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Recovery of potassium chloride from blast furnace flue dust

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Abstract: A simple, efficient, economic and environment-friendly recovery process of high-content potassium chloride from blast furnace flue dust (BF flue dust) with abundant potassium content is developed. This process is mainly composed of water-leaching, purification, decolorization, vacuum evaporation and cooling crystallization. In this study, the basic properties of blast furnace flue dust were identified by X-ray diffraction (XRD), inductively coupled plasma analysis (ICP), and laser granulometer (LG). The purity of the KCl products was analyzed by ICP combined with sodium tetraphenylborate (Na-TPB) chemical method and XRD. The particle sizes of the KCl products were characterized by LG and SEM. The results showed that the BF flue dust had a good recovery value with a potassium chloride content of 39.58%. After treated the dust by water-leaching and processed the as-prepared eluent via purification, decolorization and vacuum evaporation, the KCl crystal products were obtained with an yield of 72.77%, 79.52% and 71.09% at 0℃，5℃ and 10℃ of cooling crystallization temperature and 2.27, 2.52 and 2.36 of the mass distribution coefficients, respectively. The KCl crystal product exhibited a narrow particle size distribution with a purity of greater than 96.00%.

Key words: BF flue dust; potassium chloride; recovery; characterization; analysis.

1. Introduction

Quite a number of dust and slag are produced as waste materials or byproducts in the iron and steel plant every day[1, 2]. Since 2013, China has been the one of the biggest crude steel producers in the world with an output exceeding 779 million tons[3]. It was reported that, in China, for 1 ton of steel production, 20 kg of the BF flue dust would be generated averagely[4]. By calculation, the output of BF flue dust is about 15.58 million tons per year. This BF flue dust is generally dumped into landfills or fields[5, 6]. As it is well known to all, the BF flue dust contains abundant alkali-metal elements such as potassium and sodium and various toxic heavy-metal elements such as lead, zinc, manganese and copper[7-9]. Meanwhile, this dust also contains a small amounts of cyanide generated from the coal or the coke which is used as the BF production raw material [8, 10]. Therefore, the traditional dumped-treatment method of the BF flue dust not only can cause environmental pollution and do harm to human beings[11-14], but also can lead to the waste of the valuable elements or the recoverable resources. Hence, the dust must be turned into environment-friendly before discharged. In addition, recovering these valuable resources from the BF flue dust can make huge economic benefits.

Meanwhile，as the world’s second largest consumer, China is extremely dependent on the import of potassium products from international market due to its lacking in potassium resources[15-17]. Thus, the recovering of the secondary potassium resources will relieve the contradiction of potassium products supply-demand currently in china and promote the national sustainable development.

It has been well demonstrated to be feasible to recycle some metal elements through physical or chemical mineral processing techniques such as hydrocyclonation, magnetic separation, grinding, chemical-leaching, floatation, and high-temperature roasting [2]. So far, several effective ways have been developed to recover potassium chloride[18], mainly including the cold-decomposition and floatation processes, the reverse flotation and cold crystallization process, the hot-melt crystallization and the dilution-cooling and reaction-extraction coupling crystallization processes. For instance, J. Chang[19] reported a method for the preparation of potassium sulphate from the discharged sintering dust. The process was as follows. Firstly, ammonium bicarbonate was used to separate impurity ions from sintering dust such as Ca^{2+}, Mg^{2+}, Cu^{2+}, Pb^{2+}, Zn^{2+}. Then, ammonium sulphate was added into solution to carry out a double decomposition reaction after decolorization by activated carbon. Finally, industrial and agricultural fertilizer product grade of potassium sulphate and agricultural combined fertilizer $(K, NH_4)Cl$ were acquired by the procedure of concentration and crystallization. Z. Shen *et al*[20] also reported a method for the recovery of potassium chloride product from sintering dust with a purity of 61.03%. However, the wider applications of these products are limited by the not high enough content or the purity of potassium in the products. Moreover, potassium chloride with the higher content or the purity of potassium has a much more wide range of application than potassium sulphate[21], such as in the production of basic or additional fertilizer for some crops in agriculture[22], medical adhibition and as a raw material of diverse non-chlorine potassium fertilizers industry. For these reasons, the recovered potassium product from the BF flue dust or sintering dust is usually in the form of potassium chloride other than potassium sulphate.

Because the BF flue dust usually contains a little amount of cyanide which generated from the coal or the coke in the raw materials in the iron and steel metallurgic process[8, 10], it will deteriorate the quality of potassium chloride. Hence, it is significant to remove the cyanide compounds from the KCl crysta product to meet with the quality standard regulated by China[23.] It was reported that cyanide could be effectively removed from aqueous solution by the adsorption of impregnated activated carbons with silver and nicked distributed on their surface[24]. However, compared with chemical purification, the adsorption purification of cyanide by activated carbon is of high cost and a little complicated in operation. Thus, it is necessary to develop an efficient chemical purification method for the removal of cyanide from potassium chloride to obtain a high purity of the KCl product.

In this paper, a novel and simple process was investigated to recover potassium chloride with high purity and content by using the BF flue dust from Tangshan Iron & Steel Corporation of China as raw material. The basic properties of the BF flue dust and the purity of the recovered product of potassium chloride were analyzed and characterized.

2. Experimental

2.1 Experimental reagents and apparatus

The main experimental reagents and apparatus used in the study were listed in table 1 and table 2, respectively.

