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TEST OF AN BAKED ANODE OF AN ALUMINUM ELECTROLYZER WITH A NEW NIPPLE SOCKET DESIGN

The results of laboratory and industrial tests on a new design of a baked anode for aluminum electrolyzers are presented. At present, in the process of dismantling anodes from anode holders, there is a problem with the incomplete removal of cast iron filling from steel nipples.

At loose contact of the nipple with the carbon block, there is the formation of a solid cast iron layer between the nipple and the anode, which leads to the formation of a thick solid bottom of the cast iron filling without a central hole provided in the corresponding drawing. This situation makes it difficult to remove the cast iron casting from the steel nipple.

Moreover, the increased thickness of the bottom of the cast iron casting results in additional electrical resistance, which reduces electrical conductivity and adversely affects the voltage across the contact between the nipple and the anode.

The anode of the new design offers a solution to this problem. A feature of the new anode design is the modification of the cast iron casting geometry by modifying the design of the anode holder nipple socket. The anode has trapezoidal protrusions located along the anode axis on both sides of the «lug» protrusion in the nipple socket. The new design provides stress concentration. It allows more efficient and less labor-intensive removal of the cast iron casting.

Keywords: baked anode, anode dismantling, cast iron casting, electrical voltage drop, aluminum electrolyzer.

Introduction

Modern electrolyzers use an anode array consisting of pre-baked carbon blocks, which are arranged in two rows along the electrolysis bath. These blocks have sockets into which steel nipples filled with cast iron are inserted. The nipples are connected to the aluminum anode holder using electric welding [1–3].

Before casting the cast iron, the anode holder with nipples is immersed in a bath with colloidal graphite preparation and undergoes the drying process at a special station for nipples. The installed anodes remain in the electrolysis bath for 27–28 days. After completion of the electrolysis process, the anode holder with nipples is sent to the dismantling station to remove the cast iron casting. However, the hydraulic press does not always ensure complete removal of the cast iron casting, so if necessary, rods with anode holders are sent to the repair station for manual removal of the casting and cleaning of the nipples [4].

In the course of research at the production site, cases of increased thickness in the bottom of the cast iron casting were found. The destruction of such a casting requires considerable effort, sometimes exceeding the capabilities of the press used. The increased thickness of the bottom of the cast iron casting is because not all nipples fit tightly to the anode protrusions when they are inserted into a nipple socket. There are four steel nipples welded on the anode holder rod, which change their geometric dimensions after the electrolysis process as a result of physical and chemical influences.

Moreover, the increase in the thickness of the bottom of the cast iron casting leads to additional electrical resistance, which adversely affects the voltage value in the contact between the nipple and the anode [4]. To address these issues, a new design of a baked anode was developed and patented [5].

The new design of a baked anode of an aluminum electrolyzer consists of a current supply rod, a steel bracket with nipples fixed by cast iron casting in a carbon block, and differs in that the carbon block is additionally provided with trapezoidal protrusions, located along the anode axis on both sides of the «lug» protrusion in the nipple socket and made with a height equal to that of the «lug» protrusion, the width of the surfaces depending on the diameter of the «lug» protrusion and equal to 0.3-0.4 times the diameter.:

$$B=f(d)=0.3-0.4$$

Methods and materials

To develop an innovative design for the baked anode, an extensive patent search [6,7] and a series of research studies were undertaken. Three distinct 3D models of cast iron casting were created, namely, the «cast iron casting of the proposed design with a mechanical stress concentrator» (Figure 1), «cast iron casting with a hole», and «cast iron casting with a poured bottom». Utilizing the APM FEM software environment for KOMPAS-3D, each model underwent meticulous computer simulations to analyze the fracture process of the cast iron casting. During the simulations, the hydraulic press punch's pressure on the cast iron pour and the anode holder nipple was thoroughly examined.

For ensuring reliable and realistic testing, a maximum load of 4000 kN was applied. This value was determined based on calculations established in prior work for a single cylinder [4]. The simulations allowed us to assess the structural integrity and performance of each cast iron casting variant under different loading conditions, providing valuable insights for the development of the new baked anode design.

