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Rheological Properties Of Solutions In The Production Of Potassium Sulfate

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Abstract
This study investigates the rheological properties and phase separation characteristics of solutions during potassium sulfate production through the conversion process involving potassium chloride and ammonium sulfate. The research focuses on the clarification kinetics, filtration rates, and solid-liquid separation efficiency in multi-stage conversion processes. Experimental investigations were conducted using graduated cylinders and Buchner funnel filtration systems to evaluate settling velocities and filtration characteristics. Results demonstrate that suspension clarification on the second stage reaches maximum values of 66.25% within 95 seconds, while filtration rates vary from 1000-1200 kg/m²·h for the first stage to 2100-2300 kg/m²·h for the second stage. The study reveals that temperature elevation from 20°C to 60°C and molar ratio adjustments from 1:1 to 1:2 significantly influence filtration efficiency. These findings provide crucial insights for optimizing industrial potassium sulfate production processes through enhanced understanding of suspension rheology and phase separation mechanisms.
Keywords: potassium sulfate, rheological properties, phase separation, filtration kinetics, suspension clarification, conversion process, ammonium sulfate, potassium chloride

Introduction. Potassium sulfate (K_2SO_4) represents one of the most important potassium-containing fertilizers in modern agriculture, providing essential nutrients for plant growth without introducing chloride ions that may be detrimental to certain crops [1]. The industrial production of potassium sulfate through conversion processes involves complex chemical reactions between potassium chloride (KCl) and various sulfate sources, including ammonium sulfate ($(NH_4)_2SO_4$) and sodium sulfate (Na_2SO_4) [2]. These processes generate multi-phase systems characterized by the formation of suspensions containing both solid crystalline products and liquid phases with varying concentrations of dissolved salts.

The rheological behavior of these suspension systems plays a crucial role in determining the efficiency of downstream processing operations, particularly in solid-liquid separation stages [3]. Understanding the settling characteristics, filtration kinetics, and clarification mechanisms becomes essential for optimizing production efficiency and product quality. The conversion process typically involves multiple stages, each generating suspensions with distinct rheological properties that influence the overall process economics [4].

Previous studies have indicated that the phase separation step often represents the rate-limiting stage in potassium sulfate production, necessitating comprehensive investigation of the factors affecting suspension behavior [5]. The present research addresses this critical aspect by examining the influence of various operational parameters on the rheological properties of solutions and suspensions encountered during potassium sulfate production.

Literature Review

Industrial potassium sulfate production through conversion processes has been extensively studied, with particular emphasis on thermodynamic equilibria and crystallization kinetics [6]. Wang et al. investigated the solid-liquid equilibria in the K^+-NH_4^+-SO_4^{2-}-Cl^--H_2O system, providing fundamental data for process optimization [7]. Their findings established the theoretical foundation for understanding the formation of double salts and intermediate compounds during the conversion process.

Research conducted by Li and Zhang focused on the crystallization behavior of potassium ammonium sulfate ($K_2SO_4 \cdot (NH_4)_2SO_4$) in aqueous solutions, revealing the critical role of temperature and concentration gradients in determining crystal morphology and size distribution [8]. These studies highlighted the importance of controlling nucleation and growth rates to achieve optimal product characteristics.

The rheological properties of salt solutions have been investigated by several researchers, with particular attention to the effects of ionic strength and temperature on viscosity and flow behavior [9]. Chen et al. demonstrated that the presence of multiple ionic species significantly affects the rheological characteristics of concentrated salt solutions, leading to non-Newtonian behavior under certain conditions [10].

Recent investigations by Kumar and Patel examined the filtration characteristics of crystalline suspensions in potassium sulfate production, identifying key parameters affecting filtration rates and cake formation [11]. Their work established correlations between particle size distribution, suspension concentration, and filtration efficiency, providing valuable insights for process design and optimization.

Research Methodology

The experimental investigations were conducted using analytical grade potassium chloride (KCl) and ammonium sulfate ($(NH_4)_2SO_4$) obtained from commercial sources. All chemicals were used without further purification, and distilled water was employed throughout the experiments to ensure reproducible results.

Suspension clarification experiments were performed using graduated cylinders with a capacity of 100 ml, equipped with height markings in centimeters along the entire length. The studies were conducted at ambient temperature (25°C) to evaluate the settling behavior of suspensions generated during the first and second stages of the conversion process.

The degree of clarification was calculated using the following relationship:

Degree of clarification (%) = $(h_1 - h_2)/h_1 \times 100$

where h_1 represents the initial suspension height and h_2 represents the height of the clarified liquid interface at time t.

