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Extraction of aluminum from alumina by disproportionation process of AlCl in vacuum

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Abstract: The extraction conditions of aluminum by the disproportionation process of AlCl in vacuum were investigated using alumina and graphite as raw materials, including reaction temperature, pre-reaction and condenser structure. The results show that the extent of the reaction between alumina and carbon increases with increasing reaction temperature at 1643−1843 K; however, the extraction rate of aluminum increases firstly, and reaches the highest at 1743 K, and then decreases with rise in reaction temperature. The pre-reaction of alumina and carbon increases the extraction rate of aluminum. The impurities C, Al_4C_3 and Al_2O_3 in the aluminum product are reduced with reducing the contact surface of the aluminum with CO and with decreasing the condensation temperature, depending on the structure of the condenser.

Key words: aluminum; AlCl; alumina; extraction; vacuum; disproportionation

1 Introduction

Although aluminum is widely distributed in nature, its prices remain high. The main reason is that the cost of the traditional Hall−Héroult process used generally in industry is high. Therefore, the alternative processes are continuously being explored in order to cut the aluminum production cost.

The carbothermal reduction of alumina to produce aluminum has the most possibility to replace the Hall−Héroult process due to its simple procedures and potential to reduce the cost [1,2]. However, it still remains a formidable technical challenge due to the high temperature required (2300−2500 K) and the difficulty in separating aluminum product from the molten residues [3−7]. The disproportionation process of AlCl in vacuum developed from the direct carbothermal reduction process could overcome the above problems, in which the required temperatures are lower and the aluminum product is apart from the residues [8,9].

WANG et al [9] attempted to extract aluminum from bauxite using the disproportionation process of AlCl in vacuum. The extraction rate and the purity of the aluminum product were not satisfying. The research on the behaviors of some additives in the process demonstrated that the extraction rate of aluminum was improved by the additions of Fe_2O_3 and TiO_2, and reduced by the addition of SiO_2, and the purity of aluminum was not affected by them [10,11].

The mechanism of the process has been explored. YUAN et al [12,13] and YU et al [14] proposed that Al_4O_4C and Al_4C_3 formed from the carbothermal reduction of alumina were chlorinated to AlCl, and AlCl decomposed to Al and $AlCl_3(g)$. FENG et al [15] suggested that AlCl was mainly generated from the chlorination of Al_2O and Al formed from the carbothermal reduction of aluminum, and Al_2O, and Al could also react with CO to form Al_4O_4C and Al_4C_3 as side products; however, FENG [16] agreed that Al_4O_4C and Al_4C_3 can also be chlorinated to AlCl. Thus it can be inferred that the pre-reaction of alumina and carbon could be an important factor affecting the extraction rate of aluminum.

The purpose of this work is to preliminarily investigate the effects of reaction temperature, pre-

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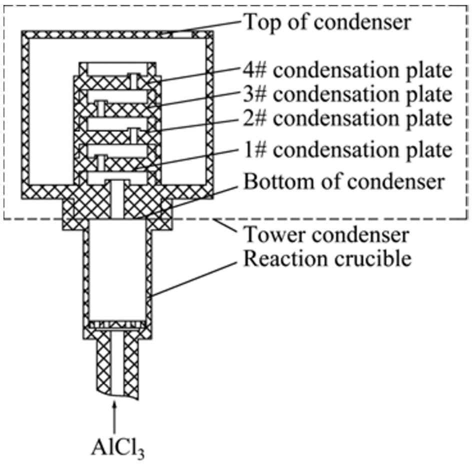
reaction and condenser structure on the extraction rate and the purity of aluminum.

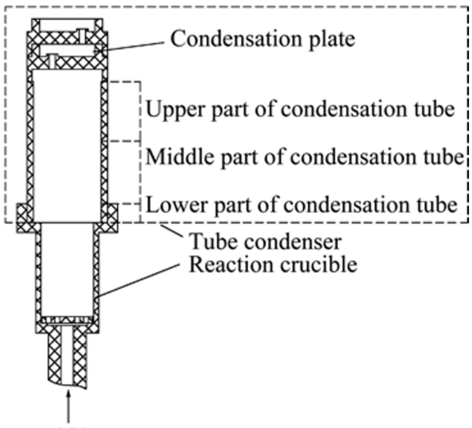
2 Experimental

2.1 Apparatus

Experiments were carried out in a furnace designed by ourselves, described in detail in Ref. [17]. The condensers used in this work are shown in Fig. 1.



(a)



(b)

Fig. 1 Schematic diagram of condensers: (a) Tower condenser; (b) Tube condenser

2.2 Experimental procedure

Alumina (analytical grade) and graphite (fixed carbon content of 99.85%) with molar ratio 1:3 were thoroughly mixed and pressed in a closed die of 20 mm in diameter under 2 MPa to produce cylindrical pellets with mass of about 5 g.

20 g pellets were held in the reaction crucible placed in the furnace. When the pressure in the furnace was pumped to below 5 Pa, the reaction crucible was heated to a certain temperature, and then aluminum chloride anhydrous (analytical grade) was heated to sublime into the crucible. The temperature of the crucible was maintained for a certain time, and then heating was stopped. When the furnace was cooled to room temperature, the residues and the condensates were collected and weighed. The condensate samples were characterized by XRD (D/max−3B).

3 Results and discussion

3.1 Effects of reaction temperature on extraction of aluminum

The tower condenser was used in the experiments, and reaction time was 1 h. The results are shown in Table 1. The residues consisted of unreacted alumina and graphite, and their amounts could reflect the extent of the reaction between alumina and carbon. The condensates on the upper wall of the crucible and the bottom of the condenser were formed by the secondary reactions of the Al_2O, Al and CO, and their amounts could reflect the extent of the secondary reactions. The condensates in the condenser consisted of metallic aluminum with impurities Al_4C_3, Al_2O_3 and C, and their amounts could reflect roughly the extraction rate of aluminum.

Table 1 Effects of reaction temperature on extraction of aluminum

Reaction temperature/K	Mass/g		
	Residue	Condensate on wall of crucible and bottom of condenser	Condensate on all parts of condenser
1643	16.6	0.3	0.1
1693	16.2	0.4	0.6
1743	10.5	0.7	1.4
1793	8.2	3.2	1.0
1843	2.9	3.7	0.9

The facts can be seen from Table 1 as follows.

1) The residues were reduced with increasing reaction temperature.

2) The condensates on the upper wall of the crucible and the bottom of the condenser increased with increasing reaction temperature.

3) The condensates in the condenser first increased and then decreased with increasing reaction temperature, and reached the maximum at 1743 K.

The process proceeds through successive steps [15,16]: Firstly, alumina reacts with carbon to generate gaseous Al_2O, Al and CO in the crucible; Secondly, the Al_2O, Al gases react with $AlCl_3$ to form gaseous AlCl, and react secondarily with CO to form Al_4O_4C, Al_4C_3, Al_2O_3 and C at the same time; Lastly, the AlCl enters condenser and disproportionates to metallic aluminum and gaseous $AlCl_3$. It was deduced that increasing