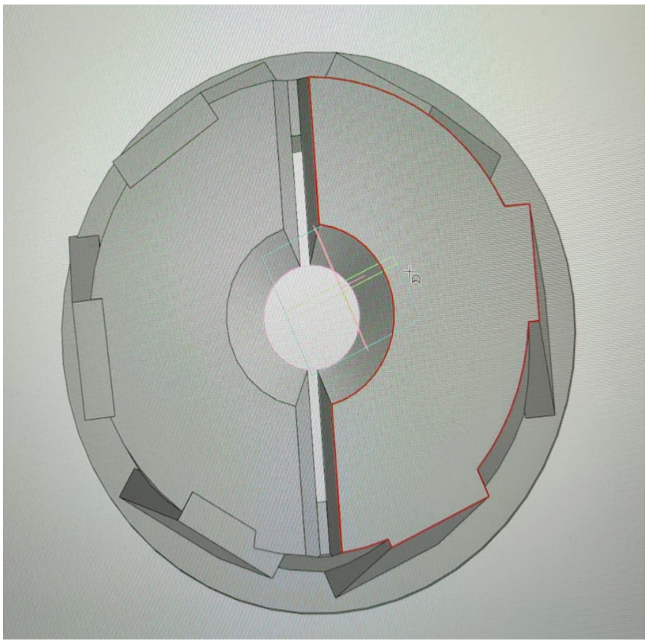

Figure 1 – 3D model of cast iron casting of the proposed design (with mechanical stress concentrator)

2) During the course of the experiment, a scale model tooling was fabricated in the laboratory. The tooling was purposefully designed to include a steel rod, which effectively simulated the anode nipple (refer to Figure 2 for details). Subsequently, employing a laboratory hydraulic press, specifically the PGM 1000-MG4, we conducted controlled fracture tests on the cast iron casting. Throughout the experiment, the actual force applied during the fracture process was accurately measured and recorded (see Figure 3 for the force measurement setup).

The scale model tooling served as a valuable experimental setup, providing crucial insights into the fracture behavior of cast iron casting under controlled conditions.

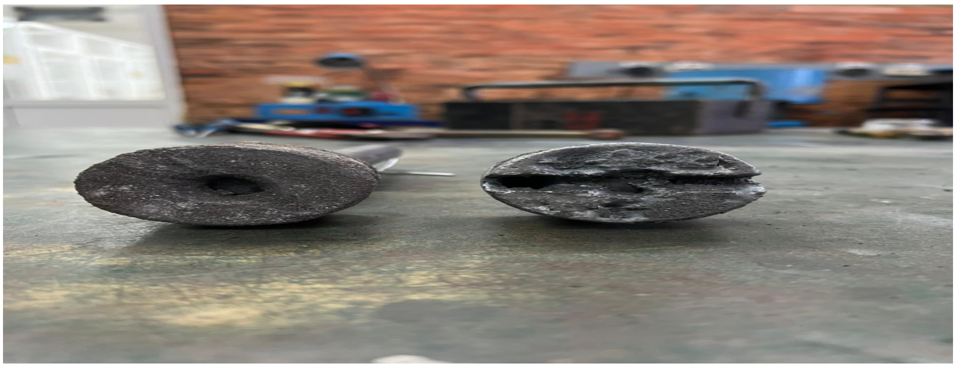

Figure 2 – Scale model tooling

Figure 3 – Results of measuring the fracture force of cast iron casting

3) To implement the experiment in the production conditions, several anode mass inserts were manufactured (Figure 4). These inserts are designed for subsequent installation in the existing nipple sockets of anodes, to create a concentrator of mechanical stresses in the cast iron casting. This concentrator helps to reduce the fracture force of the cast iron casting when using a hydraulic press.

The use of these inserts serves as an essential step in enhancing the accuracy and applicability of the experimental findings, ensuring that the results obtained can be effectively applied to real production environments.

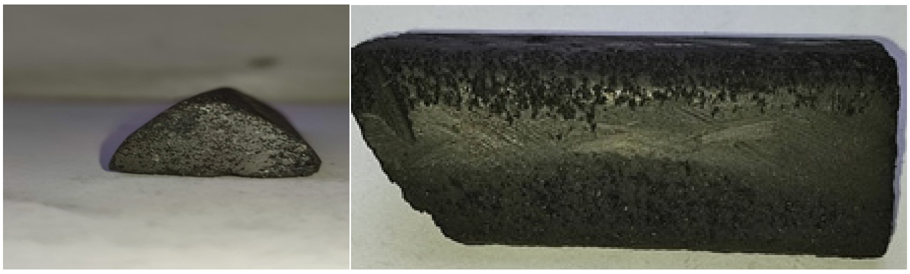

Figure 4 – Graphite insert sample

Results and discussions

The essence of the new design of the baked anode lies in the incorporation of trapezoidal protrusions within the nipple socket, effectively altering the geometry of the cast iron casting and thereby forming concentrators of mechanical stresses in the structure.