Table 1 the main experimental reagents used in the research

Reagent	Specification	Manufacturer
Hydrochloric acid	AR	Hunan Huihong reagent Co., Ltd., China
Sulfuric acid	AR	Hunan Huihong reagent Co., Ltd., China
Sodium carbonate	AR	Changsha Xiangke fine chemical plan, China
EDTA	AR	Tianjin Hengxing Chemical Preparation Co., Ltd., China
Sodium hydroxide	AR	Changsha Xiangke fine chemical plant, China
Potassium dichromate	AR	Tianjin Fengchuan Chemical Reagent Co., Ltd., China
Na-TPB or K-TPB	AR	Shanghai Shanpu Chemical Co., Ltd., China
Magnesium chloride hexahydrate	AR	Tianjin Kermel Chemical Reagent Co., Ltd., China
phenolphthalein	AR	Foshan Chemical Demonstration Plant, China
Ferrous chloride	AR	Tianjin Guangfu Fine Chemical Research

		Institute, China

Table 2 the main experimental apparatus used in the research

Apparatus	Specification	Manufacturer
Magnetism Msier	D-971	Zheng Zhou Great Wall Scientific Industry And Trade Co.,Ltd, China
Electronic Scales	ALC-2100.1	BSISL, Switzerland
Water-circulation Multifunction vacuum Pump	SHB-IIIA	Zheng Zhou Great Wall Scientific Industry And Trade Co.,Ltd. , China
Three-column Centrifuge	SS600mm	Zhangjiagang Juda centrifuge manufacturing plant, China
Vacuum rotatory evaporator	RE-2000A	Shanghai Yarong Biochemistry Equipment Apparatus Co.,Ltd. , China
Thermostatic cooling tank	HC2010	Chongqing Sida Experimental Instrument Co., Ltd. , China
ICP	Perkin-Elmer OPTIMA 3000	Rhys Scientific Ltd. , USA
XRD	D/Max2550-18KW	Rigaku, Japan
Drying oven	101-2AB	Tianjin Taisite Instrument Co.,Ltd. , China
SEM	JEOL 7500F	JEOL, Japan
LG	Mastersizer 2000	Mastersizer, UK

2.2 Physicochemical characterization of the BF flue dust

The samples of the BF flue dust from Tangshan Iron & Steel Corporation were used as raw material in the recovery of potassium chloride. The structural characterization of the BF flue dust was performed by XRD, and the patterns were analyzed using Search-match software. Particle size distributions of the BF flue dust and the product of potassium chloride were measured with a laser granulometer (LG). The contents of the elements of Zn, Fe, Pb, Cu, Na, Ca and Mg in the dust samples were analyzed by inductively coupled plasma (ICP), the detection of total-cyanide was identified by China standard method (GB 7487-1987), and the content of potassium chloride was tested by sodium tetraphenylborate (Na-TPB) chemical method.

2.3 The fundamental of the recovery flow of potassium chloride

As we know, the chloride compounds of potassium, sodium, calcium and magnesium can easily be dissolved in water and the carbonate compounds of Ca, Mg, Fe, Pb and Cu are insoluble in water. Therefore, water-leaching can be used to separate potassium, sodium, calcium and magnesium chloride from the metal elements of Fe, Pb and Cu.

In addition, it is found that both ferro- and ferric-cyanide complexes are insoluble in water and exhibit extreme stability under most environmental conditions[25, 26]. Hence, this property can be used to eliminate cyanide effectively from the leached aqueous solution by adding ferrous chloride into the eluent.

Furtherly, by chemical precipitation via adding sodium- or potassium-carbonate into the eluent, the elements of Ca, Mg, Fe, Pb and Cu will be effectively separated from sodium and potassium in the eluent. Thus, the eluent will be purified for the impure metal elements except sodium. Meanwhile, by adding activated charcoal into the eluent, the chroma and the trace metal such as iron and copper in the eluent will be removed.

Finally, by evaporation and cooling-crystallization, the desired product of potassium chloride will be separated from the sodium chloride in the purified eluent.

The chemical reaction equations for the removal of cyanide and the impure metal elements are shown as follows.

$$6CN^{-} + Fe^{2+} \rightarrow [Fe(CN)_6]^{4-} \qquad (1)$$

$$[Fe(CN)_6]^{4-} + 2\ Fe^{2+} \rightarrow Fe2[Fe(CN)6]\downarrow \qquad (2)$$

$$CO_3^{2-} + M^{2+} \rightarrow MCO_3\downarrow \qquad (3)$$

$$3CO_3^{2-} + 2Fe^{3+} + 3H_2O \rightarrow 2Fe(OH)_3\downarrow + 3CO_2\uparrow \qquad (4)$$

Where M= Ca, Mg, Fe, Pb, Cu and Zn.

According to the above ideologies, a flow chart for the preparation of the potassium chloride product was designed as shown in Figure 1.

