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## DEVELOPMENT OF A NEW TECHNOLOGY FOR THE PRODUCTION OF MAGNESIUM CHLORATE DEFOLIANT

### Abstract

This abstract describes a research paper devoted to optimizing the process of defoliation (artificial leaf shedding) of cotton, which is critically important for machine harvesting. The focus is on magnesium chlorate ( $\text{Mg}(\text{ClO}_3)_2$ ), which is a classic mild defoliant. Unlike harsh drugs, it does not cause instant drying of the plant, but stimulates the natural processes of aging and leaf fall. The work highlights the relevance of the production of such drugs directly in the Republic of Kazakhstan, which reduces the dependence of the agricultural sector on imports. The novelty does not just describe the existing production, but also suggests a technology for producing complex-action defoliants. Complexity usually implies the addition of physiologically active substances (for example, nitrogen fertilizers or growth regulators) to the composition. This allows you to reduce the consumption rate of magnesium chlorate and at the same time prepare the plant for the ripening of the pods. The work includes biological control — checking the defoliating ability on live cotton plants.

**Keywords:** defoliant, magnesium chlorate, system, concentration, production, temperature, solubility, conversion, reaction kinetics

### Introduction

The main purpose of defoliants and desiccants is to prepare agricultural crops for mechanized harvesting, reducing labor costs and resources for their cultivation [1,2]. The key difference between these two groups of chemical agents is that defoliants cause leaf drop without damaging other parts of the plant, while desiccants dry not only the leaves but also stems and fruits. Defoliants are effective only on deciduous plant species, while the activity of desiccants does not depend on whether the plants exhibit deciduous characteristics or not [3]. Many chemicals act as both defoliants and desiccants simultaneously, with their specific effects depending on the dosage and the target object.

Defoliants were first used in cotton farming in the early 1940s, which made mechanized cotton harvesting possible [4]. Currently, defoliants are used on about two-thirds of global cotton crops annually [5,6]. In addition, they are applied to remove leaves from grapevines, seedlings, and saplings of fruit trees and shrubs [7]. Desiccants are used on crops such as sunflower, castor, soybeans, potatoes, hemp, flax, rapeseed, cereals, seed crops of sugar beet, vegetables, lupine, alfalfa, clover, and forage beans [1,8,9]. Among plant growth regulators, defoliants and desiccants occupy a leading position in terms of practical significance. The existing range of these agents has been formulated by selecting compounds from various classes of inorganic and organic chemical substances [7,10-13].

Defoliants are widely used in viticulture as well. They are applied to bearing vineyards to prepare for mechanized harvest, in nurseries to remove leaves from seedlings before digging them out of the nursery, and on rootstocks to facilitate the collection of cuttings during the winter period. Leafless grapevines are easier to dig up, store, and, during the storage process, the risk of fungal diseases is reduced.

The most studied defoliants include calcium cyanamide, magnesium chlorate, and calcium chlorate chloride. The global market also includes products such as Pholex ( $\text{C}_4\text{H}_9\text{S}$ )<sub>3</sub>P, butifos ( $\text{C}_{12}\text{H}_{27}\text{OP S}_3$ ), 2-chloroethylphosphonic acid (ethephon)  $\text{C}_2\text{H}_6\text{ClO}_3\text{P}$ , sodium chlorate and borates, cacodylic acid  $(\text{CH}_3)_2\text{As}(\text{O})\text{OH}$ ,  $\text{CaCN}_2$ , dimetipin (Harvey, II), paraquat dichloride, and Endotal.

Magnesium Chlorate [ $\text{Mg}(\text{ClO}_3)_2 \cdot 6\text{H}_2\text{O}$ ] is a hygroscopic powder, highly soluble in water, or a colorless crystalline substance containing 58-62% active ingredient – magnesium chlorate hexahydrate. It is non-explosive

and safe in terms of fire hazards; it is moderately toxic to warm-blooded animals, with an LD<sub>50</sub> value of 620 mg/kg for mice.

### Materials and Methods

The high defoliating activity of magnesium chlorate is attributed to its strong redox properties. Under the influence of this defoliant, the water balance in leaves is disrupted, photosynthesis is inhibited, plastid pigments are destroyed, and carbohydrate and protein metabolism is impaired. Hydrolytic processes in the leaves begin to dominate over synthetic ones. The leaves then wilt, a separation layer forms at the base of their petioles, and they eventually fall off. These processes occur in the leaves when magnesium chlorate is applied in relatively small doses, approximately 10–15 kg/ha. However, higher doses of the substance cause severe plant burns, and cells in the separation layer die without forming the separation layer, resulting in the leaves not falling off.

