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Water leaching kinetics and recovery of potassium salt from sintering dust

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Abstract: Surface morphology and inner structure of the dust were observed by ICP-AES, SEM-EDS and XRD to examine the strengthening measures of leaching potassium salt from the sintering dust by water. The results showed that the main component of the sintering dust was iron−oxygen compound, with KCl adsorbed on its surface. Leaching experiments showed that the KCl in the ESP dust could be separated and recovered by water leaching and fractional crystallization. The yield of K−Na vaporized crystalline salt was 18.56%, in which the mass fractions of KCl, NaCl, $CaSO_4$ and K_2SO_4 were about 61.21%, 13.40%, 14.62% and 10.86%, respectively. The leaching kinetics of potassium salt from the sintering dust fits the external diffusion model well. The leaching speed and the leaching rate of the potassium salt can be increased by increasing the leaching temperature, strengthening the stirring speed and increasing the liquid−solid ratio.

Key words: potassium salt; sintering dust; leaching kinetics; intensified leaching

1 Introduction

Potash, an essential fertilizer for crop growth, is very important for China, which feeds 22% of people on earth with less than a tenth of the world's arable land. In the first ten months of 2012, the potash fertilizer imports in China increased by 9.7% to 5.714 million tons (pure KCl) [1,2] and the CFR (cost and freight) price increased by 23.7% to 470 dollars per ton [3]. The main reasons for the increasing price of the potash were the increase of the consuming capacity of potash fertilizer as well as the decrease of its production in China. The reason for the price of the potash soaring up is that the consuming capacity of potash fertilizer in China is rising whilst its production is shrinking, which is mainly attributed to the limited reserves, the backward technology with complex procedures, the low production capacity (only 4.8 million tons per year, pure K_2O), and the geographic location too remote, inconvenient traffic and very harsh climate [1,4,5].

Sintering dust generated during the steel-making sintering process and collected by electrostatic precipitator, is usually considered a kind of solid waste. It is considered a dangerous dust because of its complicate components such as heavy metals and hazardous components [6]. A usual way to treat the sintering dust is returning it to the sintering furnace to reuse Fe and C. However, great amount of other elements such as, K, Na, Zn and Pb are also reused in the recycle, which is harmful for normal operation of blast furnace and sintering machine [7−12]. Thus, it is necessary to study new technologies for its processing. It is obtained that the mass contribution of KCl is up to 30%, some even up to 40% in the dust. Statistically, there is approximate 4 kg of this kind of dust produced per ton steel [13]. So, it is a considerable number of the total amount of this dust, which contains 0.84 million tons of KCl in 2012 (calculating with KCl content of 30%) [14].

Based on a large number of experiments [15,16], a national invention patent of producing potassium chloride from sintering dust was applied by GUO et al [17], and a potassium chloride plant with a capacity of 10000 t/a sintering dust was built in Tangshan, China. The simplified potassium recovery process shown in Fig. 1 was designed as follows: leaching the sintering dust with water at a certain temperature (step 1); and filtering the leaching solution after some time (step 2); then removing heavy metal impurities from the filtrate and recycling the residue as iron ore concentrate (step 3); finally, evaporating the purified filtrate step by step to obtain the high purity products (step 4).

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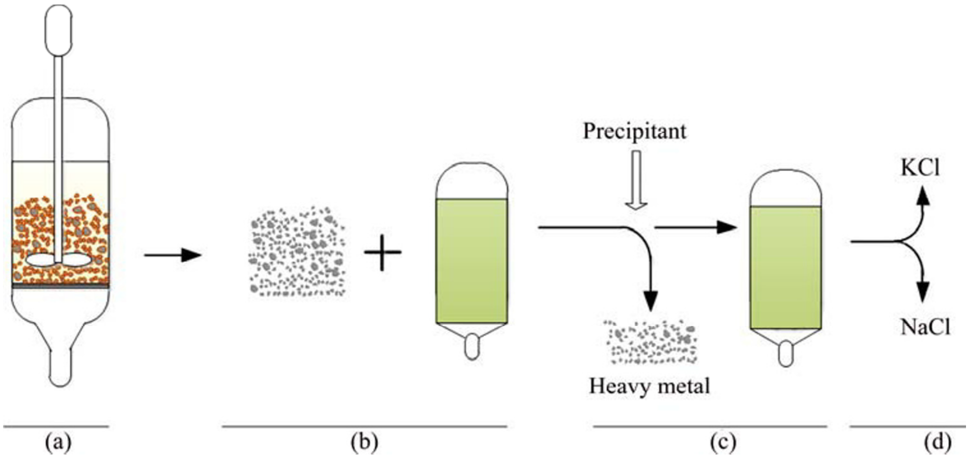

