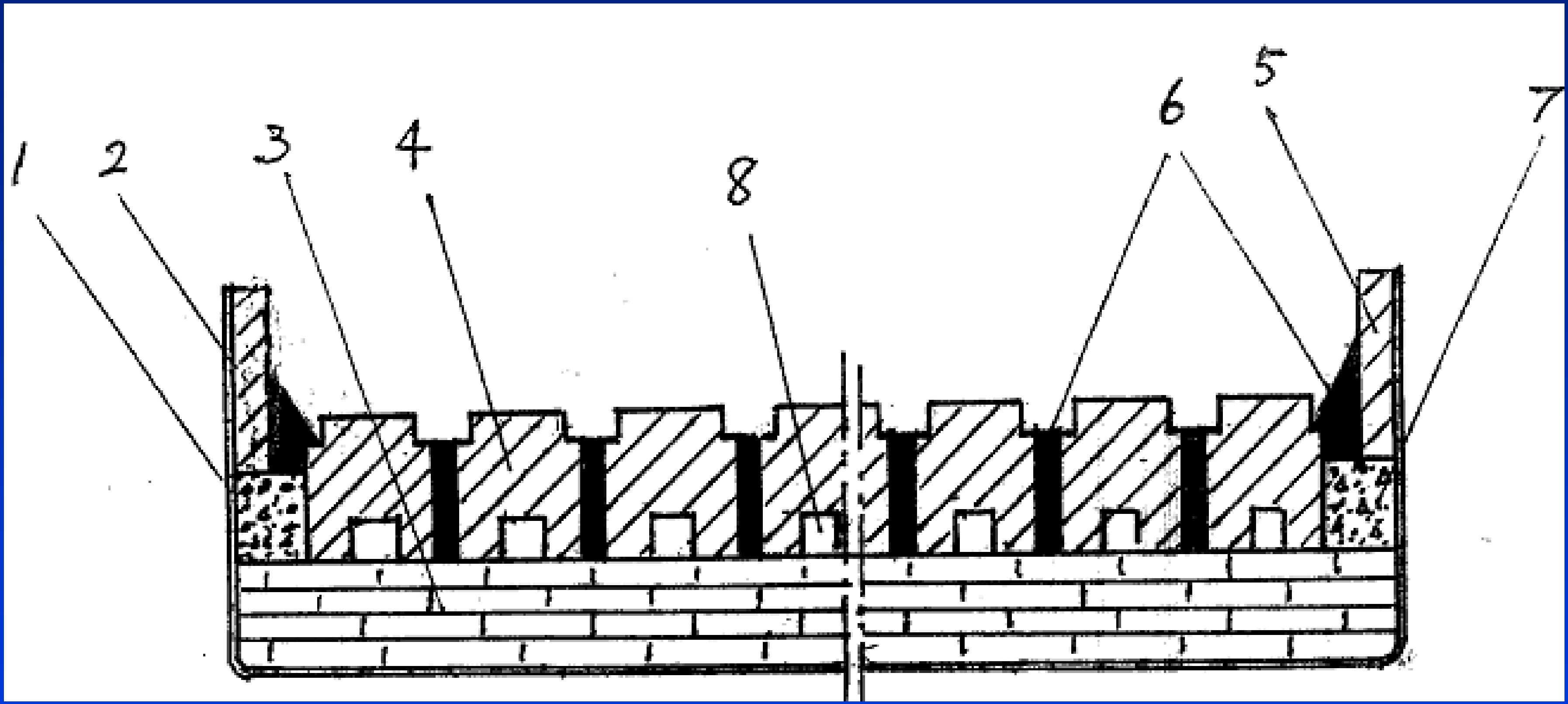
3) Current intensification.

Irregular cathode technology

In 1994, Vittorio de Nora put forward the thinking of the irregular cathode structure.