Magnesium chlorate is used in the form of aqueous solutions. The defoliating activity of this substance is observed at relatively low temperatures, around 9–10°C. A significant advantage of magnesium chlorate over calcium cyanamide is its ability to be effectively used as a defoliant in the complete absence of dew and under low air humidity. Magnesium chlorate is not a systemic defoliant and only affects the leaves to which it is applied. The full penetration of the substance occurs within one hour. Under the influence of magnesium chlorate, leaves fall off much faster than with calcium cyanamide.

Magnesium chlorate is used for cotton defoliation by spraying the plants 6–12 days before harvest, with application rates of 10–12 kg/ha. This substance has also proven effective as a defoliant on castor bean (*Ricinus communis*) crops. The best time to apply magnesium chlorate to castor bean is during the period when the capsules on the central raceme begin to turn brown, signaling that the processes of dry matter and oil accumulation in the seeds are complete. The optimal application rate for defoliation is 15 kg/ha. Harvesting of defoliated castor beans begins 10–15 days after treatment. When applied at the optimal time, defoliation does not reduce seed yield, and the sowing and market qualities of the seeds remain unaffected.

Magnesium and sodium chlorates belong to defoliants-desiccants in terms of their action. Their defoliating effect is observed on deciduous plant species, with cotton being the main crop treated. Leaf drop in plants treated with chlorates occurs when they are moderately desiccated, affecting the leaf blade while the cells in the abscission zone remain undamaged. However, in cases of strong dehydration, the leaf cells and the abscission zone die, preventing the formation of the separation layer, resulting in dry leaves being firmly retained on the plant. This is referred to as the desiccation effect.

The difference in doses between chlorate formulations that cause defoliation and desiccation is minimal. Therefore, pure defoliation is rarely observed, and typically, defoliation is accompanied by desiccation of a portion of the leaves. The defoliating activity of chlorates, like other chemical leaf-abscission stimulants, depends on various factors: plant variety and species, cultivation conditions, developmental phase, air temperature, and humidity.

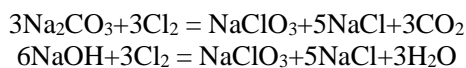
Long-term trials on cotton have shown that effective doses of sodium chlorate for medium-fiber varieties *Gossypium hirsutum* are 5-10 kg/ha, magnesium chlorate 8-13 kg/ha, and calcium chlorate 12-22 kg/ha [7,13]. For fine-fiber varieties *Gossypium barbadense*, these doses increase by 15-20% [13]. Chlorates cause 75-85% leaf drop, and the total effect (sum of dried and fallen leaves) can exceed 90% [7,15]. Compared to other defoliants, chlorates act consistently. The optimal daily air temperature for these chemicals is 17-18°C, although they are also effective at 14-15°C, albeit less intensely.

In cotton cultivation, chlorates also act as desiccants. To achieve the desiccation effect, higher doses of chlorates are required compared to those needed for defoliation. The recommended dosage for magnesium chlorate for cotton desiccation is 25-35 kg/ha, and for calcium chlorate 40-50 kg/ha. Chlorates are effective agents for pre-harvest drying of various crops. They are successfully used as desiccants for sunflower, soybean, castor bean, hemp, lupine, fodder beans, potatoes, rice, wheat, beetroot, radishes, and carrots [14].

### Experimental methods

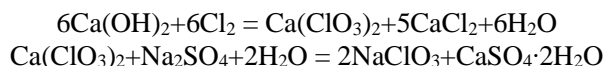
Currently, defoliants are used annually on approximately two-thirds of the cotton crops worldwide. Additionally, defoliants are applied for leaf removal in vineyards, as well as on seedlings of fruit-bearing trees and shrubs.

There are various methods for the production of defoliants. Under laboratory conditions, sodium chlorate is easily obtained by chlorinating solutions of soda and caustic soda.

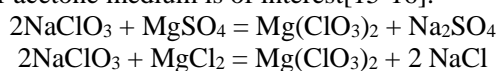


In industry, sodium chlorate was previously produced by chlorinating lime milk, followed by partial removal of excess calcium chloride through cooling and treatment of the calcium chlorate solution with sodium

sulfate.

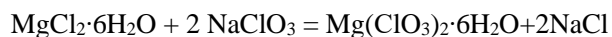


The industrial production of sodium chlorate by the described method was first implemented in France. Currently, sodium chlorate is predominantly obtained through the electrochemical oxidation of sodium chloride. Various methods are known for producing the target product in both crystalline form and aqueous solution. For obtaining small quantities of magnesium chlorate, the exchange reaction of sodium chlorate with magnesium sulfates and chlorides in an aqueous or acetone medium is of interest [15-16].