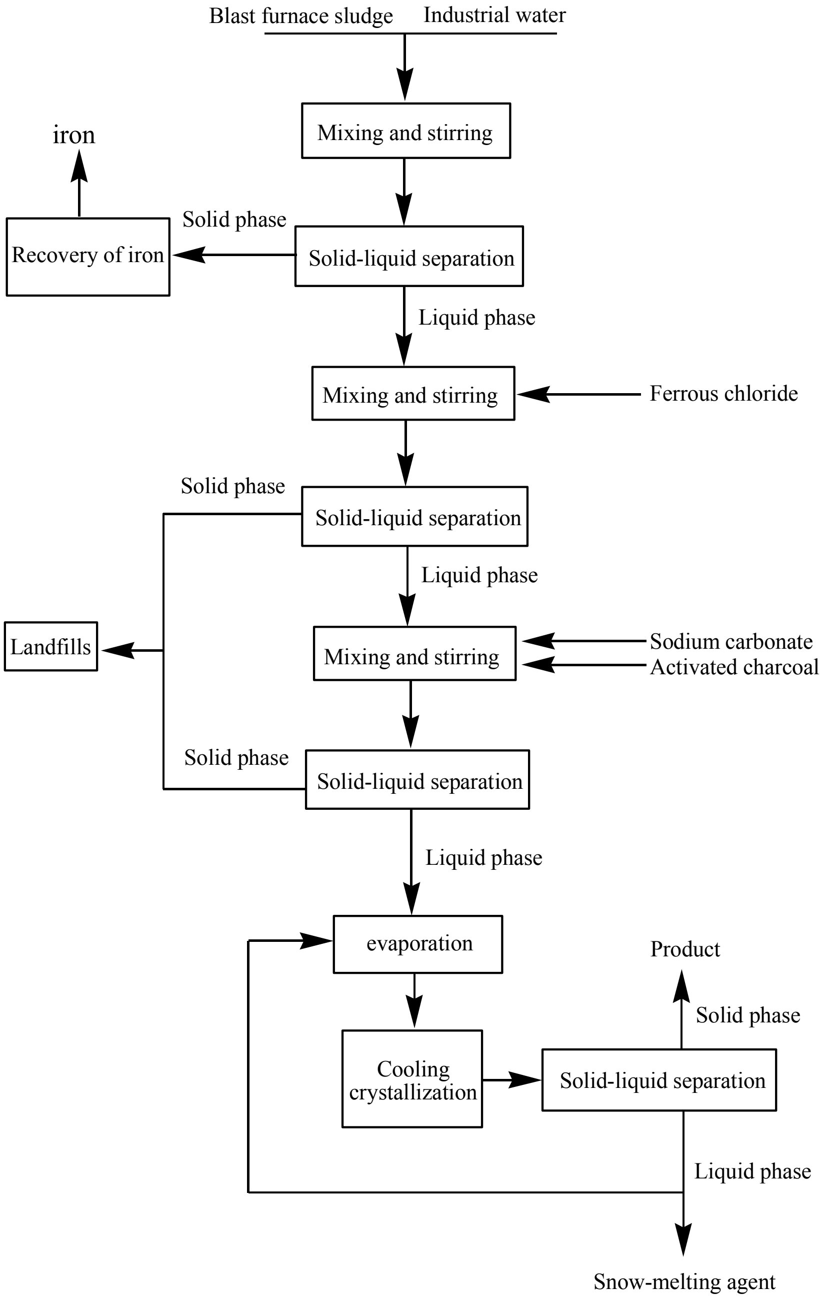


Fig.1 Flow chart of experimental process

2.4 Recovery of potassium chloride from the BF flue dust

All the reagents used in the experiments were of analytical purity without further purification. On the basis of the previous probing experiments, 2.0 kg of the BF flue dust was mixed with 8.0 L of water, stirred with the speed of 200 r/min at room temperature and filtered after 20 min. Then, the obtained eluent was treated by ferrous chloride with 2.5 times of theoretical quantity and stirred for 30 min. After filtration, a certain amount of sodium carbonate was added into the eluent until pH was up to 8.0. Then, activated charcoal of 2.5 gram per liter of the eluent was added for decolorization. The purified eluent was filtered after 25-40 min. Finally, 700 mL of the purified eluent (with KCl of 51.80 g/L or 0.65 mol/L, and NaCl of 4.02 g/L or 0.069 mol/L) was used for vacuum evaporation by rotary evaporator [27, 28] in each run.

When a certain concentration of the condensed eluent was reached, the condensed liquor was cooled in thermostatic cooling tank at 0℃， 5℃ and 10℃ with the stirring speed of 120 r/min for 4 h [29,30], respectively. Then, by filteration, the dried crystal of KCl and the residual mother liquor was analyzed via Na-TPB method to determine the content of potassium chloride. Several runs of the repeat experiments were carried out to ascertain the reliability of the process. The as-prepared products were also identified and characterized by XRD, LG, SEM, and ICP, respectively.

2.5 Characterizations of the KCl product

2.5.1 XRD Characterization

The structural characterization of the KCl product was performed by XRD. The X-ray patterns of the samples which powdered to 300 mesh were acquired in the 2θ-range from 10° to 90° with a scan step of 0.05°/2θ and a fixed counting time of 1 sec for each step. Finally, the patterns were analyzed by Search-match software.

2.5.2 Granulometric analysis

The particle size distributions of the KCl products were measured with a laser granulometer (LG) by dry analysis.

2.5.3 SEM Characterization

The products were examined by a SEM instrument for the granulometric distributions and the particle shape.

2.5.4 ICP analysis

The products were analyzed with an ICP instrument to determine their contents and compositions.

3. Results and discussion

3.1 Physicochemical characterization of the BF flue dust

As shown in Fig.2, the XRD pattern of the BF flue dust sample is presented by five major phases: iron oxide[31], potassium chloride, sodium chloride, magnesium chloride and calcium chloride. The strong diffraction peaks of potassium chloride illustrate its high content in the BF flue dust. In particular, the characteristic peaks of other potassium-containing compounds have not been discovered, probably due to the different compositions of iron ore. These results are identical with the data obtained by ICP analysis. Thus, potassium chloride is the only form of potassium-containing compounds in the BF flue dust, which provides the theoretical foundation for the further research to recover high content potassium chloride from the BF flue dust.

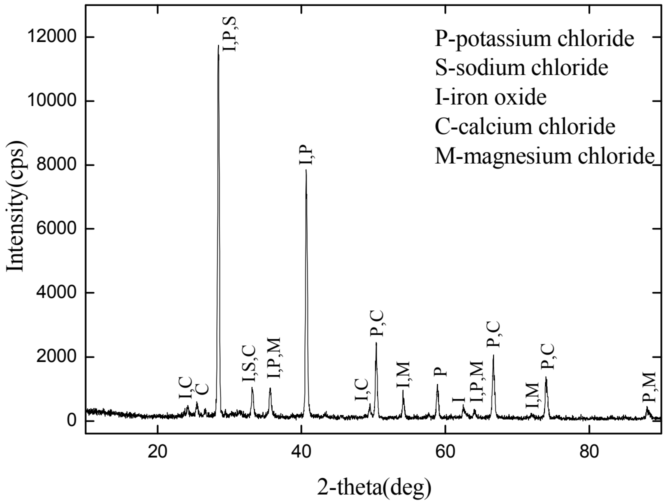


Fig.2 XRD pattern of the BF flue dust

The granulometric distribution analysis of the BF flue dust sample is shown as in Fig.3 and Table 3. It exhibits a wide and non-uniform distribution of particle sizes, possibly owing to the capture technology of the BF flue dust in the ferrous metallurgy. The mean particle size P50 (the mass percentage of the particles at 50%), P10 and P90 of the BF flue dust is 37.47 μm, 6.27 μm and 254.64 μm, respectively. Combined with the small specific surface area of the dust which shown in Table 3, a conclusion can be draw that such granulometric distribution of the BF flue dust is beneficial to the leaching of soluble potassium compounds without the additional of dispersant or surfactant.