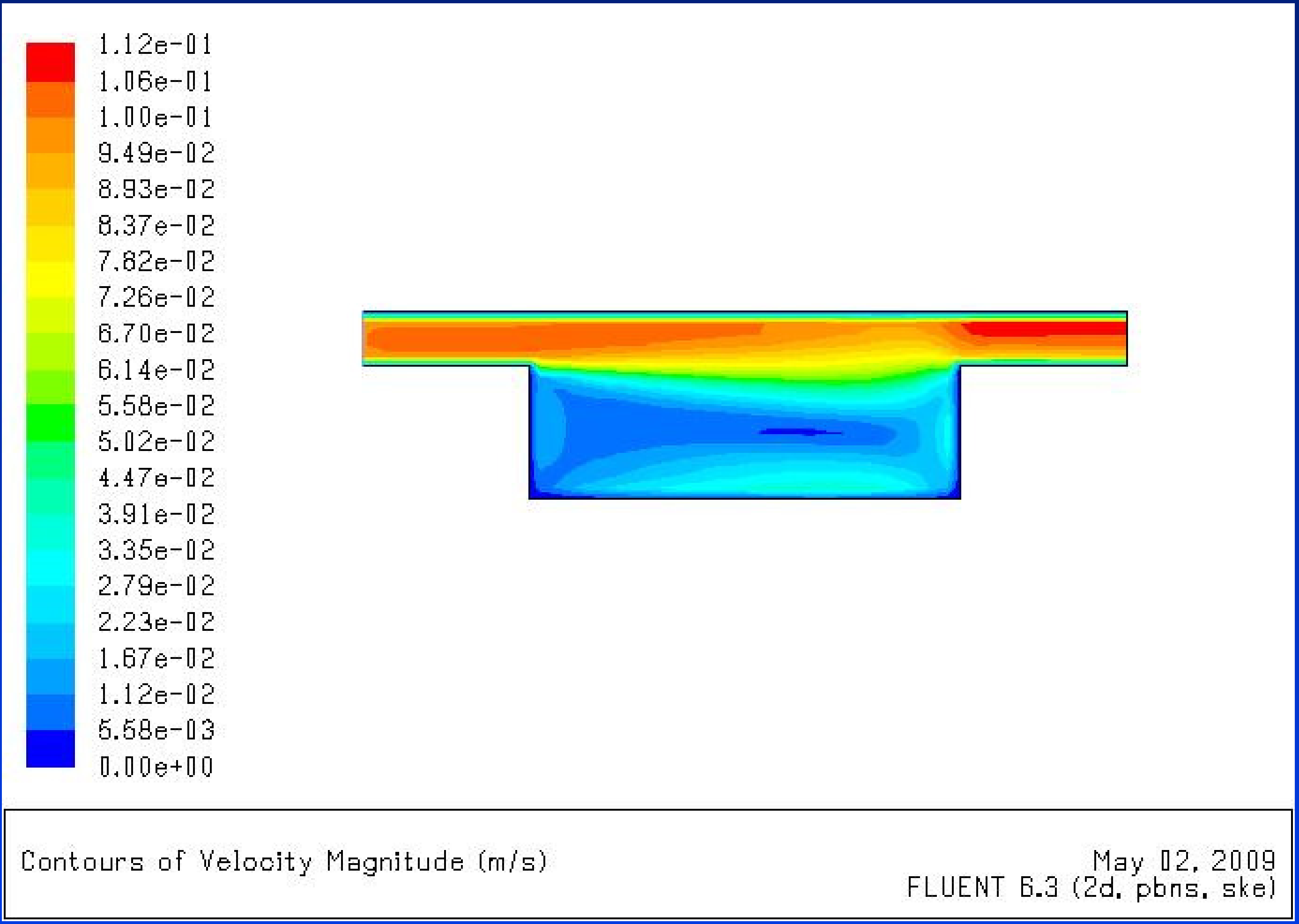
The irregular cathode structure is adopted to change the metal and bath flow state and reduce the melt flow velocity and the interface wave range of metal surface, thus improve the pot stability in order to gain the option to reduce the ACD.

