The Key Technologies for Energy Efficient $Al(OH)_3$ Dilute Phase Fluidized Bed Roasting Furnaces

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Abstract

Research work on new types of castable refractory, pre-casted assembly parts and thermal insulation materials, with resistance to high wear, thermal shock and erosion and low thermal conductivity, were done to solve problems of high system energy consumption, cracking and spalling of partial lining and mismatch of furnace top material and hanging material and so on, caused by unreasonable design of domestic $Al(OH)_3$ dilute phase fluidized bed roasting furnace lining. Several difficult problems such as the matching of different materials, preservation of dilatation joint between different zones and reasonable mechanical distribution of lining were solved. A full set of techniques including construction, furnace lining drying, lining maintenance and corresponding standards were developed according to the properties of lining materials and features of the furnace type. Using the ideas of furnace integration and new theory of furnace lining, we have solved the key technologies of high-efficiency and energy-saving for furnaces. The achievements have been applied to domestic $Al(OH)_3$ dilute phase fluidized bed roasting furnaces to reduced energy consumption by one thousand MJ per ton of alumina, thus making a furnace lining with higher production, lower energy consumption and less exhaust gas emission.

1. The problems of structure and materials of lining in domestic $Al(OH)_3$ dilute phase fluidized bed roasting furnaces

As a kind of mainly dilute and dilute-dense phase combined large-scale roasting plant, $Al(OH)_3$ dilute phase fluidized bed roasting works in a very short period of time to complete the process of the dehydration of 10% moisture in $Al(OH)_3$ feeding and the transformation from $Al(OH)_3$ to alumina lattice. At present, most of $Al(OH)_3$ dilute phase fluidized bed roasting furnaces in China are of gas suspension calciner type and the lining structure and indices of lining materials are an important part of the integrated technology.

The features of these lining materials and structural are the following:

(1) the proportion of Al_2O_3 and SiO_2 is 1.1 (1): 1 (1.1) or so, and the total content of Al_2O_3 and SiO_2 in the material should be as high as 95%.

(2) Working layer of lining material, which is basically semi-mullite phase and low density to meet the request of roasting process, is of the types of low temperature tolerance metallurgical furnace refractory.

(3) The impurity content is very low, thus revealing high mechanical properties. However, in different materials the linear shrinkage shows from -0.1% to -0.5%. This indicates that some foreign materials of working lining use high purity treated natural clay or synthetic semi-mullite material.

(4) The lining is double-layer composite structure, consist of boride insulation layer and work layer.

(5) Anchoring brick and the distance of anchoring arrangement is 200 x 200 mm, anchor plate is used and the net spacing should be 100 x 100 mm.

(6) The castable working layer of main lining is designed as less than $1.5m^2$, its four sides are 1-3cm expansion joints and filled by fiber products.

(7) As the common way to design the lining position, no steps has been taken to avoid the stress in the steel and lining structure.

(8) Expansion joints are wide and in pass form.

Although China is rich in clay resources, the natural mineral in line with the foreign material indicators is rare. The domestic roasters lining material is produced by local manufacturers while the physical and chemical indicators of the original demand may not be followed. According to domestic manufacturers' understanding on materials of different grade and the market price, different lining materials were prepared using different formulations and mineralogical composition of the roaster. Thus, in the procurement and use of refractory in the domestic roaster the price of the same grade refractory lining can vary 3 to 4 times, and different material systems using the same model structure lining, causing the decline of lining stability and integrity. In some cases serious wearing will happen, tear off into pieces and shedding in early operation. Therefore, the main direction of our research is the use of available high-quality aluminum roaster combination lining material, the development of appropriate production standards and technology and the design of lining structures that meet the current materials systems. Major physical and chemical indicators of refractory used in dilute phase fluidized bed roasting furnaces are shown in Table 1.

Table 1 The major physical and chemical indicators of refractory used in dilute phase fluidized bed roasting furnaces

Grade	maximum use temperature/C	Refractoriness /C	chemical constituents /%			Density /cm^{-3}	Compressive (flexural) strength /N•mm^{-2}			thermal conductivity /W•m^{-1}•K^{-1}			linear change rate /%	refractoriness under load /C	apparent porosity /%	Remarks
			Al_2O_3	SiO_2	Fe_2O_3		110C	500C	1,000 C	400C	600C	1,000 C				
DCL-45	~1,400	1,690~1,790	45	40	1.0	2.3	55	55	55		800C 0.9	1,C 1.0	1,000C -0.5			castable
DCL-50	~1,500	1,750	50	45	1.5	2.35	90 (10)	80 (10)	80 (10)		800C 1.25	1,200 C 1.4	1,000C -0.1			castable

