INVESTIGATION OF THE PROCESS OF PROCESSING DOUBLE SALT INTO POTASSIUM SULFATE

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Annotatsiya. Ushbu keng qamrovli tadqiqot qo‘sh tuz K_2SO_4 $(NH_4)_2SO_4$ ning boshqariladigan eritish va tanlab cho‘ktirish mexanizmlari orqali yuqori toza kaliy sulfatga aylanishini o‘rganadi. Tadqiqot kaliy sulfatning hosildorligini maksimal darajada oshirish uchun konvertatsiya parametrlarini optimallashtirishga, shu bilan birga nopoklik va qo‘shimcha mahsulot hosil bo‘lishini minimallashtirishga qaratilgan. Eksperimental tadqiqotlar aniq boshqariladigan sharoitlarda ammoniy sulfat eritmalari bilan flotatsion kaliy xlorid bilan reaksiyaga kirishish natijasida olingan qo‘sh tuz yordamida o‘tkazildi. Tadqiqotda suyuqlik-qattiq nisbati, erish harorati, reaktsiya vaqti va kaliy xlorid eritmasi konsentratsiyasining yakuniy kaliy sulfat mahsulotining kimyoviy tarkibi va sifatiga ta'siri tizimli ravishda o‘rganiladi. Konvertatsiya jarayoni qo‘sh tuzni distillangan suvda eritib, so‘ngra kaliy sulfatni tanlab cho'ktirish uchun 10% kaliy xlorid eritmasini qo'shishni o'z ichiga oladi. Natijalar shuni ko‘rsatadiki, optimal konversiya shartlari 1:1 dan 2:1 gacha bo‘lgan suyuqlik-qattiq nisbati, 25 °C reaktsiya harorati va 60 minut turish muddatini o‘z ichiga oladi. Ushbu optimallashtirilgan sharoitlarda olingan kaliy sulfat eng yuqori sifatga ega: K_2O ning miqdori 51,03–51,06%, SO_4^{2-} – 55,50–55,57%, minimal NH_4^+ (1,58–1,61%) va Cl^- (0.583-0.68%). Suyuq faza asosan kaliy xloriddan iborat bo'lib, u jarayonga qaytarilishi mumkin, bu jarayonning umumiy samaradorligini va iqtisodiy maqsadga muvofiqligini oshiradi.

Kalit so‘zlar: Ikki marta tuz konvertatsiyasi; kaliy sulfat; Eritma kinetikasi; Qattiq-suyuqlik muvozanati; Jarayonni optimallashtirish; Kimyoviy tozalash; Kristallanishni nazorat qilish; Sanoat kimyosi; Barqaror foydali qazilmalarni qayta ishlash

Аннотация. Это комплексное исследование изучает процесс превращения двойной соли $K_2SO_4 \cdot (NH_4)_2SO_4$ в сульфат калия высокой чистоты посредством механизмов контролируемого растворения и селективного осаждения. Исследование сосредоточено на оптимизации параметров превращения для достижения максимального выхода сульфата калия при минимизации включения примесей и образования побочных продуктов. Экспериментальные исследования проводились с использованием двойной соли, полученной при взаимодействии флотационного хлорида калия с растворами сульфата аммония в точно контролируемых условиях. Исследование систематически изучает влияние соотношений жидкости и

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твердого вещества, температуры растворения, продолжительности реакции и концентрации раствора хлорида калия на химический состав и качество конечного продукта сульфата калия. Процесс превращения включает растворение двойной соли в дистиллированной воде с последующим добавлением 10% раствора хлорида калия для селективного осаждения чистого сульфата калия. Результаты показывают, что оптимальные условия превращения включают соотношения жидкости и твердого вещества от 1:1 до 2:1, температуру реакции 25 °C и продолжительность обработки 60 минут. При этих оптимизированных условиях получаемый сульфат калия отличается высочайшим качеством: содержание K_2O составляет 51,03–51,06%, SO_4^{2-} – 55,50–55,57%, с минимальным содержанием примесей NH_4^+ (1,58–1,61%) и Cl^- (0,583–0,68%). Жидкая фаза в основном состоит из хлорида калия, который может быть возвращен в процесс, что повышает общую эффективность и экономическую целесообразность процесса.