The laboratory tests conducted to assess the performance of the baked anode for aluminum electrolyzers have yielded promising results. The obtained data revealed that during the cast iron casting fracture process at the dismantling station after the electrolysis, an average 32.4 % reduction in the required press force was achieved compared to the existing production design [5].

For industrial-scale testing, graphite inserts were installed in the experimental anode (refer to Figure 5). These inserts represent a key feature of the experimental setup, aiming to replicate real-world conditions and validate the practical applicability of the proposed anode design.

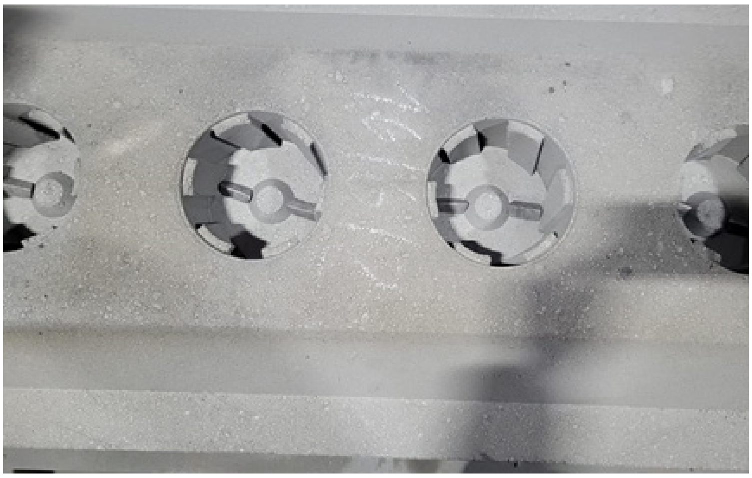

Figure 5 – Installed graphite inserts in the experimental anode

Extensive industrial testing has revealed and verified the significant effectiveness of enhancing the contact area between the carbon block and the steel nipple through the implementation of a novel nipple socket design.

The carbon blocks comprising the anode array play a pivotal role in facilitating electrical contact with the nipples, which serve as conduits for delivering electric current during the electrolysis process [8–10]. It has been identified that a loose fit between the carbon block and the nipple can result in reduced contact area, adversely impacting the overall efficiency of the electrolysis process. Table 1 presents the measured results of voltage drop in anodes utilized during the production process.

Table 1 – Results of voltage drop measurements in the nipple-anode contact

No. of Electrolyzera	Voltage drop of anode No.1, mV	Voltage drop of anode No.2, mV
221	121	119
223	170	184
224	172	155
229	143	150
230	137	133
232	167	107

The acquired findings hold crucial practical significance for industrial enterprises involved in aluminum production. The augmentation of the contact area between the carbon block and steel nipple can yield a substantial improvement in the efficiency and stability of aluminum electrolyzers. This, in turn, leads to enhanced product quality, reduced energy consumption, and increased economic viability of the overall process.

Based on the results obtained during the tests of the new design conducted at the production site, a notable reduction in voltage drop at the contact point between the nipple and the anode was observed. The average voltage drop of the proposed design's baked anode for the aluminum electrolyzer was measured at 37.8 mV. In comparison to the anode used in regular production, the voltage drop exhibited an average reduction of 73.12 % [5].

These outcomes highlight the substantial benefits of the proposed design, underscoring its potential to revolutionize aluminum production processes and contribute to greater sustainability and competitiveness in the industry. The significant decrease in voltage drop signifies improved electrical performance and more efficient utilization of resources, leading to a more cost-effective and environmentally friendly approach to aluminum production.

Conclusion

The research thoroughly investigated the problem of incomplete removal of cast iron casting from steel nipples of anode holders during the process of dismantling burnt anodes. The primary influencing factors include the loose contact between the nipple and anode protrusion caused by uneven ends of four nipples on one crosshead and the formation of a solid cast iron layer leading to the absence of a central hole.

To solve the aforementioned problem, a new baked anode was developed and extensively examined through laboratory and industrial testing. The design had two primary objectives: to establish an efficient and convenient process for removing cast iron casting and to reduce the electrical voltage drop at the contact interface between the nipple and the anode. The new anode design's key feature is modifying the cast iron casting geometry by altering the anode holder's nipple socket design.

Test results indicate that the new anode design concentrates stress effectively in areas where crack localization occurs, leading to the subsequent destruction of the cast iron casting. This feature aids in the efficient dismantling of cast iron casting. One important result is that the average press force required to break the cast iron casting after electrolysis at the dismantling station is reduced by 32.4 % compared to using the existing design.

Additionally, the modified geometry of the cast iron casting leads to a substantial increase in the contact area between the steel nipple and the carbon block. As a result, there is an average reduction of 73.12 % in the electrical voltage drop at the nipple-anode contact. This decrease in electrical voltage is instrumental in establishing a more stable and efficient electrolysis process.