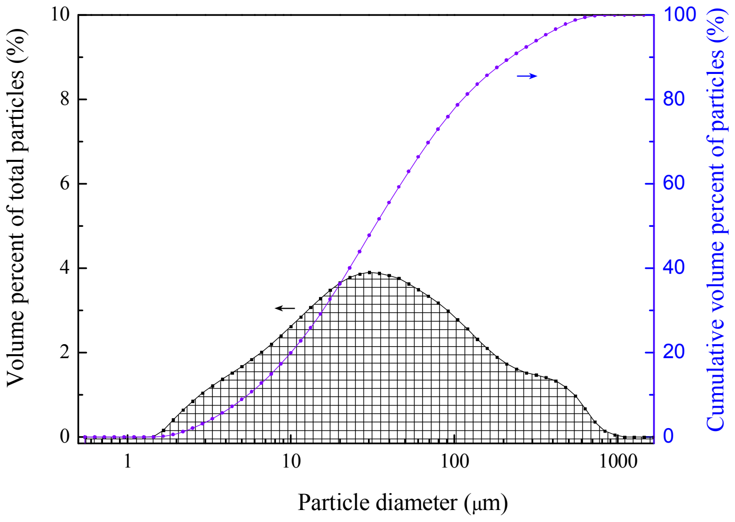


Fig.3 Granulometric distribution of the BF flue dust

Table 3 The Granulometric characteristic parameters of the BF flue dust

Granulometric Characteristic parameter	Value
Median diameter , μm	6.63
Volume mean diameter, μm	91.44
Superficial area mean diameter, μm	16.87
Specific surface area, m^2/g	0.36

The element contents of the BF flue dust by chemical analysis combined with ICP method were demonstrated in Table 4. The results showed that the metal content in the BF flue dust was 41.00% of Fe, 20.72% of K and 4.39% of Mg, respectively, including a small amount of Pb(0.65%), Cu(0.12%), Zn(0.03%), Ca(0.51%), Na(0.55%) and Total-cyanide(0.03%). This result indicates that the BF flue dust is a ferric oxide mixture with a high content of potassium, implying it is of great potential values of recovering.

Table 4 The main metal element constituents of the BF flue dust

Element	TFe	K	Pb	Cu	Zn	Ca	Na	Mg	Total-cyanide
Content, wt%	41.00	20.72	0.65	0.12	0.03	0.51	0.55	4.39	0.03

3.2 The effect of operation conditions on the KCl recovery process

3.2.1 The effect of the dosage of activated charcoal on decolorization

The dosage of activated charcoal is a key factor in the adsorption for the decolorization of the eluent. The relationship between the dosage of activated charcoal and the chroma of the eluent was studied and the result was shown as in Fig.4. It can be found that the decolorization efficiency becomes better with the increase of the amount of activated carbon. Particularly, when 2.00g /L of activated charcoal is used to dispose the eluent, the chroma of the eluent decreases from 170 °to 4 ° and the removal rate of chroma is up to 97.65%, possiblely owing to the increase of active molecular particles in the sorbent. Moreover, when the dosage of activated charcoal is increased to 2.50g /L, the chroma in the eluent reduces to near 0. Therefore, 2.50g/L was chosen as the optimum parameter of the dosage of activated charcoal in decolorization.

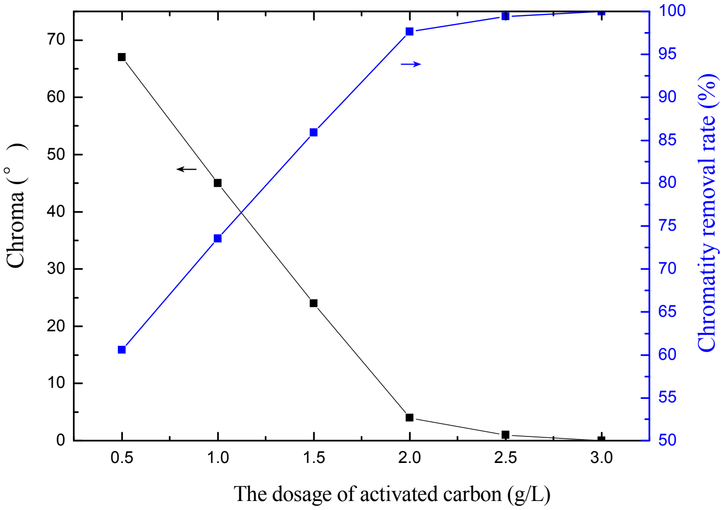


Fig.4 the relationship between the dosage of activated charcoal and the chroma (Experiment conditions: decolorization time=30 min; agitation speed=120 r/min; temperature=room temperature)

3.2.2 The effect of time on decolorization

Decolorization time is also a significant factor which has an important influence on the adsorption effect of activated charcoal. As shown in Fig.5, the chroma decreases with the increase of the decolorization time. The chroma of the eluent declines from 170 °to 17° at 25 min of adsrorption time. Correspondingly, the chroma removal rate reaches to 90%. Whereas at 35 min of adsrorption time, the removal efficiency of the chroma reaches to the highest value of 90.59%. Thus, 30 min was chosen as the proper decolorization time from the viewpoint of cost and the treatment capacity in industrial practice.