Irregular cathode technology



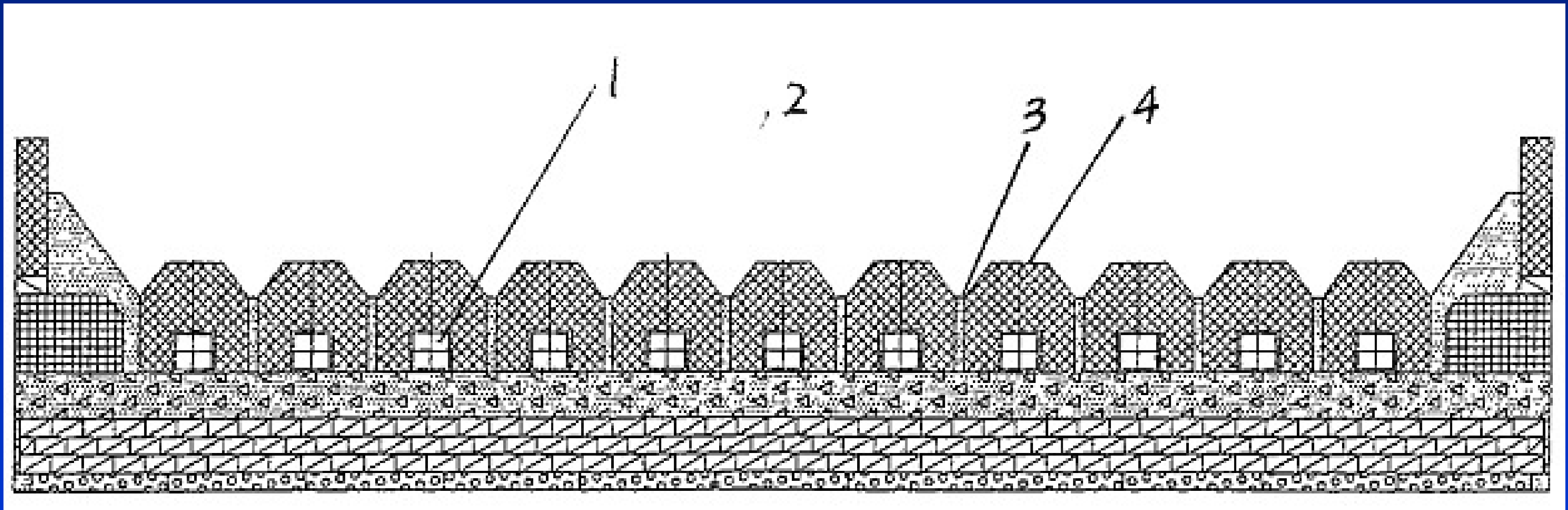
Stepped surface cathode design

Irregular cathode technology



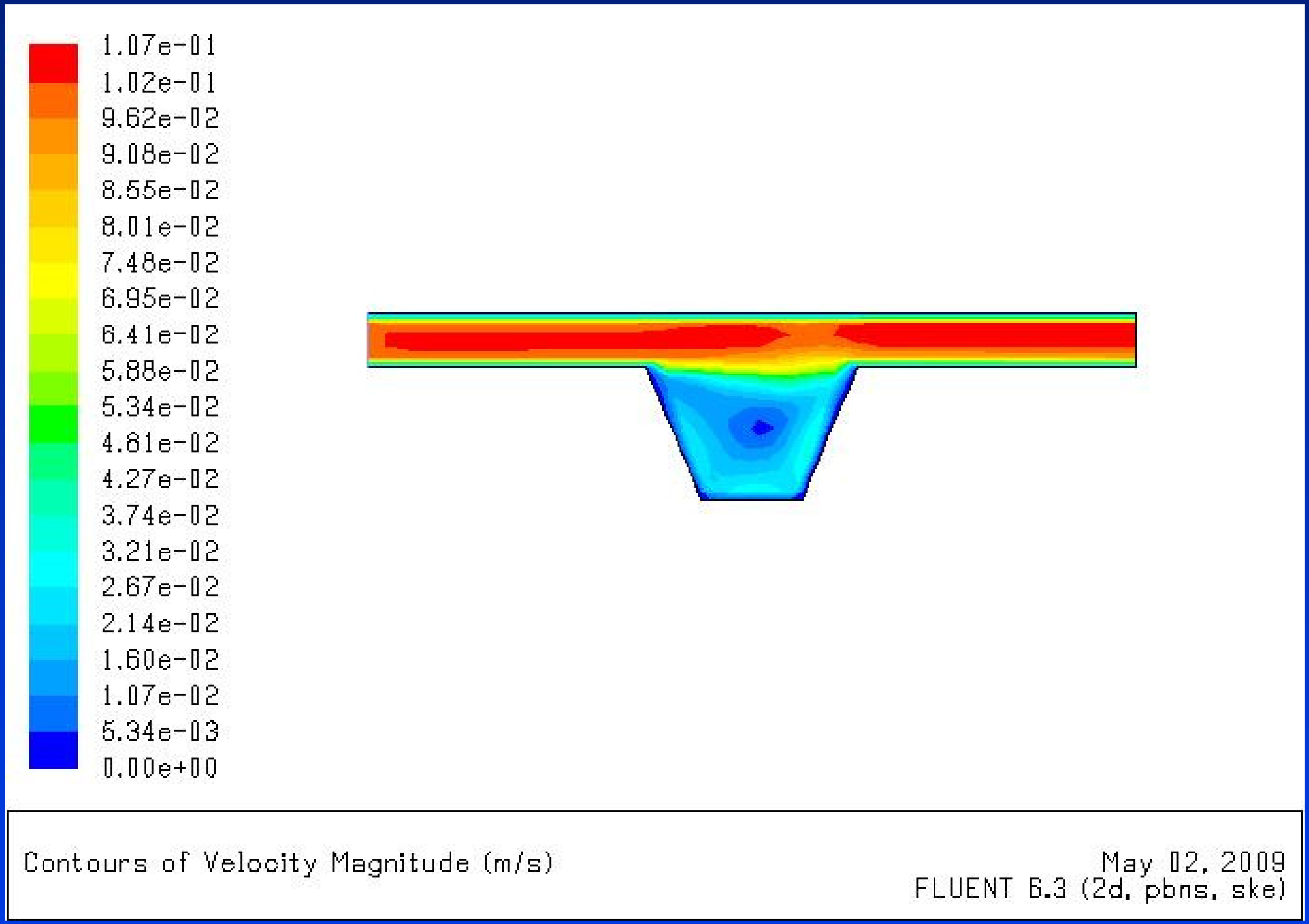
Model of metal flow velocity of stepped surface cathode

Irregular cathode technology



Sloped surface cathode design

Irregular cathode technology



Model of metal flow velocity of sloped surface cathode

Irregular cathode technology

	Max. flow velocity (cm/s)		Max deformation of metal surface (cm)	
	Calcula-tion	Measure-ment	Calcula-tion	Measure-ment
Standard pot	15.73	14.99	1.82	1.97
Irregular cathode	7.47	8.24	0.65	0.51
Variation percentage	52.50%	45%	64.30%	74.10%