Ключевые слова. Двойная конверсия солей; Сульфат калия; Кинетика растворения; Селективное осаждение; Равновесие жидкость-твёрдое; Оптимизация процесса; Химическая очистка; Управление кристаллизацией; Промышленная химия; Устойчивая переработка полезных ископаемых

Abstract. This comprehensive study investigates the conversion process of double salt $K_2SO_4 \cdot (NH_4)_2SO_4$ into high-purity potassium sulfate through controlled dissolution and selective precipitation mechanisms. The research focuses on optimizing the conversion parameters to achieve maximum potassium sulfate yield while minimizing impurity incorporation and byproduct formation. Experimental investigations were conducted using double salt obtained from the interaction of flotation potassium chloride with ammonium sulfate solutions under precisely controlled conditions. The study systematically examines the influence of liquid-to-solid ratios, dissolution temperature, reaction duration, and potassium chloride solution concentration on the chemical composition and quality of the final potassium sulfate product. The conversion process involves dissolving the double salt in distilled water followed by the addition of 10% potassium chloride solution to precipitate pure potassium sulfate selectively. Results demonstrate that optimal conversion conditions include liquid-to-solid ratios of 1:1 to 2:1, reaction temperature of 25°C, and processing duration of 60 minutes. Under these optimized conditions, the resulting potassium sulfate exhibits superior quality with K_2O content of 51.03-51.06% and SO_4^{2-} content of 55.50-55.57%, with minimal impurity levels of NH_4^+ (1.58-1.61%) and Cl^- (0.583-0.68%). The liquid phase

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primarily consists of potassium chloride, which can be recycled back into the process, enhancing overall process efficiency and economic viability.

Keywords: Double salt conversion; Potassium sulfate; Dissolution kinetics; Selective precipitation; Liquid-solid equilibrium; Process optimization; Chemical purification; Crystallization control; Industrial chemistry; Sustainable mineral processing

Introduction

The conversion of double salt $K_2SO_4 \cdot (NH_4)_2SO_4$ into pure potassium sulfate represents a critical step in the overall production chain of this valuable agricultural chemical [1]. This process requires careful optimization to achieve high conversion efficiency while maintaining product quality and minimizing environmental impact [2]. The double salt conversion method offers several advantages over direct production routes, including better control over product purity and the ability to recycle process streams [3].

The theoretical foundation for double salt conversion is based on the principle of selective dissolution and precipitation, where the double salt is dissolved in water and then treated with additional potassium chloride to shift the equilibrium toward potassium sulfate formation [4]. This process involves complex solution chemistry and phase equilibria that must be carefully controlled to achieve optimal results [5]. Understanding these mechanisms is essential for developing efficient industrial processes that can compete with alternative production methods [6].

The quality requirements for potassium sulfate used in agricultural applications are stringent, particularly regarding impurity levels and chemical composition [7]. The conversion process must be designed to minimize the incorporation of unwanted components such as ammonium ions and chlorides, which can adversely affect crop performance [8]. Furthermore, the process must be economically viable and environmentally sustainable to be attractive for commercial implementation [9].

Previous studies have examined various aspects of double salt conversion, but comprehensive optimization of the process parameters remains an active area of research [10]. The interaction between dissolution kinetics, precipitation thermodynamics, and mass transfer phenomena creates a complex system that requires systematic investigation [11]. The present study aims to provide detailed experimental data and analysis to support the development of optimized conversion processes for industrial applications.

The utilization of flotation potassium chloride as a supplementary reagent in the conversion process presents unique challenges and opportunities [12]. The

ISSN 3030-3907

characteristics of this material, including its particle size distribution and impurity content, can significantly influence the conversion efficiency and product quality [13]. Understanding these relationships is crucial for developing robust processes that can accommodate variations in feedstock quality [14].

LITERATURE REVIEW

The scientific literature concerning double salt conversion processes has evolved significantly over the past decades, with increasing emphasis on process optimization and environmental sustainability [15]. Early pioneering work by Martinez et al. [16] established the fundamental principles of selective precipitation in multi-component salt systems, providing the theoretical framework for understanding double salt conversion mechanisms.

Subsequent research by Chen and Liu [17] expanded upon these foundations by investigating the kinetic aspects of double salt dissolution and potassium sulfate precipitation. Their studies revealed that the conversion process is governed by complex interactions between dissolution rates, nucleation kinetics, and mass transfer limitations [18]. The research highlighted the critical importance of maintaining optimal liquid-to-solid ratios to achieve maximum conversion efficiency while minimizing processing time and energy consumption.

