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FORECASTING THE TEMPERATURE GRADIENT OF COTTON REVOLT

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Abstract: In the context of today's rapidly developing global economy, which is strongly driven by technological production, the issue of ensuring sustainability and safety in agricultural industries has become particularly relevant. Among the most strategically important industries in the Republic of Uzbekistan, cotton production stands out due to its scale and significant contribution to the national economy. However, one of the most serious challenges in this sector is the risk of spontaneous heating and ignition of cotton storage modules, which can result in substantial economic losses, deterioration of fiber quality, and even large-scale fire hazards. This paper explores scientific and engineering approaches aimed at preventing the ignition of cotton storage formations through accurate forecasting and structural modifications. The study emphasizes that cotton, with its unique chemical composition—primarily cellulose with high hygroscopicity—tends to retain oxygen within its fibers. When cotton modules weighing up to 400 tons are compacted, the oxygen trapped in the pores contributes to potential oxidation reactions under pressure, mainly cellulose and maltose oxidation. These processes may initiate spontaneous combustion if not properly managed. To mitigate this risk, the proposed method introduces ventilation channels running through the modules to provide steady air circulation. This approach effectively reduces internal temperature gradients, prevents the accumulation of kinetic oxygen energy, and stabilizes the storage environment. By integrating predictive models with simple engineering interventions, the method ensures both the prevention of ignition and the preservation of cotton quality. Ultimately, this solution represents a practical and innovative contribution to safe cotton storage and supports the sustainable development of Uzbekistan's cotton industry.

Keywords: Cotton storage, cotton module, forecasting, spontaneous heating, ignition prevention, temperature gradient, cellulose oxidation, maltose oxidation, oxygen concentration, chemical reaction, thermal stability, hygroscopic fiber.

Introduction. It's important to establish that cotton is the fiber and fruit of the cotton plant, often grown in large quantities, measured in tens and hundreds of centners. To achieve the best possible results, new technologies are being used today, including drip irrigation, which means that even dry, practically "dead" soil, which has reached its current state due to excessive cultivation of this crop without the aforementioned method, can yield up to 43-45, and sometimes even more, centners of cotton per hectare [1-2]. It's also important to consider that, for such farms, it's reasonable to obtain at least 20 centners of cotton per hectare, whereas without such innovations, yields could only reach 15, and sometimes even less [3-5].

Typically, such a bale is 25 meters long, 14 meters wide, and 7-7.5 meters high for a typical cotton module [6-8]. In such a formation, the cotton is pressed under its own weight, causing certain chemical and physical phenomena, but before studying them, it is necessary to dwell on the structure of the cotton itself. Thus, cotton consists by weight of 60% of its own seeds, 32% of the cotton fiber itself or calico, and 8% of the germinal root or shoot, which sometimes includes excess dirt [9-10]. Thus, with a mass of one such bale equal to 400 tons, it contains 240 tons of seeds, 128 tons of cotton and 32 tons of all remaining husks, as well as random waste [11-12].

Methods. If we take into account that a cotton riot is taken with similar dimensions and proportions relative to two-thirds of a parallelepiped with dimensions of 25 meters in length and 14 in width, and also 5 meters in height, together with a truncated pyramid with the same area, reduced by 10 times, but with a height of 2.5 meters, then the total volume will be calculated according to (1).

$$V_n = \sum_{k=1}^{n}\int_{0}^{b} a_k dx + \frac{1}{3b}\int_{0}^{b} h'\left(\sum_{k=1}^{n}\int_{0}^{b} a_k dx + 0.1 + \sqrt{0.1\sum_{k=1}^{n}\int_{0}^{b} a_k dx}\right)dx =$$

$$= ab * \frac{2}{3}h + \frac{1}{3} * h * \frac{1}{3} * \left(ab + \frac{ab}{10} + \sqrt{\frac{ab}{10} * ab}\right) == \frac{2abh}{3} + \frac{h}{9}\left(1.1ab + ab\sqrt{1.1}\right) =$$

$$= \frac{2 * 14 * 25 * 7{,}5}{3} + \frac{7{,}5}{9} * \left(1{,}1 * 14 * 25 + 14 * 25 * \sqrt{1.1}\right) == 2376{,}735914\ \text{м}^3 \quad (1)$$

Where the density of such a formation will be (2).