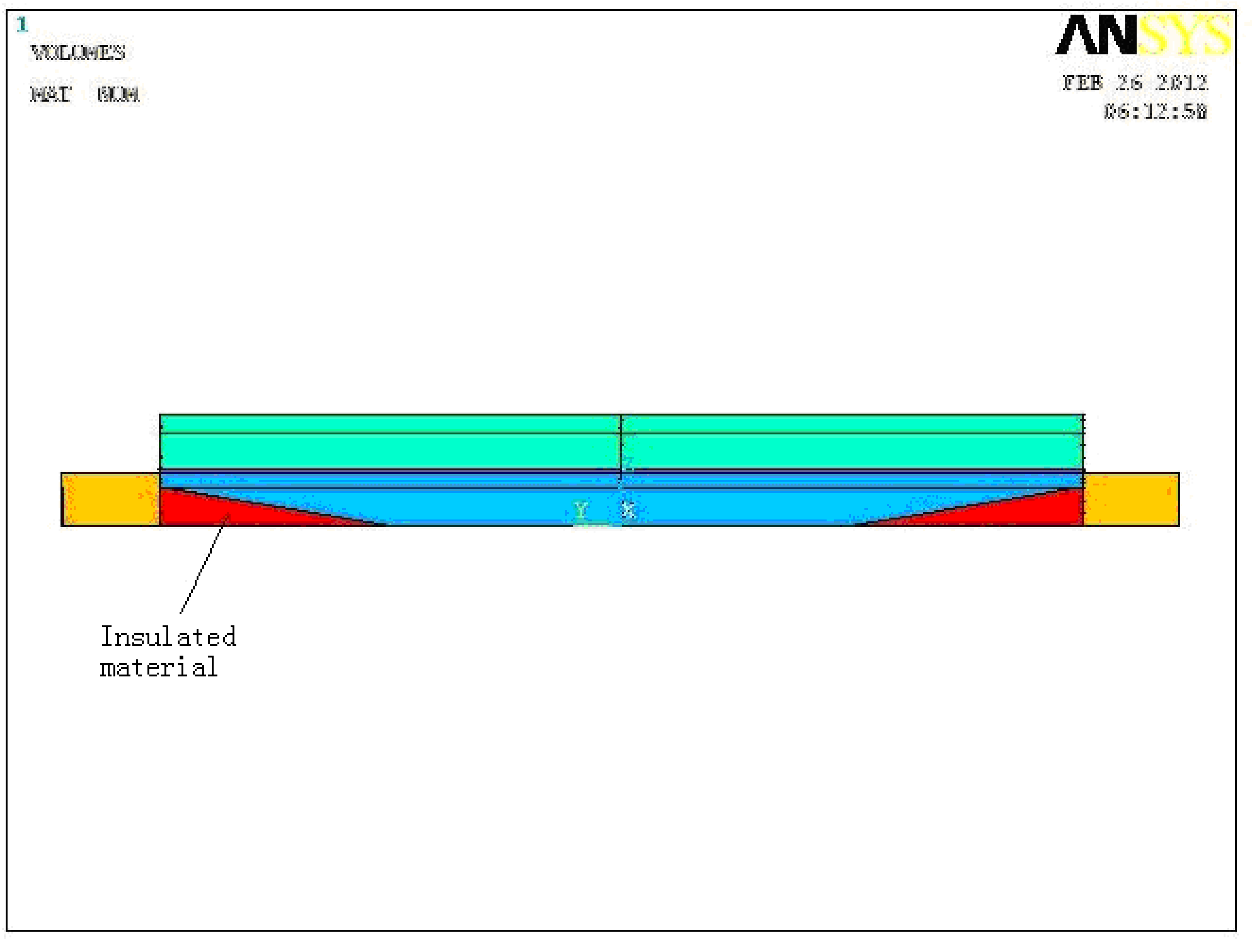
Comparison of calculation and measurement between irregular cathode and standard cathode in a plant

Horizontal current reduction technology

The horizontal current has relationship with the following factors:

