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INFLUENCE OF MODIFICATION OF AMMONIUM NITRATE WITH GLAUBER'S SALT ON THE MAIN COMMERCIAL PROPERTIES

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Abstract

This article presents the results of a study on the production of non-caking ammonium nitrate (AN) samples by adding Glauber's salt (GS) powder to its melt. The AN: GS weight ratio was varied from 100: 0.25 to 100: 3. The resulting GS-nitrate melt was granulated using the prilling method. In accordance with the requirements of international GOST 2–2013, a sample obtained with an AN: GS weight ratio of 100: 2.5 (AN-0.025GS) was selected as optimal for producing non-caking AN. It was found that the total nitrogen content of the AN-0.025GS sample was at least 34%, while the granule strength was 3.46 MPa, caking property was 2.58 kg/cm^2, porosity was 7.96%, and diesel fuel absorption was 2.5 g, while in the traditional non-caking AN (AN-0.028MgO) with the addition of magnesite, taken for comparison, these indicators were 1.58 MPa, 4.67 kg/cm^2, 9.1% and 4.33 g respectively. GS can not only provide AN granules with low caking and explosiveness, but also improve their agrochemical properties. Thus, the prepared optimal sample of AN-0.025GS, in addition to 34.06% nitrogen for plant nutrition and 100% absorption, also contains beneficial elements such as 1.01% Na_2O and 1.22% SO_3. Thus, the use of GS as a modifying additive can be considered an effective and promising approach to improving the stability, safety, and controllability of granular nitrogen fertilizers based on AN.
Keywords: *ammonium nitrate, Glauber's salt, non-caking ammonium nitrate, SEM analysis, strength, caking, porosity, granule absorption and rheological properties*

Introduction

The accelerating increase in the world's population, along with the decreasing availability of arable land per capita, has intensified the need to enhance the efficiency of agricultural production systems (Mingolla S., Rosa L., 2025; Ali A., Jabeen N., Rasulov F., Chachar Z., Ali Laghari A., Chachar S., Ahmed N., Ahmed Sh., Yang Zh., 2025).

In this context, mineral fertilizers are of critical importance for maintaining global food security. The production of high and quality yields in agricultural crops is strongly influenced by the functional roles of key macronutrients, including nitrogen, phosphorus, potassium, and sulfur (Wang N., Ai Z., Zhang Q., Leng P., Qiao Y., Li Z., Tian Ch., Cheng H., Chen G., Li F., 2024; Liu J., Wang D., Yan X., Jia L., Chen N., Liu J., Zhao P., Zhou L., Cao Q., 2024; Cui S., Liu S., Zhang Y., Zhang X., Feng G., Wang S., Gao Q., 2026; Nabati J., Yousefi A., Hasanfard A., Nemati Z., Kahrom N., Malakshahi A., 2025).

It is important to highlight that nitrogen is an irreplaceable macronutrient, whose role cannot be substituted by any other element, and it serves as a key determinant of plant growth and crop yield (Giraldo-Silva L., Ferreira B., Rosa E., Alberto C. Dias P., 2023; Zhang H., Liu Y., Gui F., Yang X., 2023).

Among nitrogen-based fertilizers, ammonium nitrate (AN) ranks second after urea in terms of production and utilization. Owing to its high nitrogen content and versatility across different soil types and agricultural crops, it demonstrates a more rapid agronomic response than urea (Kodirov B., Mamatov K., Yusupov A., Kuziboev Sh., Rustamov M., 2023; Helbig Pasa E., Weinert C., Peralta Ferreira J., Tavares Ferreira H., Pereira Martinez F.,·Pedó T., Da Silveira Pasa M.,· Selau Carlos F., 2024; Helbig Pasa E., Weinert C., Pedó T., 2024).