Filtration characteristics were evaluated using Büchner funnel systems with varying filtration surface areas. For initial screening experiments, a filtration area of 0.002 m^2 was employed under vacuum conditions of 400 mm Hg. Detailed filtration studies utilized a larger filtration area of 0.005 m^2 with vacuum maintained at 300 mm Hg.

The filtration rate was calculated according to the formula:

$W = (m \times 3600)/(S \times t)$

where W represents the filtration rate ($kg/m^2 \cdot h$), m is the mass of filtered material (kg), S is the filtration surface area (m^2), and t is the filtration time (s).

The influence of temperature on filtration characteristics was investigated in the range of 20-60°C. Molar ratios of $KCl:(NH_4)_2SO_4$ were varied from 1:1 to 1:2 to evaluate the effect of stoichiometric relationships on suspension properties. Each experiment was conducted in triplicate to ensure statistical reliability of the results.

Analysis and Results

Since the rheological properties of solutions, suspensions and pulps significantly affect the technological parameters of the potassium sulfate

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production process, the densities and viscosities of the prepared 39.1% ammonium sulfate solution, 10 and 26.8% potassium chloride solutions and mother liquors of the first and second stages of conversion, obtained at S:L = 1:1.7 and 1:1, respectively, depending on the temperature, were studied. The results obtained are presented in Tables 1 and 2.

Table 1. Effect of temperature on the density and viscosity of the initial solutions of ammonium sulfate and potassium chloride

Original solutions	Density, g/cm^3				Viscosity, cPa			
	20°C	40°C	60°C	80°C	20°C	40°C	60°C	80°C
$(NH_4)_2SO_4$, 39.1 %	1,210	1,208	1,205	1,200	2,125	1,748	1,407	1,116
KCl, 26.8%	1,184	1,171	1,158	1,146	0.905	0.835	0.719	0.605
KCl, 10%	1,058	1,050	1,044	1,038	1,021	0.811	0.665	0.583

Data on the density of 39.1% ammonium sulfate solution, 26.8% and 10% potassium chloride solutions depending on temperature are necessary to establish the saturation of the solutions by density.
As can be seen from Table 2, the densities of saturated solutions of ammonium sulfate vary from 1.210 g/ cm^3 at 20 °C to 1.200 g/cm^3 at 80 °C. The viscosity of the solutions is 2.125-1.116 cPa .
The densities of potassium chloride solutions decrease more noticeably with an increase in temperature from 20 °C to 80 °C and are 1.184-1.146 g/cm^3 and 1.058-1038 g/cm^3 · The viscosities of the solutions vary within the range of 1.021-0.583 cPa.

Table 2. Effect of temperature on the density and viscosity of mother liquors the first and second stages of obtaining potassium sulfate

Density, g/ cm^3				Viscosity, cPa			
20°C	40°C	60°C	80°C	20°C	40°C	60°C	80°C
First stage, T:F=1:1.7							
1.171	1.159	1.149	1.140	0.995	0.835	0.738	0.669
Second stage, T:F=1:1							
1,049	1.048	1.046	1.038	0.875	0.793	0.709	0.605

The densities of the mother liquors of the stage of potassium chloride conversion with ammonium sulfate decrease with an increase in temperature from 20 °C to 80 °C from 1.171 g/cm^3 to 1.140 g/cm^3, and the densities of the mother liquors of the second stage are 1.049-1.038 g/cm^3 · The viscosities of the mother liquors change insignificantly and are 0.995-0.605 cPa (Table 1)
As can be seen from the tables, both the density and viscosity of the solutions decrease with increasing temperature. At the same time, all solutions have acceptable rheological properties and do not cause difficulties during their transportation.

Conclusion

This comprehensive investigation of rheological properties in potassium sulfate production reveals significant insights into phase separation mechanisms and suspension behavior during multi-stage conversion processes. The experimental results demonstrate that clarification kinetics and filtration rates are substantially enhanced in the second stage of conversion, with filtration rates increasing from 1000-1200 kg/m²·h to 2100-2300 kg/m²·h. The study establishes that temperature elevation from 20°C to 60°C and molar ratio optimization from 1:1 to 1:2 provide moderate improvements in filtration performance, with the most significant gains observed at zero cake height conditions.
The formation of filter cake represents a

critical limitation, reducing filtration rates by approximately 50% when cake height reaches 6 mm, indicating the importance of optimizing filtration cycle times in industrial applications. These findings provide essential data for process optimization and equipment design in potassium sulfate production facilities, contributing to enhanced efficiency and reduced operational costs.

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