DCL-55	~1,500	1,750	55	40	1.5	2.4	75	75	75		800C 1.4	1,200 C 1.45	1,000C -0.1			castable
fireclay brick		1,750	40	50	3	~2.2	30				800C 1.3	1,200 C 1.4	1,400C + 0.1 -0.4	1400	22	Forming brick
fireclay insulating refractory brick	~1,250		38~42	40~45		0.5	1.5				0.17	0.21	1,250×2 1.0			
non-asbestos silicate cover plate	~1,050					0.25	1.2			0.16	0.10	800C 0.11	1,000C ×3 1.5			
Aluminosilicate refractory fibrebrick	~1,250					0.128				0.09	0.13	0.28	1,200C 2			
Aluminosilicate refractory fibre rope	~1,150					0.4										
slag wool						0.2				0.09						

2. The ideas of development of a new series of refractory lining, research and development process and results

The major firing surface in $Al(OH)_3$ dilute phase fluidized bed roasting furnace uses castable refractory materials, our research and development efforts focus in new castable material for $Al(OH)_3$ dilute phase fluidized bed roasting furnaces.

Selection of a new castable material is based on the following principles:
(1) Most new calciners built in China in recent years are dilute phase fluidized bed roasting .The operation level are mostly very well, for instance, the original design of the 1,850 t/d capacity furnace can operate at 2,350 t/d ~ 2,400 t/d and the 1,350 t/d ~ 1,400 t/d capacity devices can reach 1,650 t/d ~ 1,700 t/d, and long-term high yield and energy efficient have been achieved. Therefore, there is a need for more tolerance to high temperature, corrosion resistance, wear resistance, spalling of high-quality casting material lining to respond to the strengthened process requirements.
(2) The abundant resources of inexpensive high-quality bauxite in China, which is the same material source with alumina, should be given priority in use.

The set of castable formula is based on the following technical requirements.
(1) Resistant to the hot erosion and wear by the alkaline moisture content of more than 10% of aluminum hydroxide in the process of flash dehydration;
(2) Withstand the huge thermal shock tear strength when opening a oven and putting into operation, and shutdown repeated in many times;
(3) Withstand the forces caused by deformation in the place of shape change in steel frames in different directions and thermal expansion force. To resist the combination of squeezing, twisting and tearing crack from thermal expansion force, lining must have very high strength;
(4) With the ability to withstand strengthened smelting process;
(5) Able to withstand accidents and sudden changes in process;
(6) Resistant to erosion, wear resistance and spalling in the long run of operation;
(7) With the possibility of quick repair;
(8) Cost effective. Local lining materials with affordability, high quality should be used. Overhaul cycle is long and annual repair work does not exceed 1% to 3% of total repair work. Operation stops caused by the blocks peeled off and Al_2O_3 contamination caused by to the particle from lining materials should not happen.

Our ideas in castable components design are:
(1)To use the material with higher Al_2O_3 content and better sintering strength when the physical strength indices are the same. This will help to ensure the purity of alumina product and improve refractoriness and creep property under high temperature of the lining materials
(2) To select a variety of natural or synthetic materials with high quality and low cost according to different temperatures and working conditions. Therefore, the Luohua Co.'s standard series Q/LYLHOO3-2000 LH-1500 is modified based on the Chinese standard JC/T498-92 (96) concerning high-strength refractory castable.

We divide the lining into the following sections: (note: Cxx means a stage of coolers and Pxx means a stage of preheaters)
(1) In the lower temperature stages of CO2 ~ CO4, the refractory with half-mullite nature under the sintering temperature of 800 ~ 1,000℃ is applied;
(2) In CO1 ~ PO2 and the flue pipes in and out of the roasters, the long-term operating temperature need to be 1,200℃ or more to maintain lasting stability. The refractory phase is mainly mullite;
(3) The side wall section of PO3 and the upper straight section of PO4 are on the main reaction zone and both the material flow rate and temperature are high. So in these parts of the lining the materials which are able to sustain the temperature about 1,550℃ in long-run, resist erosion wear and keep phase stability should be used. Primarily the material is mullite - corundum phases;
(4) For the internal wall of the top of ignitors PO3, top, lower cone section and a discharge pipe of PO4 the material should be used in long-term temperature of 1,600℃ or higher, and the refractoriy is also good at thermal shock resistance, overall strength, spalling resistance and good wear resistance. Composite materials are mainly in aluminum corundum phase. The part of the physical and chemical specifications of the castable is shown in Table 2.