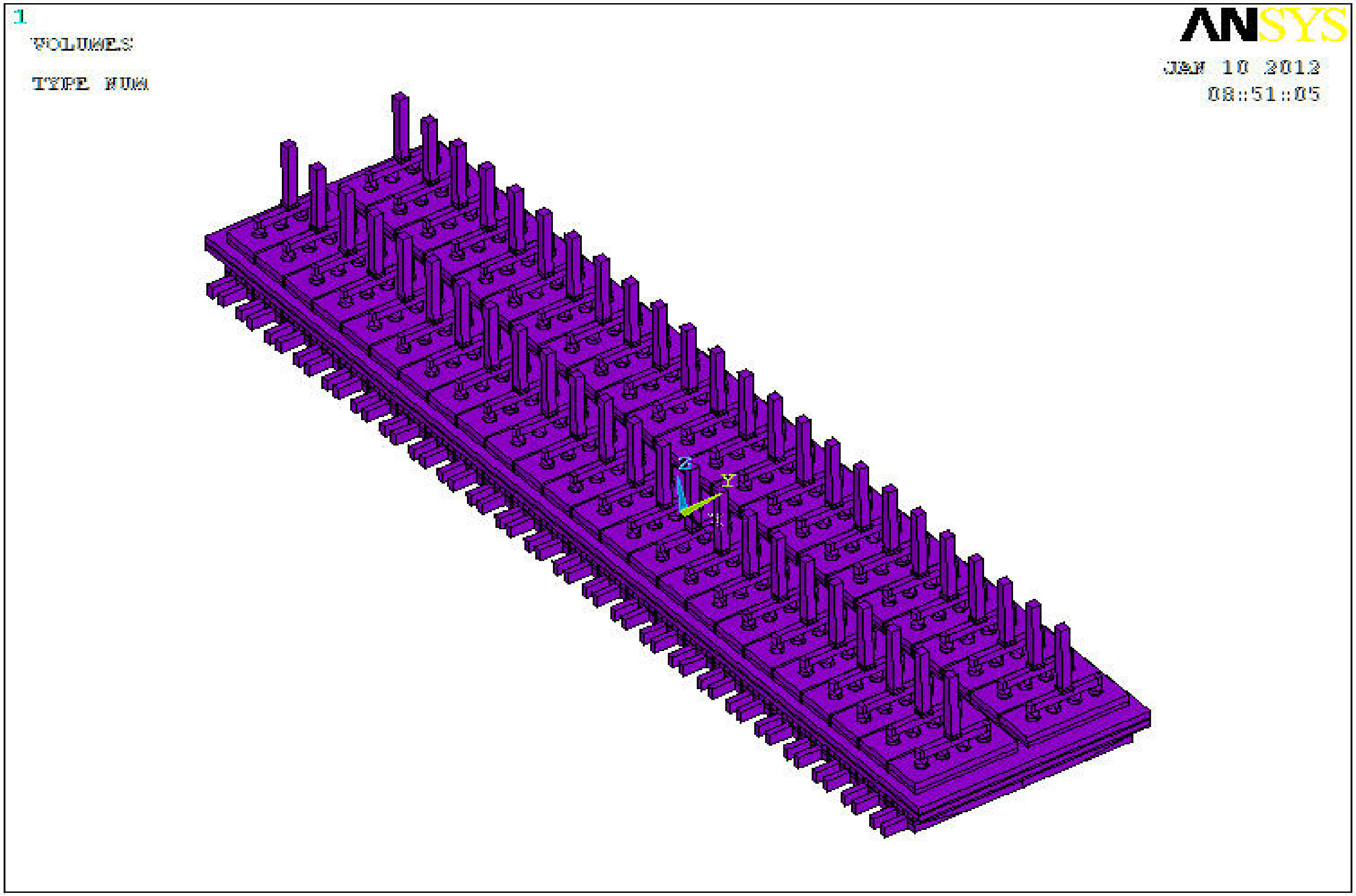
1) **Geometric dimensions, such as width and length of cathode, width and height of collector bars;**
2) **Material of cathode, such as material of cathode carbon block, connection method between the cathode carbon block and the collector bar;**
3) **Geometric dimensions of the pot, such as dimension of thermally insulating pier, hence the position of the ledge toe;**
4) **The location of the collector bars exit out of the pot (side wall or otherwise).**

Horizontal current reduction technology



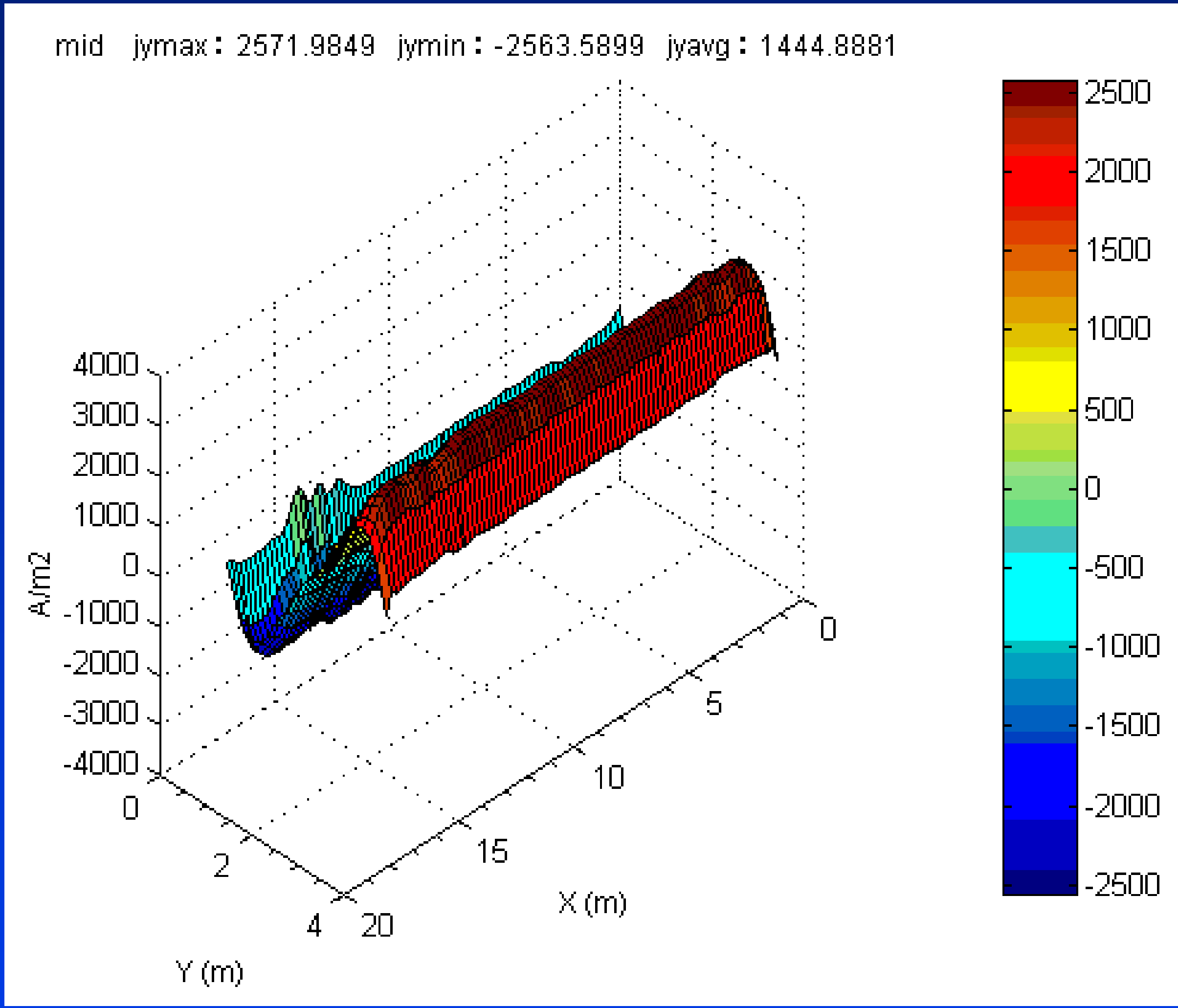
Cathode assembly for restraining the horizontal current (JY)