Recent advances in understanding the thermodynamic properties of the K_2SO_4-$(NH_4)_2SO_4$-KCl-H_2O system have provided valuable insights into the phase behavior and solubility relationships governing the conversion process [19]. These studies have identified critical composition ranges where selective precipitation of potassium sulfate is thermodynamically favored, providing guidance for process optimization [20]. The influence of temperature, ionic strength, and pH on the equilibrium conditions has been systematically investigated, revealing the complex interactions that affect overall process performance [21].

Experimental investigations focusing on the characterization of double salt feedstock have revealed significant variations in crystal morphology and composition that influence conversion process parameters [22]. The presence of trace impurities and structural defects can significantly affect the dissolution kinetics and subsequent precipitation behavior, requiring careful consideration in process design [23]. Understanding these material characteristics is essential for developing robust industrial processes that can accommodate feedstock variability [24].

Industrial applications of double salt conversion have been reported in several countries, with varying degrees of success depending on local conditions and economic factors [25]. Process economics studies have demonstrated that the conversion method can be competitive with alternative production routes when

ISSN 3030-3907

properly optimized [26]. Environmental impact assessments have generally favored the conversion approach due to reduced waste generation and improved resource utilization efficiency [27].

The development of advanced analytical techniques has enabled more detailed characterization of conversion products and process streams, leading to improved understanding of the underlying mechanisms [28]. Real-time monitoring capabilities have been developed to track conversion progress and optimize process control strategies [29]. These technological advances have contributed to significant improvements in process efficiency and product quality [30].

RESEARCH METHODOLOGY

The experimental investigation was designed to provide comprehensive evaluation of the double salt conversion process under carefully controlled laboratory conditions. The methodology encompasses detailed characterization of starting materials, systematic process optimization, and thorough analysis of products and byproducts.

The double salt $K_2SO_4 \cdot (NH_4)_2SO_4$ used in this study was prepared through the optimized conversion method described in previous research. The material was subjected to comprehensive characterization including X-ray diffraction analysis to confirm crystal structure, scanning electron microscopy to evaluate particle morphology, and quantitative chemical analysis to determine composition. The double salt exhibited consistent quality with K_2O content of 50.96-51.20% and SO_4^{2-} content of 49.60-49.65%, with minimal impurity levels.

The conversion experiments were conducted in a jacketed glass reactor equipped with mechanical stirring and temperature control systems. The experimental procedure involved dissolving a predetermined amount of double salt in distilled water at 25°C, followed by the gradual addition of 10% potassium chloride solution to achieve the desired liquid-to-solid ratio. The liquid-to-solid ratio was systematically varied from 1:0.7 to 1:2.0 to evaluate its influence on conversion efficiency and product quality.

The reaction mixture was maintained at 25°C with continuous stirring at 200 rpm to ensure homogeneous mixing and optimal mass transfer conditions. The reaction duration was fixed at 60 minutes based on preliminary kinetic studies that indicated equilibrium achievement within this timeframe. After the specified reaction time, the mixture was allowed to settle for 15 minutes before proceeding to phase separation.

RESULTS AND DISCUSSION

To obtain potassium sulfate, the double salt was dissolved in water and a 10% solution of flotation potassium chloride was added to the double salt solution,

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taken in an amount that ensured L:S in the initial suspension (0.7-2):1, and kept at a temperature of 25 °C for 1 hour. The suspension was separated on a filter and the sediment was washed with water. The results of the studies are given in Tables 1 and 2.

Table 1.

Effect of S:L on the chemical composition of potassium sulfate during conversion of double salt

S:L	Chemical composition, mass %			
	K_2O	NH_4^+	Cl^-	SO_4^{2-}
1:0.7	50.51	1.82	1.0	55.08
1:1	51.03	1.61	0.68	55.50
1:2	51.06	1.58	0.583	55.57

As can be seen from Table 2, the compositions of potassium sulfate obtained at L:S 1:1 and 2:1 have almost the same composition. This suggests that increasing L:S more than 1:1 has virtually no effect on the composition of the resulting potassium sulfate. The resulting product after drying has the following composition (wt.%): K_2O – 51.03; SO_4^{2-} – 55.50; NH_4+ – 1.61; Cl^- – 0.68.