Table 2 [Test set]Physical and chemical specifications of castable in various parts

Parts used		CO2~ CO4	CO1~PO2	CO1、CO2、cone，PO3、PO4 side wall	PO4 cone & top PO3 top、blanking tube、burner etc.
Chemical composition	Al_2O_3	≥60	≥70	≥75	≥80
Compressive (flexural) strength /MPa	110℃	≥50 (7)	≥60 (8)	≥70 (10)	≥80 (12)
	1,100℃	≥70 (9)	≥80 (10)	≥90 (12)	≥100 (12)
Bulk density /g/cm^3		≥2.4	≥2.5	≥2.7	≥2.8
Thermal shock resistance (1,100℃ water)		≥20	≥30	≥40	≥40
Linear change rate / %	1,100℃	≤-0.2	≤-0.2	≤-0.2	≤-0.2
Wear resistance / cc	1,100℃	——	——	8	6

Compared with some foreign casting material, this series of casting material in the series has the following characteristics:

(1) Alumina bulk density is 3.9 ~ 4.0g/cm^3 and bulk density of aluminum hydroxide is 2.42g/cm^3, while the bulk density of foreign castable is between the 2.1 ~ 2.4 g/cm^3. In addition to reasons unable to choose, it is necessary to enhance the overall strength of refractory lining level and quality level in order to resist the jet erosion wear of the charge. Therefore in the production, higher bulk density materials were used to improve the distribution of energy in the combat of furnace lining against furnace burden, thus improving overall strength and stability of the lining;
(2) The test materials have higher alumina content. That will help to increase product purity;
(3) Based on the modern composite materials theory, with the introduction of effective forms of high-grade binders and additives making the lining material with a variety of mineralogical composition and excellent quality, such as materials, increased bulk density, elasticity, wear resistance, spalling resistance, corrosion resistance and thermal shock stability which are all enhanced. These materials agree with the related product standards, but the performance specifications are better than any of these product standards.
(4) In foreign castable specifications, rate of linear change after high temperature firing from ± 0.7% to ± 0.01%, could not truly be representative of the current castable material. Refer to China's production of casting material the linear shrinkage rate of -0.1 ~ -0.3% is set, It is in line with national standards, but also better than the national standard;
(5) In the dehydration process the lining of thermal shock is great power so that there must have clear refractory thermal shock strength requirements and testing conditions as a standard, It is missing in the foreign roaster castables specifications. Then it will not be able to determine the starting point of breakage rate and the ultimate life of the lining and there is no way to arrange standard maintenance procedure. There are two China's thermal shock resistance test standard either by water cooling or by air cooling, the standard numbers are YB/T 376.1-1995 and YB/T 376.2-1995. Among the two we choose the more strict water cooling type and select the rate of linear change as -0.1~ -0.3 and thermal shock resistance as 1,100℃ water at 25 to 40 times.
(6) Test with the cast refractory cuisine of indicators into the national standard range of domestic and production of the standard range, can be programmed to carry out quality tracking, quality inspection and quality determination.

3. The lining structure improvement

As a kind of mainly dilute and dilute-dense phase combined large-scale roasting plant, $Al(OH)_3$ dilute phase fluidized bed roasting works in a very short period of time to complete the process of the dehydration of 10% moisture in $Al(OH)_3$ feeding and the transformation from $Al(OH)_3$ to alumina lattice. At present, most of $Al(OH)_3$ dilute phase fluidized bed roasting furnaces in China are of gas suspension calciner type and the lining structure and indices of lining materials are an important part of the integrated technology.
The features of these lining materials and structural are the following:
(1) The proportion of Al_2O_3 and SiO_2 is 1.1 (1): 1 (1.1) or so, and the total content of Al_2O_3 and SiO_2 in the material should be as high as 95%.
The principles and directions for improving lining structure are the following:
(1) The steel skeleton is used for strengthening and fixing fire-resistant lining, the changes of strength and volume of the lining in thermal process is in decisive and dominant position. Meanwhile the steel skeleton is also an important channel of heat loss. How to solve the contradiction of support stability and heat dissipation of the steel skeleton is an important aspect of energy conservation issue.
(2) The effect of the thermal engineering process depends on the inner lining of the interface within the interface effect the integrity of the lining. The lining should be to protect and optimize the effects of cavity lining the starting point of interface to configure and optimize the lining structure. Not only high-quality lining materials must be used, lining design and construction are also very important;
(3) The expansion stress in lining occurs mainly at the structural deformation in the lining and the lining tearing also appears in this position. The more the lining was strengthen, the less the structural defromation were eliminated. So how to deal with the contradiction between lining strengthening for structural deformation and reducing deformation of the lining is an important issue for lining stability;
(4) A reasonable set up of expansion seal and its form to ensure the sealing performance of the whole lining.