Horizontal current reduction technology



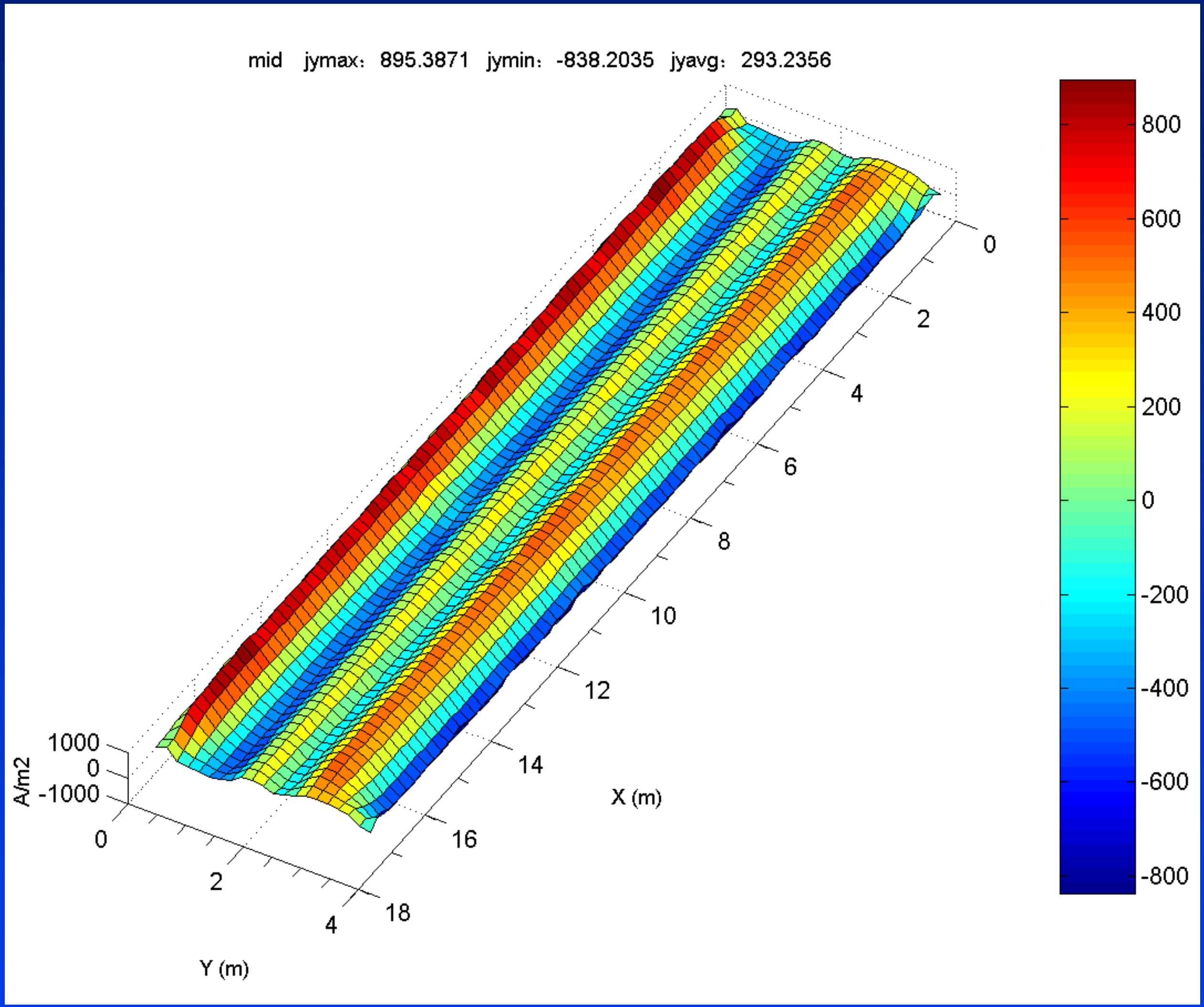
Geometry of the ANSYS® based 3D generic parametric whole pot model