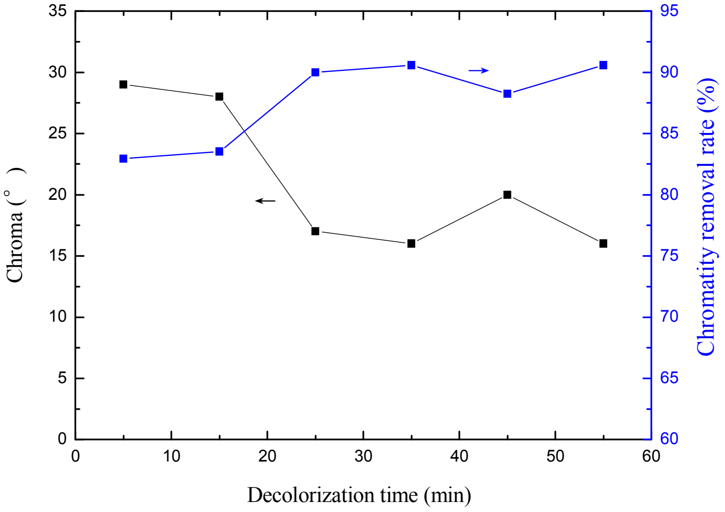


Fig.5 the relation between decolorization time and chroma

(Experiment conditions: dosage of activated charcoal=2.00g/L; agitation speed=100r/min; temperature=room temperature)

3.2.3 The effect of agitation speed of on decolorization

The speed of the agitator is a non-ignorable factor which does impact on the dosage of activated charcoal. As shown in Fig.6, the whole tendency of the chroma in the eluent decreases with the increase of the stirring speed of the agitator. The residual chroma in the eluent markedly decreases from 170° to 15° at the stirring speed of 80 r/min and the removal efficiency of the chroma reaches to 91.18%, probably due to the increase of the turbulence and mixing degree. Therefore, 80 r/min was selected as the suitable agitation speed.

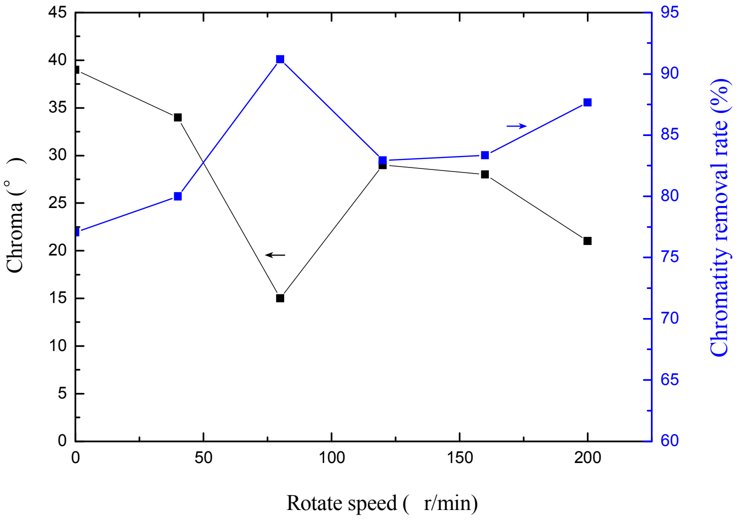


Fig.6 the relation between the stirring speed and the chroma

(Experiment conditions: dosage of activated charcoal=2.00 g/L; decolorization time= 5min; temperature=room temperature)

To validate the reliability of the selected operation conditions for the KCl recovering process, a further experiment was conducted under the conditions of the dosage of activated charcoal at 2.50 g/L, decolorization time at 30 min, agitation speed at 80 r/min and the temperature of 25℃. The result shows that the chroma of the eluent decreases from 170 °to 2 ° with a removal efficiency of 98.82%, indicating that the selected operation conditions is befitting to purify the chroma of the eluent.

After decolorization and purification, the element contents in the purified eluent were analyzed by ICP with other chemical methods. The results are shown as in Table 5. Table 5 indicates that the purified eluent is mainly composed of K with few of Na, Ca and Mg, and the elements of Fe, Pb, Cu, Zn and the cyanide (CN) are not detected in the eluent, manifesting that the impurities are effectively removed by the separation process.

Table 5 The main element contents in the purified eluent

Element	Fe	K	Pb	Cu	Zn	Ca	Na	Mg	CN
Concentration, g/L	Not detected	50.69	Not detected	Not detected	Not detected	0.08	0.03	0.55	Not detected

3.2.4 The effect of temperature on the KCl crystallization process

In the KCl crystallization process, the influences of temperature on the purity and the yield of the KCl crystal are shown as in Fig.7.

Fig.7 reveals that the potassium chloride purity of the crystal increases with the increase of the cooling crystallization temperature, whereas the yield of the KCl crystal decreases with the increase of the temperature. Therefore, to get more potassium chloride product from the eluent, the cooling crystallization temperature should be lower. Contrarily, the cooling crystallization temperature must be higher for the purpose of obtaining a high content of potassium chloride. Aimed at getting a higher content of potassium chloride to suffice the quality demand regulated by the KCl product market, a higher cooling crystallization temperature at the range of 10℃ to 15℃ may be of feasibility, but the yield of the KCl product will be sacrificed a little.

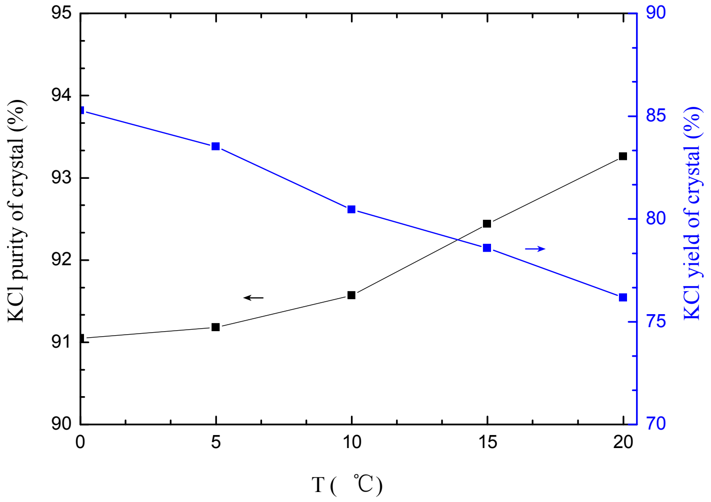


Fig.7 the influence of crystallization temperature on the KCl purity and yield (Experiment conditions: mass distribution coefficient= 2.27; initial KCl crystallization concentration=1.29 mol/L or 96.2 g/L; crystallization time=4.0 h)

3.2.5 The effect of KCl crystallization concentration on the crystal recovery

The influence of the initial KCl crystallization concentration in the condensed eluent on the purity and the yield of the product crystal are demonstrated as in Fig.8.