In industry, magnesium chlorate is produced by reacting sodium chlorate with bishofite ( $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ ) in a molten state. The commercial product, known as magnesium chlorate defoliant, contains  $60 \pm 2\%$  of hexahydrated magnesium chlorate. The essence of the technological process lies in obtaining the molten magnesium chlorate defoliant by melting bishofite with sodium chlorate in a 1:2 molar ratio, followed by crystallization of the target product.

Bishofite is melted by introducing dry steam into special furnaces equipped with mechanical stirrers and a steam jacket, where the calculated amount of sodium chlorate is also fed in. The temperature of the reaction mixture is maintained within the range of 110–120°C. As a result of the exchange reaction, magnesium chlorate is obtained.



After the excess moisture is blown off from the molten defoliant, the product is crystallized on a rotating drum crystallizer in the form of a film, which is then cut by a knife. The cut plates or flakes of magnesium chlorate defoliant are packed into bituminized paper bags with polyethylene liners.

A major drawback of the technology for producing crystalline magnesium chlorate defoliant is that it does not involve the separation of sodium chloride from the main reaction product — magnesium chlorate. As a result, the obtained product contains up to 40% of ballast, physiologically inactive sodium and magnesium chlorides, which leads to high consumption rates of the defoliant and increased costs for its transportation, storage, and application.

The goal of the proposed utility model is to develop a method for obtaining a complex defoliant based on sodium chlorate, magnesium chloride, magnesium sulfate, trichloroacetic acid, triethanolamine, phosphocholine, and water.

In the process of obtaining the defoliant, sodium chlorate is dissolved in an aqueous solution of magnesium chloride and magnesium sulfate with the addition of trichloroacetic acid, triethanolamine, and phosphocholine at a temperature of 25–50°C. The components are used in the following mass ratios:

- Sodium chlorate: 21.51–23.90%
- Magnesium chloride: 18.0–20.0%
- Magnesium sulfate: 18.0–20.0%
- Trichloroacetic acid: 3.21–3.7%
- Triethanolamine: 3.21–3.7%
- Phosphocholine: 0.9–1.0%
- Water: 24.80–27.97%

To provide practical recommendations for the production of magnesium chlorate defoliant, the conversion process of magnesium chloride with sodium chlorate was investigated depending on temperature and time duration. The study was conducted at temperatures of 50°C, 75°C, and 100°C, and with experimental durations of 15, 30, 45, 60, 90, and 120 minutes.

### Results and Discussion

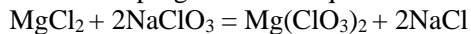
In a 250 mL round-bottom flask, equipped with a stirrer, 100 g of a 37.14% aqueous solution of magnesium chloride was loaded, along with the equivalent amount of sodium chlorate. The flask was placed in a thermostat set to the desired temperature and mixed vigorously. After the specified time intervals, the liquid phase was separated from the precipitate, and a corresponding chemical analysis was performed.

Based on the obtained data, the conversion degree of magnesium chloride with sodium chlorate and the consumption of initial components during the conversion process were determined (see Figures 2 and 3).

From Figure 2, it is clear that the degree of conversion is significantly influenced by temperature and increases as the temperature rises. After 45 minutes, the degree of conversion at temperatures 323, 348, and 373 K is 40.1%, 49.9%, and 62.9%, respectively. After 60 minutes, the degree of conversion reaches 48.7%, 60.8%, and 71.98% at 323, 348, and 373 K, respectively. Subsequent increases in conversion time do not significantly

improve the conversion degree of magnesium chloride with sodium chlorate.

At 373 K and a reaction time of 120 minutes, the conversion degree was 72.3%. Extending the reaction time from 60 to 120 minutes resulted in only a slight increase of 0.32% in the conversion degree. This is likely because, during the first 60 minutes of the reaction, a sufficient amount of sodium chloride is produced through reaction (2), which negatively affects the reaction's progress in the aqueous medium thereafter.



Analysis of the kinetic curves for the consumption of magnesium chloride and sodium chlorate in 100 g of 37.14% aqueous magnesium chloride solution during conversion at temperatures from 323 to 373 K (Figure 3) shows that the amount of consumed reactants increases during the first 60 minutes, and then remains almost unchanged after 60 minutes.