1. Despite its widespread use, the practical application of AN in agricultural systems is constrained by several critical disadvantages. Its pronounced hygroscopic nature results in caking during storage, whereas its high detonation sensitivity raises considerable safety concerns in both production and utilization (Lu Q., Yang H., Hu Y., Xu X., Kou Y., Yang J., Xiao L., Zhao F., Gao H., Jiang W., Hao G. 2024; Jabborova A. B., Khayrullayev Ch.K., Mamataliyev A. A., Tahirova N. B.; Wolny P., Tuśnio N., Mikołajczyk F., 2026; Maciej Kaniewski. 2025). Numerous strategies have been proposed to mitigate these issues, including the introduction of various modifiers-such as carbonates, sulfates, phosphates, and mineral fillers-into concentrated solutions or melts of ammonium nitrate (Wang N., Ai Z., Zhang Q., Leng P., Qiao Y., Li Z., Tian Ch., Cheng H., Chen G., Li F. 2024; Liu J., Wang D., Yan X., Jia L., Chen N., Liu J., Zhao P., Zhou L., Cao Q., 2024).

To improve the commercial properties of ammonium nitrate (AN), Glauber's salt (GS), the main product of mirabilite processing, was selected. The potential of modified AN with the addition of sodium sulfate, which contains the agronomically important elements sulfur and sodium, has been insufficiently studied. Therefore, the aim of this study was to evaluate the effect of GS on the structural, mechanical, and physicochemical properties of nitrate granules, as well as to produce a non-caking AN with improved consumer characteristics.

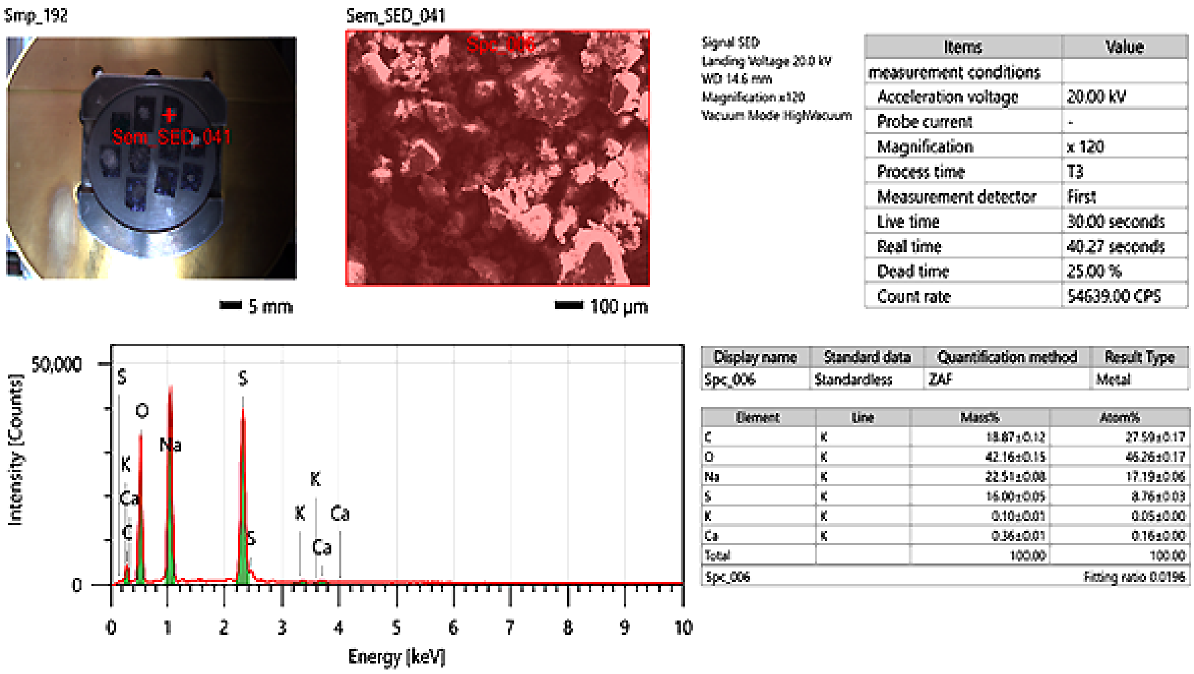
Objects and methods of research

At the initial stage, GS crystals, chosen as the primary material for enhancing the commercial properties of ammonium nitrate, were subjected to thermal drying at 100ºC for 4 hours to eliminate free moisture. The elemental composition of the dried GS crystals was then analyzed by scanning electron microscopy – SEM (Figure 1).