Fig.8 indicates that, at a certain cooling crystallization temperature, the potassium chloride purity of the product crystal decreases with the increase of the initial crystallization concentration of KCl in the condensed eluent, whereas for the yield, it rises up. This implies that the content of sodium chloride in the crystal product will be increased with the increase of the initial KCl crystallization concentration, which will leads to the deterioration of the crystal product quality.

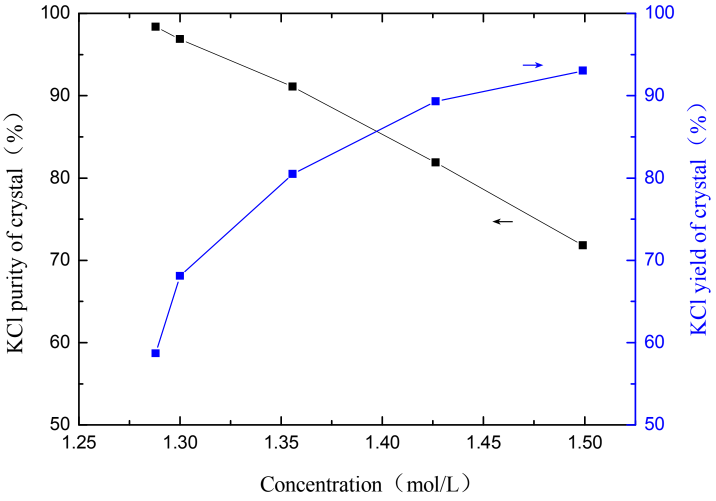


Fig.8 the influence of KCl crystallization concentration on the crystal purity and yield (Experiment conditions: mass distribution coefficient= 2.27; crystallization temperature=10℃; crystallization time=4.0 h)

3.3 Characterizations and Analysis of the KCl product

3.3.1 XRD results of the KCl products

The potassium chloride crystals obtained at different crystallization temperature with the distribution coefficient (the mass of KCl in the crystal to that in the mother liquor) of 2.27 and the initial KCl crystallization concentration of 1.33 mol/L or 99.2 g/L, were characterized by XRD and the results were shown as in Fig.9.

Combined with the standard XRD spectrum of potassium chloride and sodium chloride, it can be seen from Fig.9 that the characteristic diffraction peaks at 2θ=28.38 °, 40.47 °, 50.15 °, 58.61 °, 66.35 °, 73.66 ° and 87.66 ° are ascribed to potassium chloride. Whereas for the characteristic diffraction peaks at 2θ = 24.24 °, 31.69 °, 45.39 °, 66.39°, 75.19 ° and 83.88 °, they are ascribed to sodium chloride. Hence it can be draw a conclusion that the recovered products contain a great amount of potassium chloride with very few amount of sodium chloride or other impurities.

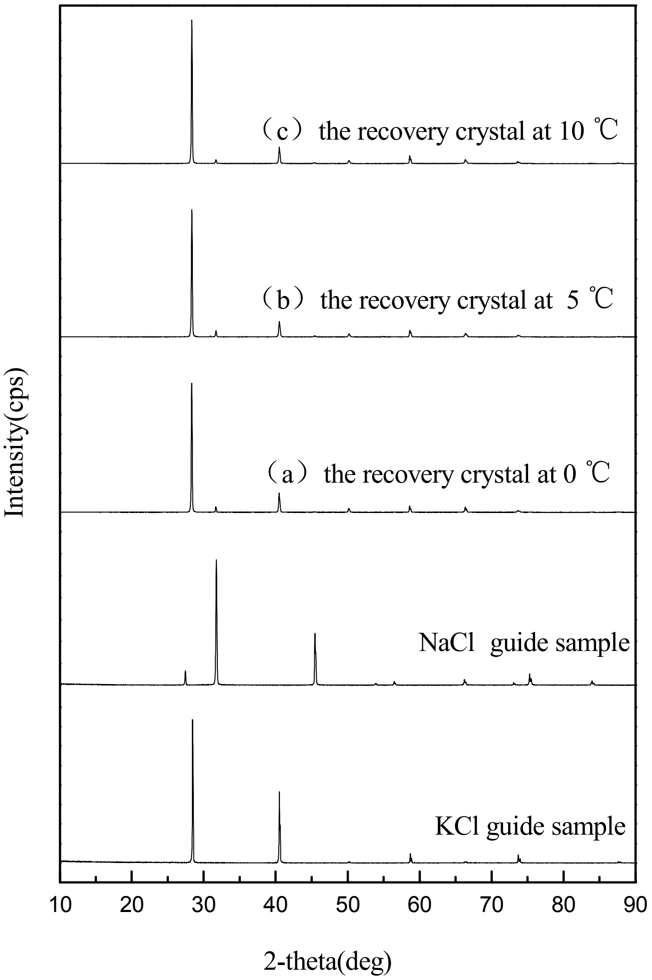


Fig.9 XRD patterns of the recovery crystals, NaCl and KCl guide sample

A further analysis to the recovered crystals was conducted by ICP combined with Na-TPB or K-TPB method and the results are shown as in Table 6. From Table 6, it can be seen that the recovered crystal is mainly composed of potassium chloride（97.08%）with very few amount of sodium chloride(1.78%) and other impurities (0.08% of Ca, 0.04% of Mg) by ICP method. Whereas by chemical analysis method for the same sample, it reveals that the recovered crystal is compose of 96.77% of potassium chloride, 1.91% of sodium chloride, 0.10% of Ca and 0.08% of Mg. Therefore, it can be concluded that the recovery crystal product is of high content and purity of KCl, Na- or K-TPB method is of similar accuracy compared with ICP method, and the quality of the KCl product is satisfactory to the demand of national product standard of China regulated by GB6549-2011.