Increasing the temperature from 323 to 373 K results in a higher consumption of magnesium chloride and sodium chlorate during the conversion process. This suggests that higher temperatures accelerate the reaction and increase the rate at which the reactants are used up.

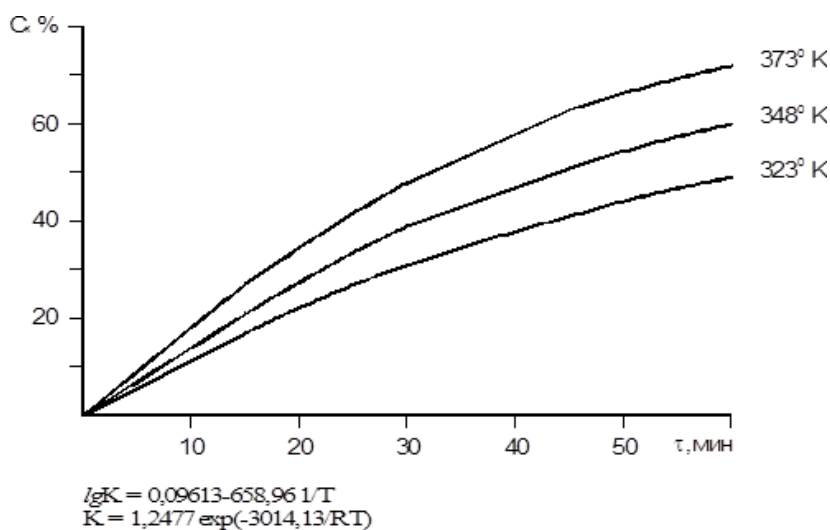


Fig. 1. Dependence of the conversion degree of magnesium chloride with sodium chlorate on temperature and time duration

The order of the reaction of the conversion process was determined using the first-order kinetic equation, similar to the work of the authors [1].

$$K = 2,303/\tau \cdot \lg C_0 / (C_0 - C_\tau), \quad (3)$$

Where  $C_0$  and  $C_\tau$  are the concentrations of magnesium chloride (or sodium) at the initial stage of the conversion and after the elapsed time  $\tau$ , respectively,  $K$  is the rate constant of the conversion reaction.

According to the obtained data, the order of the conversion process of magnesium chloride with sodium chlorate is one. This is confirmed by the fact that the rate constant of conversion, calculated from equation (2) based on experimental data, remains almost constant for each temperature.

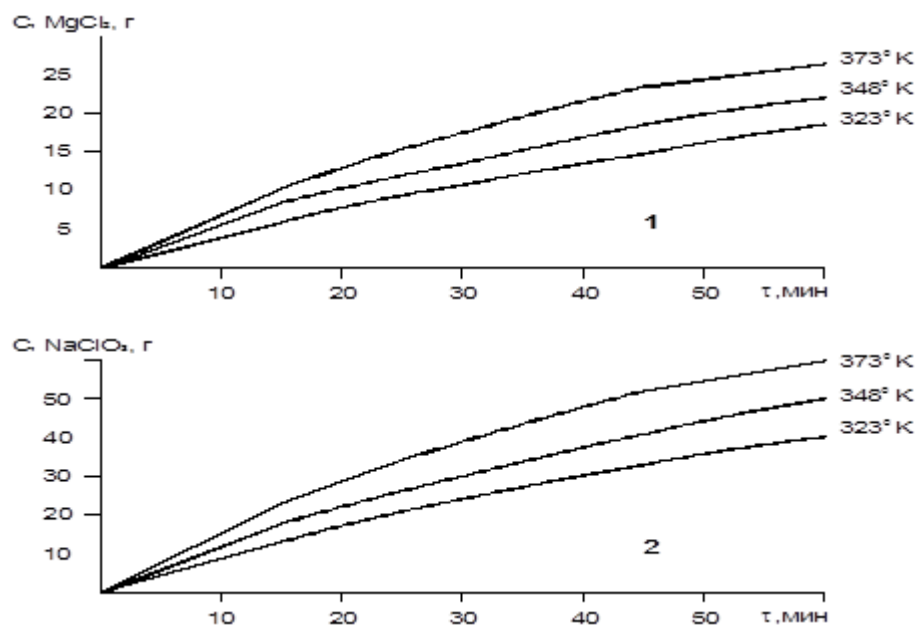


Fig. 2. Kinetic curves of magnesium chloride (1) and sodium chlorate (2) consumption for 100 g of 37.14% magnesium chloride solution

### Conclusion

In the method of obtaining the defoliant, sodium chlorate is dissolved in an aqueous solution of magnesium chloride and magnesium sulfate with the addition of trichloroacetic acid, triethanolamine, and phosphatidylcholine at temperatures ranging from 25 to 50°C, with the following mass ratios of components:

Sodium chlorate: 21.51–23.90

Magnesium chloride: 18.0–20.0

Magnesium sulfate: 18.0–20.0

Trichloroacetic acid: 3.21–3.7

Triethanolamine: 3.21–3.7

Phosphatidylcholine: 0.9–1.0

Water: 24.80–27.97

During the study, the optimal technological parameters for producing magnesium chlorate defoliant were identified.