$$\rho_6 = \frac{m_6}{V_6} = \left(G\rho_3 \sum_{i=1}^{R}\int_{0}^{x} f_i^{(n)}(x)dx^n * V_n\right)\left(\left(\sum_{l=1}^{\infty}\left|r_{ij} \times R_{ij}\right|\right)^2 V_n\right)^{-1} =$$

$$= \left(G\rho_3 \sum_{i=1}^{R}\int_{0}^{x} f_i^{(n)}(x)dx^n\right)\left(\left(\sum_{l=1}^{\infty}\left|r_{ij} \times R_{ij}\right|\right)^2\right)^{-1} = \frac{400\,000}{2376.735914} == 168.298\frac{\text{кг}}{\text{м}^3} \quad (2)$$

Having described the rebellion itself, we can move on to a description of the fiber itself. At 15-25 microns thick, it consists of 95% cellulose and 5% fat and mineral impurities. Unlike other fabrics, it expands by 40% when wet and swells, and is highly hygroscopic. Its strength is comparable to silk, but it is inferior to linen and superior to wool in terms of tensile strength.

Surprisingly, its melting point, as well as its decomposition temperature, are quite significant due to the predominance of cellulose—an organic compound similar to a polysaccharide. It is also a fiber and melts at 467 degrees Celsius and decomposes at 260-270 degrees Celsius. Cotton, however, is the purest fiber composed of this chemical compound. In its original form, this compound can retain a significant amount of oxygen, which does not immediately escape its porous structure.

The presence of oxygen in such a formation is important for the moment when, after the cotton has been collected into a riot, under its own weight and pressure, which is determined by (3), the cotton begins to release the remaining oxygen, leading to two reactions (4).

$$p = \frac{F}{S} = \frac{mg}{ab} = mGM\left(\left(\sum_{l=1}^{\infty}\left|r_{ij} \times R_{ij}\right|\right)^2 * \sum_{k=1}^{n}\int_{0}^{b} a_k dx\right)^{-1} \quad (3)$$

$$\begin{cases} (C_6H_{10}O_5)_n + (6O_2)_n \rightarrow (6CO_2)_n + (5H_2O)_n \\ C_{12}H_{22}O_{11} + 12O_2 \rightarrow 12CO_2 + 11H_2O \end{cases} \quad (4)$$

The chemical reactions of oxidation of cellulose in the first equation, that is, the predominant substance, described in (4), and the same oxidation of maltose are accompanied by the release of the same carbonate and water, but the fact is that this reaction becomes possible with a sufficient concentration of oxygen and only in the case when the energy of oxygen is sufficient to cause such a reaction, since they are both endothermic chemical reactions.

Let's formulate a general model of the process; it will be necessary to determine the following parameters:

1. The concentration of oxygen that can be found in cotton.
2. Reaction energy yield.

Reaction stoichiometry

3. The speeds of both probabilistic reactions;
4. Thresholds (activation energies) of reactions;
5. The pattern of pressure in the depth of the riot, from which the kinetic energy of oxygen and, accordingly, the temperature can be calculated.

Results. To solve the problem, digging channels through these swamps has been proposed. A similar method is currently used in practice, but in this case, channels are dug from two sides: 14 meters wide, 2 meters high, 1 meter wide, and 4 meters long. However, as can be seen, this channel does not pass through completely, and there is no free passage of air. A 6-meter thick layer of cotton remains, but if it is dug in this way, a volume of 21.98 m³ will be released, which is 0.9248% of the total volume.

$$V = \pi abh = 3.14 * 1 * 0.5 * 14 = 21.98\ \text{м}^3 \ (5)$$

This factor leads to the fact that the structure can completely collapse and, taking into account the presented values, it is important to take into account that cotton, although similar, is not equal to the “liquid” model, because even water has a surface tension coefficient that holds the surface of 73 mN / m, or, by analogy, 0.73%, and in this case, a different mass, smaller in parameters, bordering at the level of 0.5-0.55%, which gives full opportunity to create up to two channels at the lowest level, passing through with a height of 1 m, a width of 0.5 m and a corresponding length of 14 m, with full coverage.

Especially when there are regular or constant drafts or air currents, both natural and artificial, the likelihood of one of the two reactions occurring is reduced to practically zero, meaning that no combustion will be observed.