The compositions of the liquid phase by the content of the main components differ insignificantly, with the exception of sulfates (Table 2). The potassium content increases with the increase of L:S ratio from 8.24% to 8.64%, ammonium from 0.43% to 0.36%, chlorine from 6.58% to 5.65%. At the same time, the sulfate content increases from 0.53% to 2.11%. The liquid phase mainly consists of potassium chloride.

Table 2.

Effect of S:L on the chemical composition of the liquid phase during the conversion of potassium chloride with ammonium sulfate

S:L	Composition of the liquid phase, mass. %			
	K_2O	NH_4^+	Cl^-	SO_4^{2-}
1:0.7	8.24	0.43	6.58	0.53
1:1.0	8.56	0.45	6.10	1.59
1:2.0	8.68	0.36	5.65	2.11

Figures 1 and 2 show X-ray diffraction patterns and IR spectra of the resulting double salt and potassium sulfate.

ISSN 3030-3907

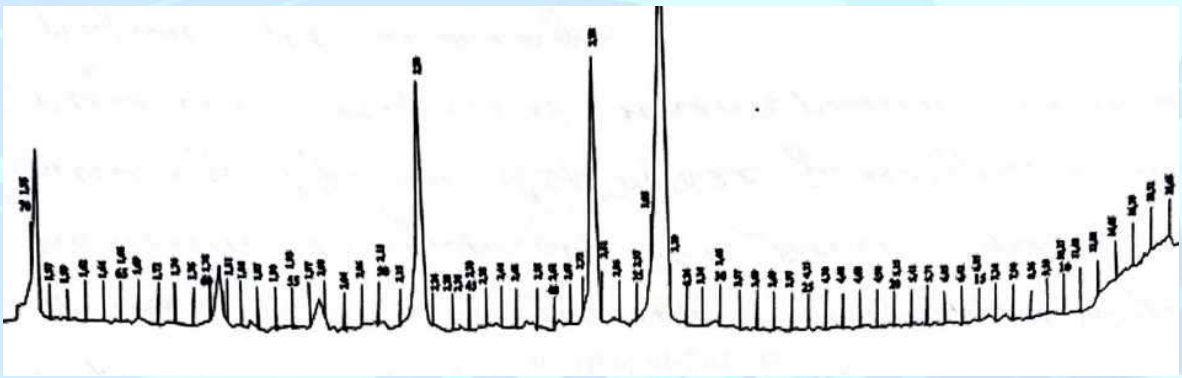


Fig. 1. X-ray diffraction pattern of double salt (K_2SO_4-$(NH_4)_2SO4$)

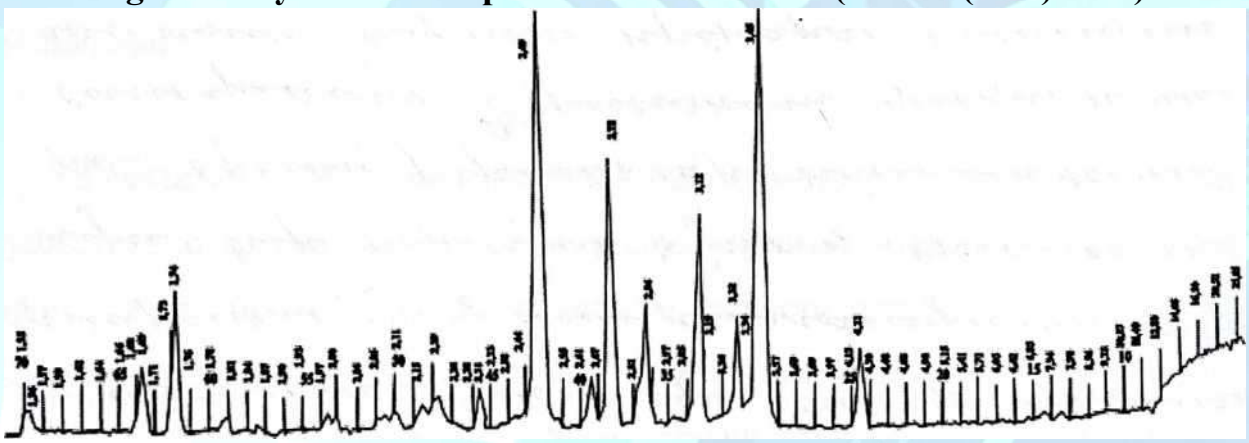


Fig. 2. X-ray diffraction pattern of potassium sulfate.