Fig. 1 Process flow diagram of recycling potassium resource: (a) Leaching process; (b) Filtration process; (c) Impurity removal process; (d) Separation process

In order to expand the applying scope of the new technology, the physical properties of different metallurgical dusts should be investigated. Furthermore, a theoretical model about controlling the production process can be built by studying the leaching kinetics in depth, which could be helpful to improving the leaching effects.

PENG et al [13] derived a leaching kinetic formula for sintering dust by the linear relationship between the concentration and electrical conductivity of the leaching solution. However, in their research, the liquid−solid ratio was enlarged to 100/1 without considering the actual situation. So, the obtained linear relationship cannot reflect the actual leaching behaviour of potassium from the sintering dust. In this work, the sintering dust collected from Baotou Steel (Group) Corporation was studied. The physicochemical properties of the dust, the leaching mechanisms, the leaching kinetic model and the intensifying leaching methods were studied in detail. This work is intended to obtain a more practical theoretical model for controlling the production process.

2 Experimental

2.1 Sample component analysis

An ESP dust sample from Baotou Steel (Group) Corporation was subjected to chemical analysis to determine the mass contribution of potassium. On one hand, the mineral elements of the ESP dust were detected using an X-ray fluorescence spectrometer (XRF−1800, Japan). On the other hand, the composition of the dust sample was analyzed by the following method: the sample was mixed with an acid mixture ($V(HNO_3)$: $V(HClO_4)$:$V(HF)$=5:3:2) in a polytetrafluoroethylene beaker and placed in a high-pressure digestion oven at 170 °C for 5 h. The digested acid mixture was analyzed with an ICP-AES (Perkine-Elmer OPTIMA 3000, USA) to measure the concentrations of the trace elements (Al, Ca, Fe, K, Mg, Na, Pb, Si and Zn).

2.2 Existing state of K element in dust

The structural characterization of ESP dust and its filter residue obtained after water leaching was performed by an X-ray diffraction analyzer (M21, MAC, Japan). Samples of the dust were examined under a scanning electron microscope (SEM) (Cambridge S−360, UK) and X-ray mapping (Tracor Northern, USA) via SEM-EDS to gain a better understanding of the ESP dust. The prepared samples were subjected to the X-ray mapping via SEM-EDS for elements Cl, K, Na, Fe, Ca, S and O.

2.3 Water leaching experiments

4.9839 g of ESP dusts were added into 100 mL deionized water in a conical flask and stirred for 10 min. After being filtrated, the residue was leached with another 100 mL deionized water at least 4 times. The combined filtrate was collected and evaporated to crystals. The concentrations of the major water-soluble particle species (K^+, Na^+, Ca^{2+}, Mg^{2+}, Al^{3+}, Cl^-, SO_4^{2-}, NO_3^-, Br^-, F^-, and PO_4^{3-}) in the crystals were determined by an ICP−AES and IC ion chromatograph (Metrohm 792 Basic, Switzerland). The structural characterization of the crystal substance was performed by X-ray diffraction analysis.

3 Results and discussion

3.1 Sample component

The ICP-AES result of the digested acid mixture is shown in Table 1. The result shows that main metal constituents of the ESP dust are iron (37.92%), potassium (6.89%) and calcium (6.76%), indicating that this ESP dust is ferric oxide with a high concentration of potassium and calcium. It is worthy to be noted that the contribution of K is high in the dust.