As evidenced by the analysis, the 0.25 mm GS crystal particles are predominantly composed of sulfur, oxygen, and sodium, along with trace quantities of calcium and potassium. This elemental composition indicates the presence of agronomically important macronutrients, implying that the use of GS can contribute to improving both the functional (consumer-related) properties and the agrochemical efficiency of AN. Non-caking AN samples modified with GS were synthesized under controlled laboratory conditions. Initially, a measured quantity of AN was transferred into a stainless steel reactor (grade 12X18H10T) and heated to 170ºC until complete melting was achieved. Thereafter, GS crystals (particle size: 0.25 mm) were incorporated into the melt at mass ratios of AN: GS = 100: (0.25–3). The resulting composite melt was maintained at 170ºC and stirred continuously with a glass rod for 10 min to obtain a uniform dispersion of the modifier. The prepared melt was then transferred into a stainless steel granulator (grade 12X18H10T) with bottom perforations of 1.2 mm diameter, where granulation was carried out using the prilling technique to obtain nitrogen-sodium-sulfur-containing fertilizer granules. After cooling, granules in the size range of 2–3 mm were collected and characterized using standard methods to evaluate their chemical composition, mechanical strength, caking behavior, porosity, and diesel fuel uptake (Kushakov J. M., 2026).

The results are presented in Table 1 and Figure 2.

Figure 1. *SEM analysis of Glauber's salt crystals with a particle size of 0.25 mm*



Results and their discussion

According to the data presented in Table 1, increasing the GS content in the range of AN: GS = 100: (0.25–3.0) results in a gradual reduction in total nitrogen content from 34.83% to 33.71%. At the same time, the concentrations of sodium and sulfur (VI) oxide increase significantly, rising from 0.10 to 1.12% and from 0.13 to 1.46%, respectively.

The developed non-caking nitrogen-sodium-sulfur fertilizer, obtained by modifying ammonium nitrate with GS, exhibited a high degree of water solubility, reaching approximately 90%. Such high solubility suggests efficient nutrient availability and uptake by agricultural crops.

Table 1. *Chemical composition of non-caking AN granules obtained by interaction of ammonium nitrate melt with powdered GS*

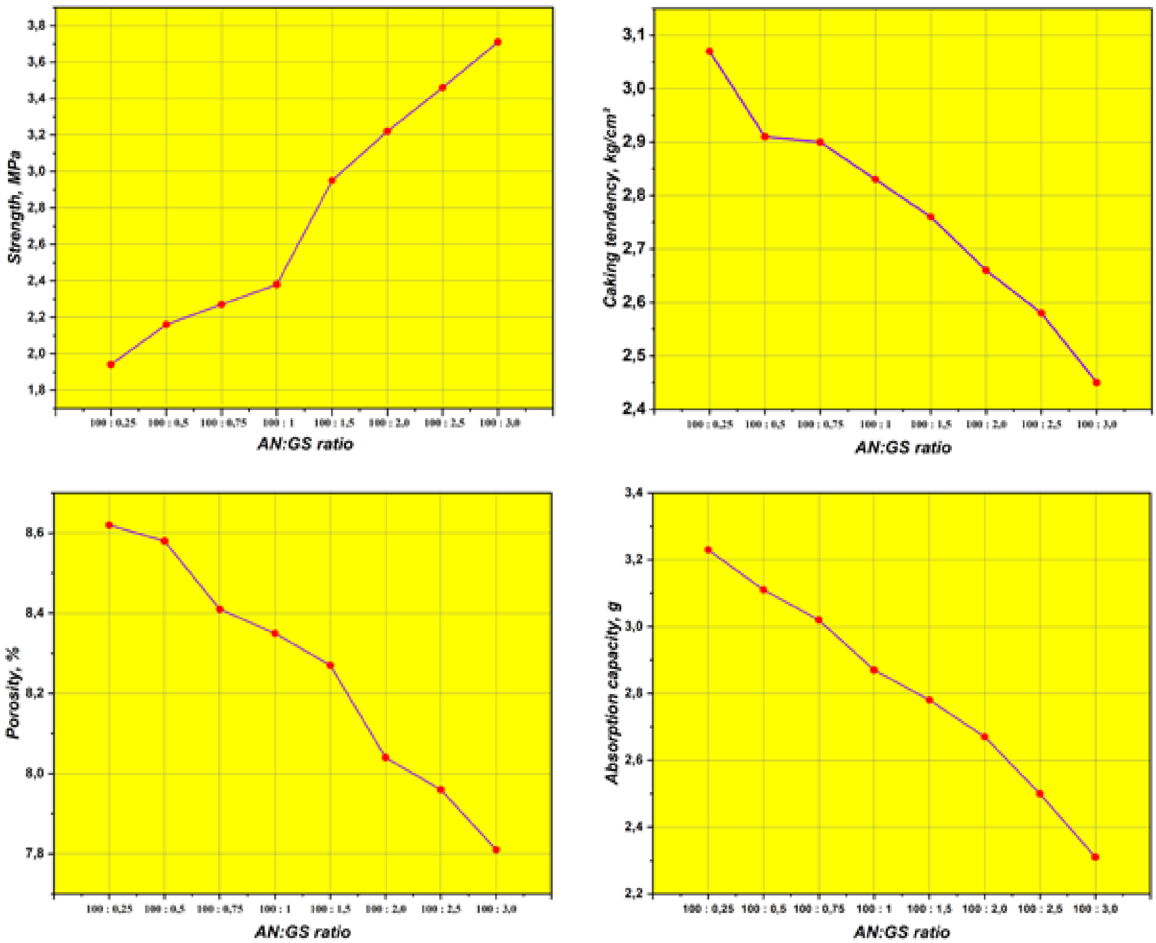
AN: GS	Component content, wt.%				SO_3 (water-soluble) / SO_3 (total), %
	$N_{tot.}$	Na_2O	$SO_{3\,tot.}$	Water-soluble SO_3	
100: 0.25	34.83	0.10	0.13	0.127	97.7
100: 0.50	34.78	0.21	0.25	0.24	96.0
100: 0.75	34.71	0.34	0.37	0.35	94.6
100: 1.0	34.59	0.42	0.49	0.46	93.9
100: 1.5	34.41	0.65	0.74	0.69	93.2
100: 2.0	34.24	0.79	0.98	0.91	92.8
100: 2.5	34.06	1.01	1.22	1.115	91.4
100: 3.0	33.71	1.12	1.46	1.31	89.7