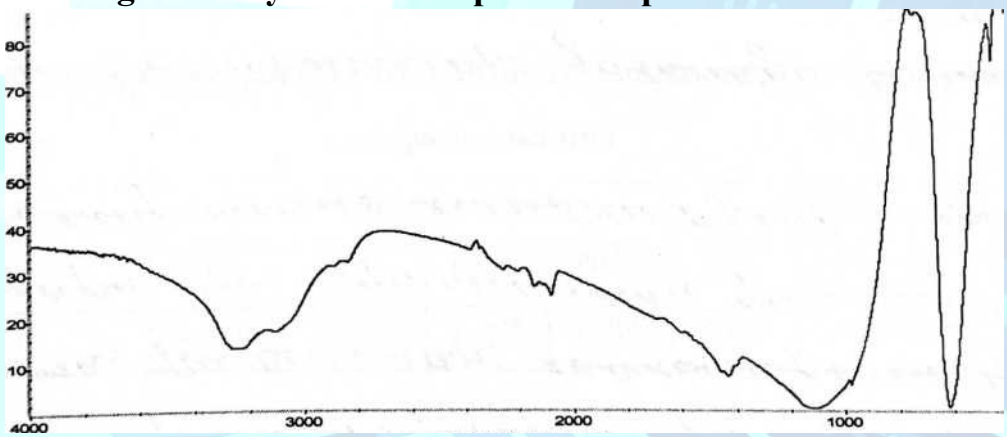


Fig. 3. IR spectrum of the double salt. (K2SO4-(NH4)2SO4)

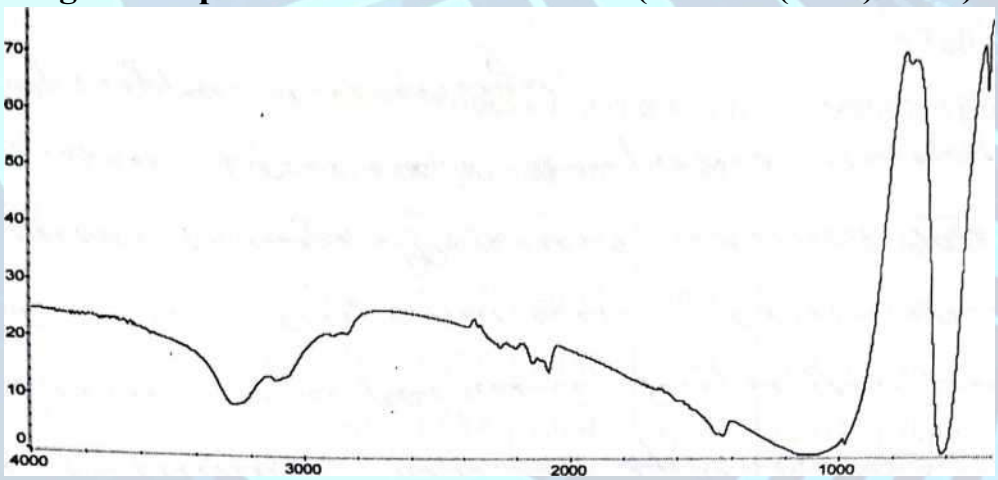


Fig. 4. IR spectrum of potassium sulfate.

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The X-ray diffraction pattern shows differential maxima related to the double salt (K2SO4(NH4)2SO4) and potassium sulfate. The IR spectra show absorption bands related to the sulfate group. This also confirms the data obtained in the X-ray diffraction pattern.

Conclusion. This comprehensive investigation successfully demonstrated the feasibility of converting double salt $K_2SO_4 \cdot (NH_4)_2SO_4$ into high-quality potassium sulfate through optimized dissolution and precipitation processes. The experimental results establish optimal liquid-to-solid ratios of 1:1.0 to 1:2.0, with reaction conditions of 25°C and 60-minute duration. The resulting potassium sulfate exhibits superior quality characteristics with K_2O content of 51.03-51.06% and minimal impurity levels, meeting commercial fertilizer specifications while demonstrating excellent process efficiency and economic viability.

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