Horizontal current reduction technology



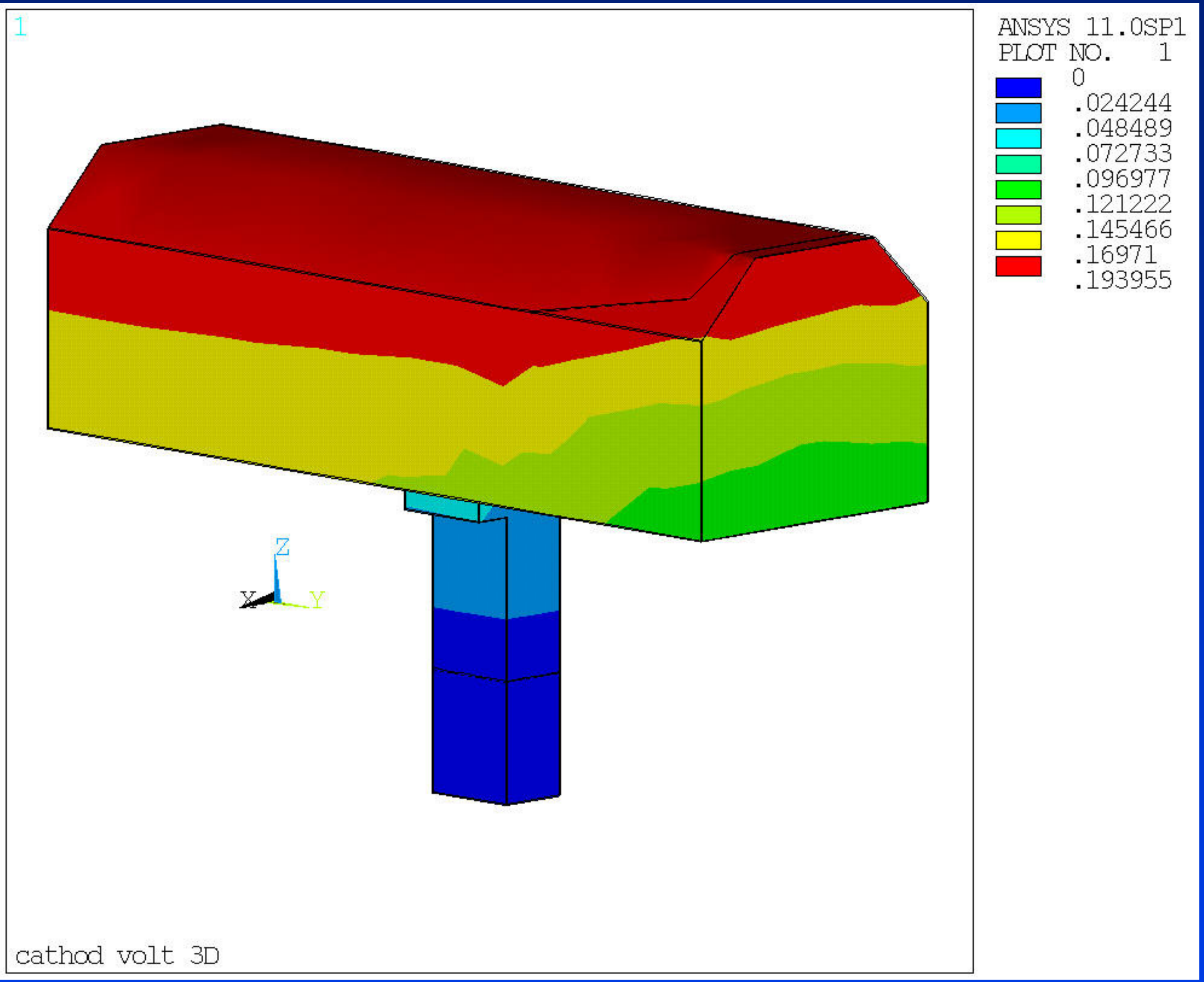
Cathode assembly without restraining horizontal current (JY)