Table 6 The analysis results of the product by ICP and Na-, K-TPB methods

Analysis method	KCl	NaCl	Ca	Mg	Ca+Mg
ICP, %	97.08	1.78	0.08	0.04	0.12*
Chemical Analysis	96.77 (Na-TPB)	1.91 (K-TPB)	0.10 (ICP)	0.08 (ICP)	0.18*
GB6549-2011[23]	≥91.94	≤2.00	≤0.5	≤0.4	≤0.2

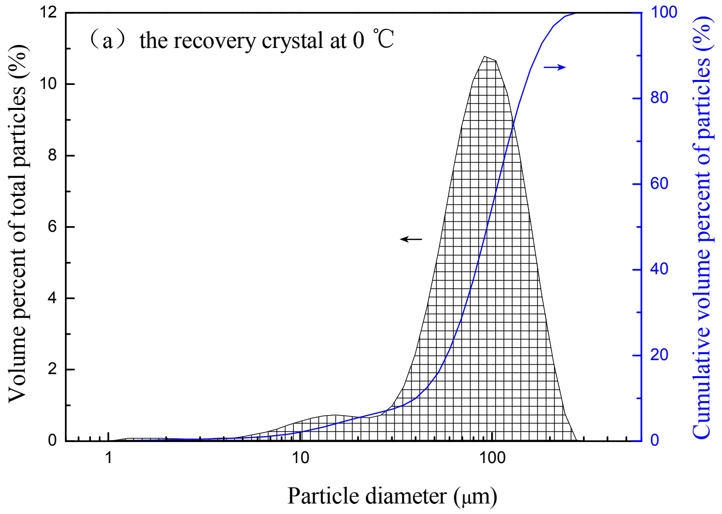
Where the "*" in Tab.5 represents the value from calculation.

3.3.2 Granulometric distributions of the KCl products

The granulometric distributions of the crystal products obtained at cooling crystallization temperature of 0□, 5□ and 10□, correspondingly with the distribution coefficients of 2.27, 2.52 and 2.36 are demonstrated in Fig.10, respectively.

Fig.10 reveals that the mean particle size of P50, P10 and P90 of the product is 94.29 μm, 39.91 μm and 169.48 μm at cooling crystallization temperature of 0℃, 98.58 μm, 38.46 μm and 178.82 μm at 10℃ and 107.74 μm, 44.18 μm and 194.59 μm at 15℃, respectively.

From Fig.10, it also can be seen that all the particles of the crystals obtained at different cooling crystallization temperature exhibit a narrow size distribution, indicating that the particles have a considerable uniform size and the crystal product is of a good extrinsic quality[32].



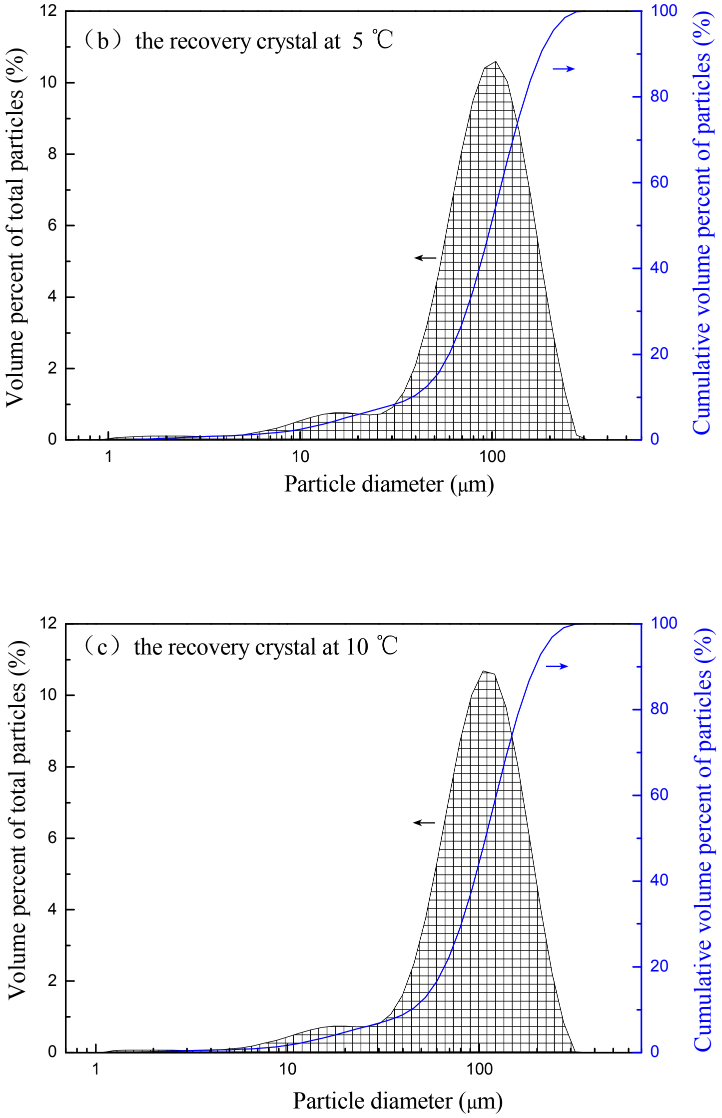


Fig.10 Granulometric distributions of the products at cooling crystallization temperature of (a) 0□, (b) 5□ and (c) 10□

3.3.3 SEM results of the KCl products

The SEM diagrams of the products at crystallization temperature of 0□, 5□ and 10□ are shown as in Fig.11, respectively. The SEM characterization testifies that the principal crystalline forms of the products at different temperature are all cubic and the size of the particles is comparatively homogeneous. Interestingly, it can be observed from the figure that the crystals become larger and larger with the rising of the crystallization temperature. It was reported that the products with small particle size would be easy to consolidation, which would affected the stability and quality of the product[33]. Therefore, the cubic potassium chloride crystal with a bigger particle size is beneficial to the stabilization of the products[34]. In conclusion, crystallization process operated at a higher temperature level is of advantages to the apparent quality of the KCl products.