The findings of this study carry significant implications for industrial enterprises engaged in aluminum production. The adoption of the new design of an baked anode has the potential to enhance productivity, lower energy costs, and improve the quality of the produced products. These advancements present exciting prospects for process optimization and elevate the overall competitiveness of the aluminum industry.

In conclusion, the results of this research pave the way for transformative changes in aluminum electrolyzer anode design and offer practical solutions to the challenges of incomplete cast iron casting removal and electrical voltage drop. The application of the proposed design has far-reaching benefits, contributing to greater sustainability, efficiency, and economic viability in the aluminum production process.

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ЕМІК ҰЯСЫНЫҢ ЖАҢА КОНСТРУКЦИЯСЫ БАР АЛЮМИНИЙ ЭЛЕКТРОЛИЗЕРІНІҢ КҮЙДІРІЛГЕН АНОДЫН СЫНАУ

Алюминий электролизерлеріне арналған күйдірілген анодтың жаңа конструкциясын зертханалық және өнеркәсіптік сынақтарының нәтижелері келтірілген. Қазіргі уақытта анод ұстағыштардан күйіктерді бөлшектеу процесінде болат еміктерден шойын құймасын толық алып тастау мәселесі бар.

Емік көмір блогымен тығыз байланыста болмаған кезде, емік пен анод арасында қалың шойын қабаты пайда болады, бұл тиісті сызбада қарастырылған орталық саңылаусыз шойын құймасының қалың, тұтас түбінің пайда болуына әкеледі. Бұл жағдай болат еміктен шойын құймасын алып тастау процесін қиындатады.

Сонымен қатар, шойын құймасының түбінің қалыңдығының артуы қосымша электр кедергісіне әкеледі, бұл электр өткізгіштігін төмендетеді және емік пен анод арасындағы кернеу мөлшеріне теріс әсер етеді.

Жаңа конструкциялы анод бұл мәселенің шешімін ұсынады. Анодтың жаңа констуркциясының ерекшелігі - анод ұстағыштың емік ұясының конструкциясын өзгерту арқылы шойын құймасының геометриясын өзгерту. Анод емік ұясындағы «дөңесше» шығыңқысының екі жағында анод осі бойымен орналасқан трапеция тәрізді шығыңқылармен жабдықталған. Жаңа конструкция жарықтар оқшаулау және шойын құймасының кейіннен бұзылуы орын алатын жерлерде кернеулердің шоғырлануын қамтамасыз етеді. Бұл шойын құймасын алып тастау тиімдірек және аз еңбекті қажеттілігін қамтамасыз етеді.

Кілтті сөздер: күйдірілген анод, анодты бөлшектеу, шойын құймасы, электр кернеуінің айырымы, алюминий электролизері.

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ИСПЫТАНИЕ ОБОЖЖЕННОГО АНОДА АЛЮМИНИЕВОГО ЭЛЕКТРОЛИЗЕРА С НОВОЙ КОНСТРУКЦИЕЙ НИППЕЛЬНОГО ГНЕЗДА

Представлены результаты лабораторных и промышленных испытаний новой конструкции обожженного анода для алюминиевых электролизеров. В настоящее время в процессе демонтажа огарков с анододержателей существует проблема неполного удаления чугунной заливки со стальных ниппелей.

При неплотном контакте ниппеля с угольным блоком возникает формирование сплошного чугунного слоя между ниппелем и анодом, что приводит к образованию толстого сплошного дна чугунной заливки без центрального отверстия, предусмотренного в соответствующем чертеже. Данная ситуация затрудняет процесс удаления чугунной заливки со стального ниппеля.

Более того, увеличение толщины дна чугунной заливки приводит к дополнительному электрическому сопротивлению, что снижает электропроводность и неблагоприятно влияет на величину напряжения в контакте между ниппелем и анодом.

Анод новой конструкции предлагает решение этой проблемы. Особенностью новой конструкции анода является модификация геометрии чугунной заливки путем изменения конструкции ниппельного гнезда анододержателя. Анод оснащен трапециевидными выступами, расположенными вдоль оси анода с обеих сторон от выступа «бобышки» в ниппельном гнезде. Новая конструкция обеспечивает концентрацию напряжений в областях, где возникает локализация трещин и последующее разрушение чугунной заливки. Это позволяет более эффективно и менее трудоемко снимать чугунную заливку.

Ключевые слова: обожженный анод, демонтаж анода, чугунная заливка, перепад электрического напряжения, алюминиевый электролизер.

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