Horizontal current reduction technology



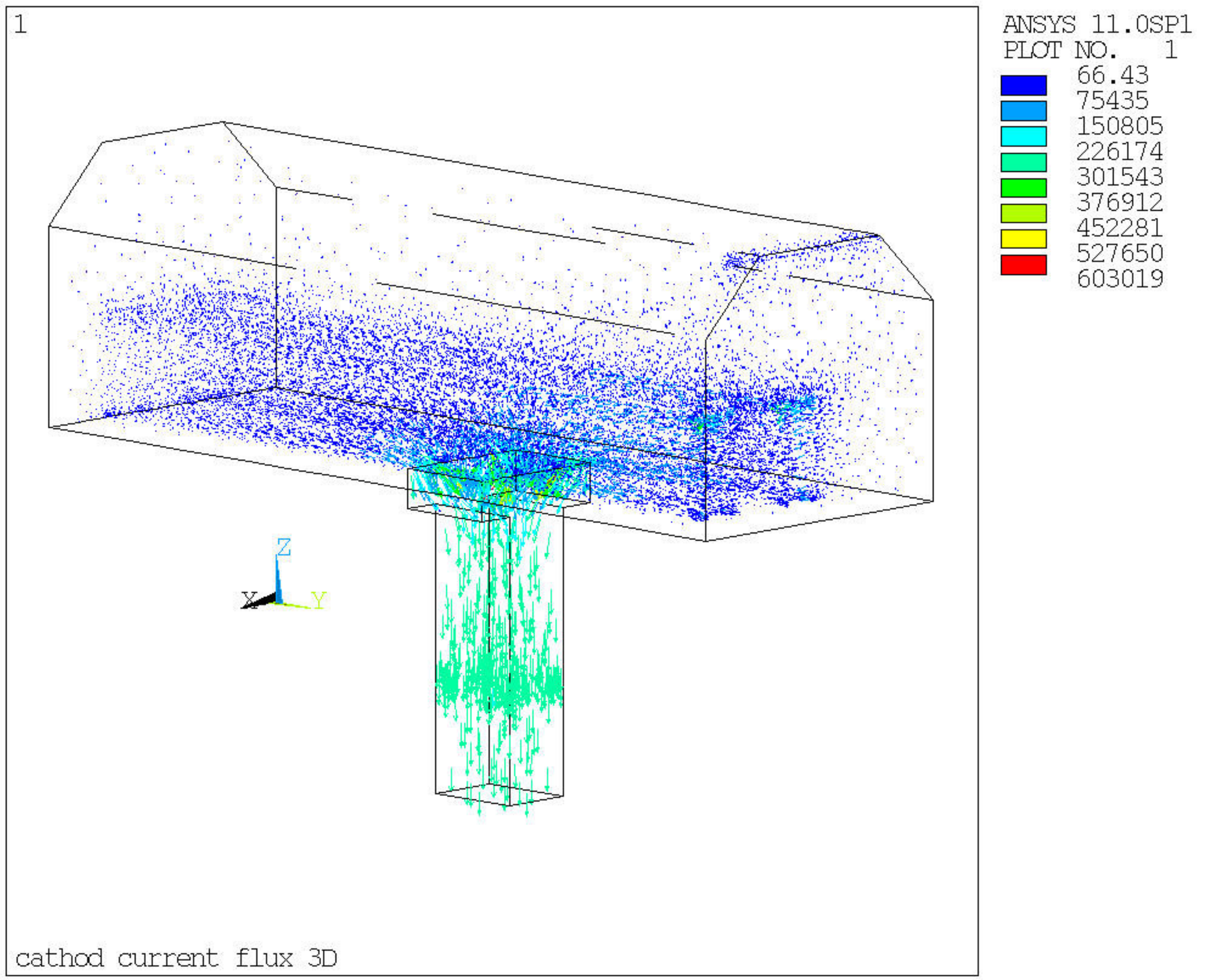
Cathode assembly with restraining horizontal current (JY)

Horizontal current reduction technology



Voltage results for the cathode with bottom exit collector bar

Horizontal current reduction technology



Current density results for the cathode with bottom exit collector bar

Horizontal current reduction technology

Cathode design with bottom exit collector bar

This kind of design is the cathode assembly which reduces the horizontal current by changing the collector bar design and cell exit location. From above figures it shows that the cathode voltage drop is 194 mV (anode current density is 0.73 A/cm2) which reduces by 70~100 mV compared to that of traditional cathode based on the same anode current density. From the horizontal current reduction analysis it shows that the vertical current density in the cathode carbon block increases by about 0.2 A/cm2 due to bottom exit. This technology is currently only in test phase, and the optential of voltage reduction needs to be proven.

Current intensification

The development trend of current intensification for advanced cell technology outside of China at present is as follows:

1) **Rio Tinto Alcan (Pechiney): pot capacity: 300 kA → 400 kA, anode current density: >0.98 A/cm^2 , pot voltage: <4.02 V, CE: 95%-96%, DC consumption: 12800 kWh/T Al;**

2) **Hydro Aluminium: pot capacity: 300 kA → 420 kA, anode current density: > 0.99 A/cm^2, pot voltage: 4.08 V, CE: 94%-95%, DC consumption: 12800kWh/T Al;**

3) **Dubal: DX type pot capacity: 340 kA → 370 kA, anode current density: >0.99 A/cm^2 , pot voltage: 4.15 V, CE: 95%-96%, DC consumption: < 13000 kWh/T Al.**

Current intensification

At present the development condition of advance representative pot type in China is: the anode current density of current intensification for pots operating from 200 kA to 400 kA already reaches 0.8~0.83 A/cm^2, and the voltage is 3.85~4.05V.

Conclusions

Through lots of prototype tests, mathematical modeling and comparison, the main effective approaches for reducing the pot voltage are as follows at present in China:

- change of bath composition
- slotted anode
- sloped surface cathode
- cathode assembly technology for restraining JY
- current intensification
- cast iron rodding for cathode

For the pot with the above technologies, for example in a plant in China the voltage is 3.75~3.85 V and the CE is above 94%. Compared to the traditional pot with voltage being 4.1~4.2 V and CE being 93%, the energy consumption can be reduce to about 1250 kWh/T Al, and reduce by about 62.5*107 kWh per year based on annual production capacity of 500 thousand tons, and the operation cost savings in about 312 million Yuan per year based on power price being 0.5 Yuan per kWh.