The study was conducted at temperatures of 50, 75, and 100°C with experimental durations of 15, 30, 45, 60, 90, and 120 minutes. In a 250 mL round-bottom flask equipped with a stirrer, 100 g of a 37.14% aqueous magnesium chloride solution and an equivalent amount of sodium chlorate were loaded. The flask was placed in a thermostat with the set temperature and stirred intensively. After the necessary period of time, the liquid phase was separated from the precipitate, and a corresponding chemical analysis was performed.

Due to the presence of physiologically active compounds in the defoliant—magnesium chloride, magnesium sulfate, trichloroacetic acid, triethanolamine, and phosphatidylcholine—the defoliating activity of the preparation is enhanced, and its application rate per unit area is reduced.

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## **РАЗРАБОТКА НОВОЙ ТЕХНОЛОГИИ ПРОИЗВОДСТВА ДЕФОЛИАНТА НА ОСНОВЕ ХЛОРАТА МАГНИЯ**

### **Аннотация**

В этом реферате описывается исследовательская работа, посвященная оптимизации процесса дефолиации (искусственного опадания листьев) хлопчатника, который критически важен для машинной уборки урожая. Основное внимание уделяется хлорату магния ( $Mg(ClO_3)_2$ ), который является классическим мягким дефолиантом. В отличие от сильнодействующих препаратов, он не вызывает мгновенного высыхания растения, а стимулирует естественные процессы старения и опадания листьев. В работе подчеркивается актуальность производства таких препаратов непосредственно в Республике Казахстан, что снижает зависимость аграрного сектора от импорта. Новинка не просто описывает существующее производство, но и предлагает технологию получения дефолиантов комплексного действия. Комплексность обычно подразумевает добавление в состав физиологически активных веществ (например, азотных удобрений или регуляторов роста). Это позволяет снизить норму расхода хлората магния и в то же время подготовить растение к созреванию стручков. Работа включает в себя биологический контроль — проверку способности живых растений хлопчатника к дефолиации.

**Ключевые слова:** дефолиант, хлорат магния, система, концентрация, получение, температура, растворимость, конверсия, кинетика реакции.

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## **МАГНИЙ ХЛОРАТЫНЫҢ ДЕФОЛИАНТЫН ӨНДІРУДІҢ ЖАҢА ТЕХНОЛОГИЯСЫН ЖАСАУ**

### **Түйін**

Мақтаны дефолиациялау (жасанды жапырақты төгу) процесін оңтайландыруға арналған зерттеу жұмысы сипатталған, бұл машинамен жинау үшін өте маңызды. Магний хлоратына (Mg Mg (ClO<sub>3</sub>)<sub>2</sub>) назар аударылады, ол классикалық жұмсақ дефолиант болып табылады. Қатты препараттардан айырмашылығы, бұл өсімдіктің тез кебуіне әкелмейді, бірақ қартаю мен жапырақтардың түсуінің табиғи процестерін ынталандырады. Жұмыста мұндай дәрі-дәрмектерді Тікелей Қазақстан Республикасында өндірудің өзектілігі көрсетілген, бұл агроөнеркәсіптік кешеннің импортқа тәуелділігін төмендетеді. Жаңалық қолданыстағы өндірісті сипаттап қана қоймайды, сонымен қатар күрделі әсер ететін дефолианттарды өндіру технологиясын ұсынады. Күрделілік әдетте композицияға физиологиялық белсенді заттардың (мысалы, азот тыңайтқыштары немесе өсу реттегіштері) қосылуын білдіреді. Бұл магний хлоратының тұтыну мөлшерін азайтуға және сонымен бірге өсімдікті бүршіктердің пісуіне дайындауға мүмкіндік береді. Жұмыс биологиялық бақылауды камтиды-тірі мақта өсімдіктеріндегі дефолиация қабілетін тексеру.

**Кілттік сөздер:** дефолиант, магний хлораты, жүйе, концентрация, өндіріс, температура, ерігіштік, конверсия, реакция кинетикасы