In accordance with these principles, the lining structure of $Al(OH)_3$ dilute phase fluidized roasting furnace has been improved in many aspects, mainly in the following areas:

(1) The furnace wall being integrated and flexibility, for the establishment of mechanical structure system based on the furnace

wall. The inter-layer drift were increased and the lining structure of the side wall in PO3 and PO4 were changed, and a flexible insulating layer was added inbetween layers. The thickness of insulating layers were thickening to 115mm and castble with good insulating effect were applied to insulating layers. The castable layers were thinning.The form and method of the expansion joints in the lining are also changed;.

(2) Add thrust beam and clamp beam, release side wall while the movement is limited, promote the furnace wall and furnace heating power vibrating in the same frequency, reduce heat resistance, protect the integrity of the furnace wall interface. Change the anchor of monolithic castable lining fixed method to cancel the brick wall of the anchor, Change the number and shape of anchors. Change the way to anchor the roof at high temperature, Separate roof and side wall. Use castable lining in all the connecting elbows between individual equipment.

(3) Enhance the stability and sealing of furnace roof to limit the shaking and offset amplitude of the furnace wall; strengthen the stability of the external pipe in the upper of single device. Change the steel-framed roof grate into network-style steel frame. Set anchor bricks in the top lining in one layer and stainless steel anchors in another layer. Replace the roof with single hot device by an integrated castable roof.

(4) Set joints at the interface between differient thermal state and structures. Srengthen the lining before reserve expansion joints. the momentum in the critical thermal decomposition of the interface, the interface structure set into the lining 'joints', which is to strengthen, then open the way, lining the border to take measures to strengthen the intensity of the first, and then reserved for expansion joints.

(5) Loosen the thermal overload of PO3. Add emergency troubleshooting under the PO3, change lining structures in discharging port of PO3, thus extending the roaster cavity.

(6)Replace the anchor plate with point-anchor anchor; replace asbestos with high temperature refractories flexible pipe seal to reduce heat loss.

4. The application results

In recent years energy reduction and productivity rising have been more and more emphasized for dilute phase fluidized bed roasting furnaces. In our practice the use of new materials and a series of accompanying technologies such as refractory setting, expansion joints preparing, lining structure setting, construction method improving and new ways of oven drying etc., all are focused under the name of "Integrated Furnace" concept, have effectively increased the capacity of dilute phase fluidized bed roasting furnaces, and lower energy consumption per ton of alumina is reduced by 25-30% by reducing the surface heat loss. Table 3 gives practical examples.

Table 3 Comparison of dilute phase fluidized bed roasting furnace production

Furnace	Xiangjiang Wanji 1#	Chalco Zhongzhou 3#	Chalco Henan 1#	Chalco Henan 2#	Chalco Guangxi 2#
Design capacity / t/d	1,400	1,300	1,850	1,350	1,300
Actual operating rate / %	95	95.57~98	>95	>95	94.97
Average daily production / t/d	1,460	1,480	2,150	1,550	1,345
Average daily production / t/d	1,500	1,650	2,337	1,659	1,500
Production rate / %	qualified	>98	>98	>98	qualified
Capacity to improve / %	7.14	26.92	26.32	22.88	15.38

Table 4 Change of gas consumption of several dilute phase fluidized bed roasting furnaces (MJ/ton-Al2O3)

Furnace	Xiangjiang Wanji 1#	Chalco Zhongzhou 3#	Chalco Henan 2#	Chalco Guangxi 2#	Chalco Guangxi 1#
July-Dec, 2007	2,108.65	3,522.4	3,360.7	3,154.93	3,570.19
Jan-June, 2008	2,375.88	3,510.5	3,128.3	3,302.19	3,555.75

In the above tables Chalco Guangxi 1# used imported refractory lining structure. In Chalco Guangxi 2# furnace PO2-PO3, volute connector to PO3-PO4 and cone repairing of PO3, PO4, CO2 and CO3, new materials and structure had been used. The whole refractory in Chalco Zhongzhou 3# and Chalco Henan 2# dilute phase fluidized bed roasting furnaces used new materials, Xiangjiang Wanji 1# furnace lining project and all imported burners applied all the above described lining mechanical structure design, materials, construction and oven drying technology.

5. Summary

Key technologies of energy efficient application in $Al(OH)_3$ dilute phase fluidized bed roasting furnaces is in the form of "Integrated Furnace" concept" as systems engineering. The six indispensable factors are: furnace lining research, refractory research and development, refractory lining structure design, construction optimization, oven drying technology and initial operation and lining maintenance technology.