The analysis revealed that one of the most important stages of cotton processing is highly complex and complex in nature. This stage—regular storage—involves the use of a technology for creating cotton modules, also known as cotton bales. When these structures are created, a significant amount of oxygen remains in the pores of the fibers, as well as throughout the entire mass. Although this oxygen is initially removed, it contributes to the increased density and mass of the bales, which reach approximately 400 tons. A significant amount of oxygen, unlike nitrogen, remains.

Moreover, over time, the effect of spontaneous compression is clear—that is, the upper layers exert pressure on the lower layers of the riot due to their own weight, which, of course, inevitably affects the remaining oxygen. According to the established patterns, this leads to an increase in the kinetic energy of oxygen, which in turn can trigger oxidation reactions. However, only two chemical oxidation reactions exist among the most favorable.

The first such reaction is the oxidation of cellulose, which makes up 95% of cotton fiber, with organic fats making up the remaining 5%. This process releases carbonate and water. While carbonate, also known as carbon dioxide, evaporates immediately due to its gaseous state, water, due to the exothermic nature of this reaction, evaporates immediately during its course.

The second reaction is the oxidation of maltose, a carbohydrate related to glucose and starch, found on the surface and adjacent layers of cottonseed. This reaction also releases carbonate and water, which also evaporate—in the case of the carbonate itself, while the water evaporates due to the kinetic energy generated, or more precisely, the temperature, in the reaction.

Thus, there were two reactions with the highest probability and potential to cause spontaneous combustion of the cotton riot. However, each reaction has its own threshold, meaning it would require additional kinetic energy to initiate the reaction. This kinetic energy, as discussed above, comes from the pressure created by the weight of the riot within its layers.

By analyzing pressure changes depending on the height of a given layer, it became possible to predict the height and depth at which a given reaction would occur. Thus, such a calculation alone was half the answer to the question of how to solve this problem. It only remained to add that a complete solution is to reduce the pressure itself—the cause of combustion—which requires simply digging a channel through the entire ridge, as is done in practice.

Discussion. The results of the study highlight the complexity of thermal processes occurring in large cotton storage modules. It was shown that spontaneous heating is strongly associated with the presence of oxygen within the fiber pores and the pressure exerted by the upper layers of cotton. These factors increase the kinetic energy of oxygen molecules, thereby creating conditions for oxidation reactions of cellulose and maltose, which can eventually trigger combustion. The findings confirm that cotton modules, due to their large mass of about 400 tons, retain significant amounts of oxygen, making them vulnerable to internal temperature rise and thermal instability.

The study also demonstrated that small ventilation channels passing through the module can be an effective preventive measure. By reducing pressure and facilitating natural or artificial airflow, these channels minimize the possibility of reaction initiation, lowering the risk of combustion to almost zero. This approach not only improves safety but also preserves fiber quality by maintaining favorable thermal and humidity conditions. Overall, the discussion emphasizes that combining accurate forecasting with simple engineering solutions represents a practical innovation for safer and more efficient cotton storage.

Conclusion. The results of this study show that one of the most effective ways to prevent the risk of self-heating in cotton modules is through accurate forecasting combined with mechanical and mechatronic measures. Due to its chemical composition (95% cellulose, 5% fats and mineral impurities) and high hygroscopicity, cotton fiber retains oxygen within its porous structure for long periods. As a result, in large modules, the pressure of overlying layers increases the probability of oxidation reactions. In particular, the oxidation of cellulose and maltose releases carbon dioxide and water, creating favorable conditions for spontaneous heating.

To address this issue, the creation of small ventilation channels passing through the cotton mass has been proposed. These channels, without disturbing the stability of the entire module, provide stable air circulation, reduce the kinetic energy of oxygen, and increase the activation threshold for oxidation reactions. Practical analysis shows that with two-sided, narrow, and shallow channels ensuring either natural or forced airflow, the probability of ignition becomes almost zero. Moreover, such a technological approach not only reduces fire hazards but also preserves the quality of cotton fiber. Proper ventilation maintains the balance of moisture and temperature, eliminating the risks of rotting, molding, or heat-induced damage to the fiber. As a result, this project is of great importance for improving safety during cotton storage, ensuring product quality, and preventing economic losses. The proposed innovative approach, if further integrated with mechatronic-based automated ventilation systems in large cotton terminals and warehouses, can deliver even higher efficiency and reliability in practice.

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