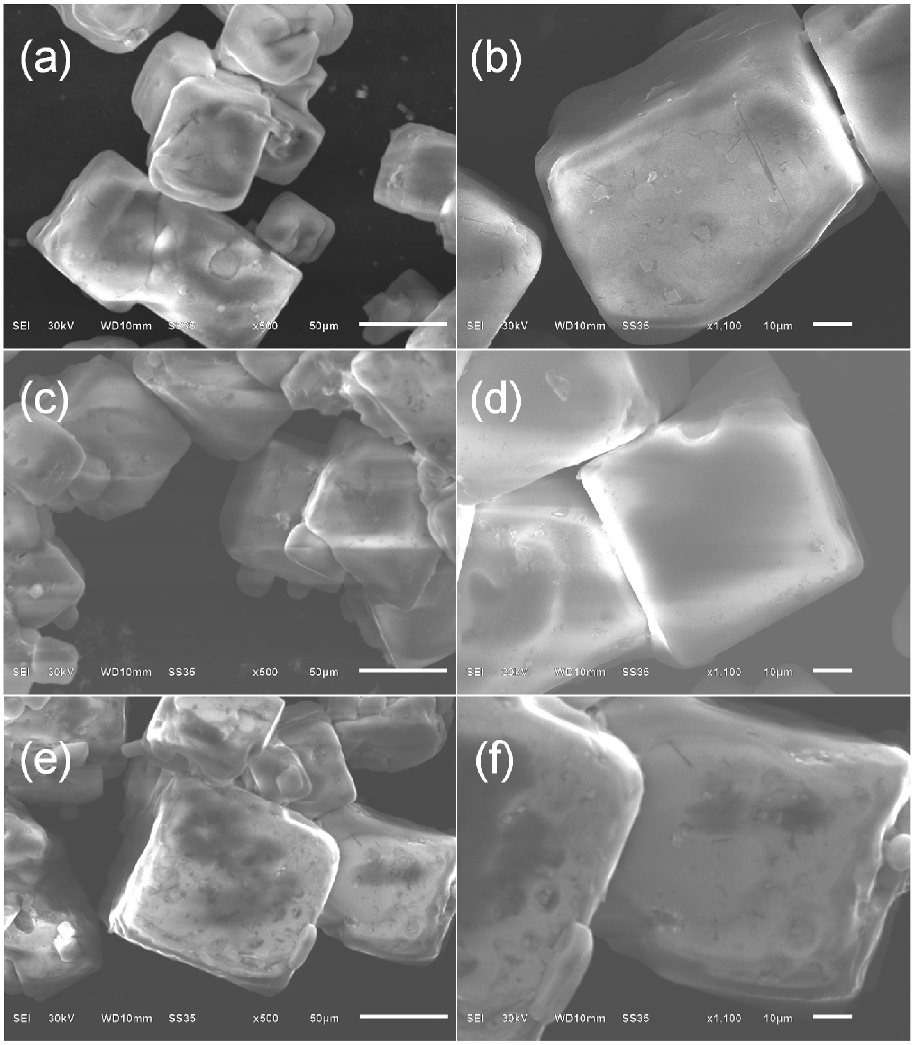


Fig.15 SEM images of the products at cooling crystallization temperature of (a) and (b): 0℃; (c)-(d): 5℃ and (e)-(f):10℃

4. Conclusions

In brief, a simple, efficient, economic and environment-friendly recovery process of high content potassium chloride from the BF flue dust is developed. This process is mainly composed of water-leaching, decolorization, purification, vacuum evaporation and cooling crystallization.

The physicochemical characterization revealed that the BF flue dust contained a high content of potassium chloride which being of recovery value.

The effects of the dosage of activated charcoal, the adsorption time and the agitation speed on the decolorization efficiency were investigated. By single-factor experiment, the appropriate operation conditions for the decolorization of the eluent from the water-leaching of the BF flue dust were selected as follows: 2.50 g/L of activated charcoal, 30 min of adsorption time and 80 r/min of stirring speed. Under these conditions, the removal efficiency of the chroma in the eluent was 98.82%. By a further chemical precipitation of sodium carbonate, the impure elements of Ca, Mg, Fe, Pb and Cu in the eluent were effectively separated from K and Na.

In the KCl crystallization process, the influence of temperature and the initial KCl crystallization concentration of the condensed eluent on the purity and the yield of the KCl crystal product were studied. The results showed that the cooling crystallization temperature at 10℃ to 15℃ was of feasibility, and the purity of the KCl crystal product decreased whereas the yield increased with the increase of the initial crystallization concentration of the KCl in the condensed eluent.

The KCl crystal products obtained at different cooling crystallization temperatures and mass distribution coefficients were analyzed by ICP or chemical methods and characterized by XRD, SEM and LG, respectively. The qualitative XRD combined with the quantitative ICP or chemical analysis results showed that, the recovered KCl products contained a great amount of potassium chloride with a purity of greater than 96.00% , and very few amount of sodium chloride or other impurities were detected in the products, implying that it is satisfactory to the national product standard of China regulated by GB6549-2011. The SEM and LG analysis revealed that the KCl crystal product exhibited a narrow particle size distribution with P50, P10 and P90 of 94.29-107.74 μm, 38.46-44.18 μm and 169.48-194.59 μm, respectively, indicating that the KCl crystal products have a good extrinsic quality, and crystallization process operated at a higher temperature level is beneficial to the stabilization and the apparent quality of the products.

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