It was determined that for conventional non-caking AN modified with magnesite (AN-0.028MgO), the granule properties-namely mechanical strength, caking tendency, porosity, and diesel fuel absorption-were 1.58 MPa, 4.67 kg/cm², 9.1% and 4.33 g respectively. In contrast, for samples prepared at AN: GS ratios of 100: (0.25–3.0), these parameters ranged from 1.94 to 3.71 MPa, 3.07 to 2.45 kg/cm², 8.62 to 7.81% and 3.23 to 2.31 g respectively.

Thus, compared to the conventional AN-0.028MgO sample, the GS-modified non-caking AN exhibited an average 2–3-fold increase in mechanical strength, along with up to a twofold reduction in caking tendency, porosity, and diesel fuel absorption.

The above results are presented more clearly in Figure 2.

Figure 2. *Some properties of non-caking AN samples with the addition of GS*



In addition, to evaluate the effect of 0.25 mm GS crystal particles on the ammonium nitrate melt, the density of the GS-nitrate melts was determined using a pycnometric method, while their viscosity was measured by viscometric analysis. It was found that at a temperature of 165ºC, the density of the GS-nitrate melts ranged from 1.372 to 1.540 g/cm³, while their viscosity varied between 9.71 and 12.31 cPz. With increasing temperature, both the density and viscosity of the melt decrease, which enhances its flowability and facilitates transport through pipelines. Accordingly, the granulation of ternary melts composed of essential elements (N, Na, and S) is recommended to be carried out via a prilling technique analogous to industrial tower-based processes.

Conclusion

On the basis of laboratory-scale experiments and comprehensive physicochemical analyses GS, obtained through the processing of mirabilite, was employed as a functional additive to enhance the commercial characteristics of AN. The results demonstrate that

GS significantly improves the performance of AN by increasing granule strength by a factor of 2–3, while simultaneously reducing caking tendency, porosity, and diesel fuel absorption by up to twofold. Moreover, the incorporation of GS enriches the fertilizer with agronomically valuable macronutrients, namely sodium and sulfur, thereby enhancing its agrochemical effectiveness. Furthermore, GS-nitrate melts exhibit favorable processing behavior and can be efficiently granulated via the prilling technique without introducing additional technological complexity.

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